RESEARCH HIGHLIGHTS 2020 - 2022

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Grande école d'ingénieurs

Foreword

Dear reader,

We are proud to present the first edition of the JUNIA Research Highlights. "JUNIA Grande Ecole d'Ingénieurs", operating in its present form since 2020, is the result of merging the 3 engineering schools HEI, ISEN and ISA of the Catholic University of Lille into a single entity. While research has been among the strengths of each of the 3 schools, JUNIA opens new perspectives at the intersection of disciplines and encourages research addressing major challenges our society will be facing over the next decades. Activities have been grouped into eleven areas relevant to the societal challenges, each area addressing several topics reflecting the expertise and strategic positioning of JUNIA. In an ongoing effort, research activities are also challenged with respect to effective contribution to the United Nation's Sustainable Development Goals.

Approximately 100 faculty members and full-time researcher, 20 engineers and technicians and close to 100 PhD Students and Pos-doctoral researchers contribute to the research activities at JUNIA. Many of the activities are hosted by major collaborative Research Units joining forces of several higher education and research institutes. JUNIA researchers also contribute to or coordinate a number of regional, national or European research projects, one of the key factors to large scale impact of the research results.

The present report covers the three-year period from 2020 to 2022 and highlights major results achieved over the period. The presentation is voluntarily kept short and accessible, while a list of openly available references allows interested readers to dig deeper into any of the topics.

We hope that you will enjoy browsing this report and please feel free to reach back on any point of particular interest to you.

Dr. Andreas Kaiser, Research Dean

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The ambition of Junia research is to contribute to the development of the sustainable agriculture of tomorrow relying on agroecology and resilience to climatic change.

Taking into account society expectations (environment, traceability, food safety and health, sustainability, ethics, etc.) is one of the biggest challenges facing agriculture. New issues around climate change are underway for all stakeholders form farm to fork. Climate change is causing increasingly extreme phenomena (storms, floods, droughts, etc.) that significantly impact the functioning of ecosystems and production systems.

The research activities of Junia fit with this context and aim at investigating the agrosystems at different scales, including cell, individual (plant/animal) farm, territorial levels. The use of bio-inputs, animal-focused approach, and digital and robotic technologies are valuable solutions that need to be explored to reach such a challenge.

The research activity focusses on 4 topics:

Biocontrol and bioprotection Investigation and development of biocontrol-based biosolutions in order to reduce the use of chemical pesticides in agriculture.

Optimization of nitrogen and water use Crop adaptation to climatic change and optimization of nitrogen and water inputs using agroforestry (crop diversity-based mixtures), biostimulants, and sensor-based models

Farm animal welfareAssessment of farm animal welfare and levers to improve it

Sustainability of agricultural sectors and territoriesAnalysis of the place of agriculture and farmers in relation to socio-economic and territorial issues

The results in these topics are detailed in the following sections.

Associated research unit :

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1.1 Management of nitrogen inputs and water use

In a context of climate change and optimization of agricultural practices, we are studying technological and agronomical innovative systems to optimize the use of nitrogen and water in agroecosystems. We both (i) conceive/test/develop decision support tools and (ii) evaluate the potential of innovative agroecological practices (eg. agroforestry and aquaponics) to well manage these resources. The challenge is to maintain the curent level of agricultural productivity with less inputs and loss of water and nitrogen. Different research projects were launched (i) to identify at territory scale the agricultural practices that presented high risk level of N leakage in air and groundwater (eg: reliquatN project), (ii) to use sensors and biostimulants to reduce water and nitrogen consumption (e.g. Bio4Safe project: https://bio4safe.eu/, OAD N project, Dripperf project) and (iii) to evaluate innovative agroecological practices (eg.1 AFRAME project with the set up of the research and demonstration agroforestry experimental site in Ramecourt https://www.agroforesterie-hautsdefrance.org and eg.2 SmartAquaponics project)

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Wheat nitrogen status estimation based on chemometric methods combining proximal and UAV-based measurements

The rapid and nondestructive prediction of crop nitrogen (N) status based on unmanned aerial vehicle (UAV) imagery or proximal sensors is of interest for precise N management. Assessing N status in real-time is important for adapting the N fertilizer rate in order to increase the N use efficiency (NUE) and minimize the N pollution in the environment, while maintaining high crop yield and satisfactory quality at harvest. Firstly UAV multispectral measurements taken at 15 wavelenghts made it possible to calculate eight vegetation indices (VI), with a total of 248 different wavelenght combinations. Among these combinations, the combination of green and near-infrared measurements at the beginning of elongation and the associations of the near-infrared with the orange-early red portion of the spectrum at the end of elongation were of interest. Four non-parametric prediction models were then constructed and evaluated to consider more

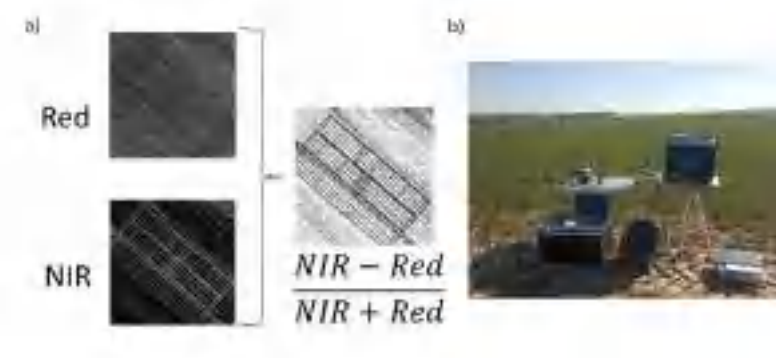
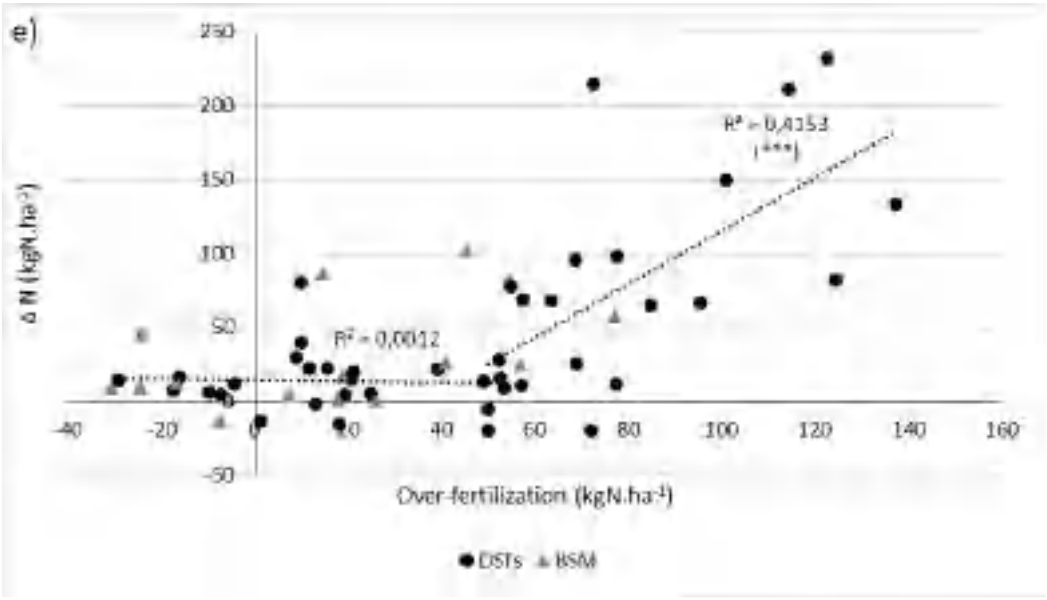


Illustration of the procedure used to calculate vegetation indices by combining reflectance measurements in different wavelengths (NIR: near infrared) for a test plot with a nitrogen fertilization gradient (a). Measurements are made with a M1Agri UAV (ADT drone, Soissons, France) equipped with a 6 lens multispectral modular camera (Kernal, Mapir, San Diego, USA) (b).

explanatory variables than simple VI which combine only a few wavelengths' measurements. The partial least squares (PLS) regression model, which was of most interest in this study, was then combined with proximal sensing measurements to significantly improve the ability to predict N status.

Agri-environmental performance of decision support tools (DST) used to monitor crop nitrogen fertilization strategies in the North of France

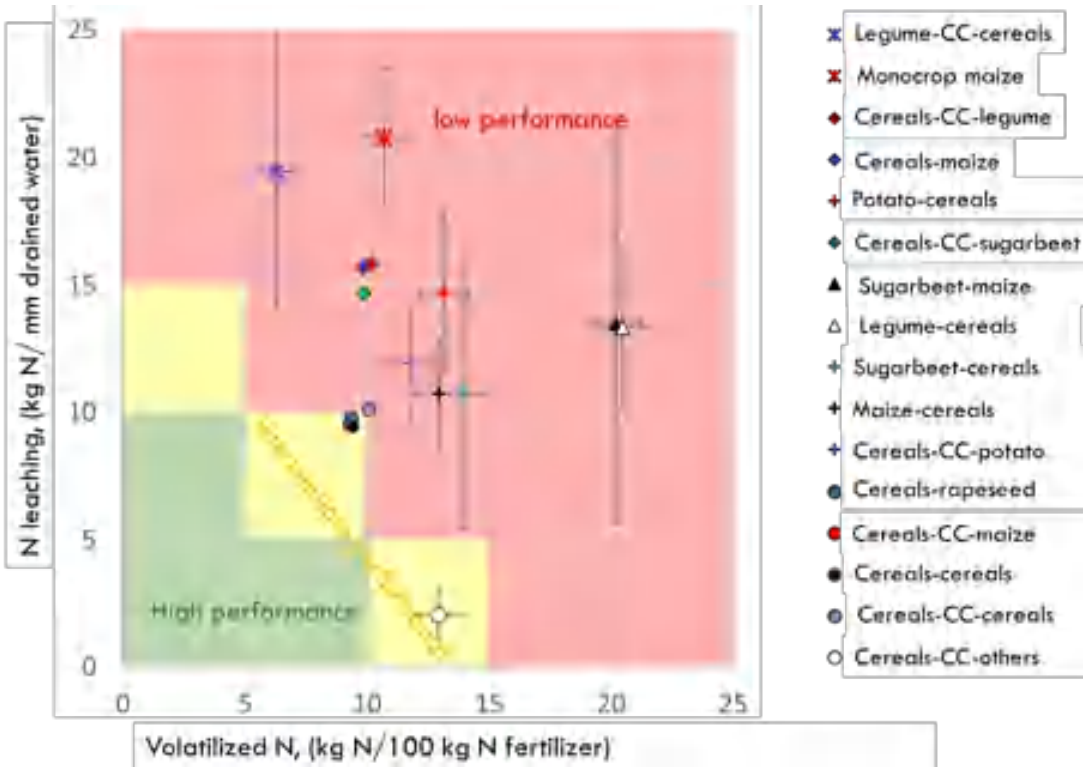
In France, decision support tools (DSTs) are used to adjust the crop nitrogen (N) fertilization. However, as they are based on different measurements and decision methods, farmers can receive contrasting advice for the same crop situation. This work aims to compare the agronomic and environmental performance of 4 DSTs using the classic balance sheet method (BSM). It was conducted between 2017 – 2020 for barley, wheat, and rapeseed on two experimental sites in the North of France according to a randomized block design with four replicates and six treatments: proximal sensing (PS), remote sensing with satellite (RS-S) or with UAV (RS-U), dynamic balance model (DBM), fertilized control with BSM and unfertilized (T0) treatments. The fertilizer N dose advised by DSTs was mostly higher than those calculated with the BSM (75% of situations), without any significant increases in either crop yield or in grain quality. For all crops in the two experimental sites, the relative number of situations in which DSTs advised higher values of fertilizer N than BSM was: RS-S (four out of four situations) > DBM (six out of seven) > PS (four out of seven) > RS-U (three out of six). The N dose was DST dependent and the difference with BSM reached up to 80 kg N.ha-1 during one crop season for the same agropedological situation. The excess of fertilizer N was under utilised by crop and led to over-fertilization which was more pronounced in 2018 than 2020 due to particularly dry conditions. The over-fertilization explained the excess of soil mineral N content observed at harvest and over-fertilization beyond 50kg N.ha-1 significantly increased the N excess in the soil at harvest (R^2 = 0.42***). Our results raise the question of taking plant and soil N status evolution and climatic conditions into account in DSTs to determine the advised N dose.



*Relationship between the excess of mineral nitrogen observed at harvest (ΔN, kg N.ha^{-1}) and the over-fertilization (OF) calculated a posteriori (kg N.ha^{-1}), for the DSTs tested in 2 trials in 2018 and 2020. Dottes lines are the linear regressions obtained between ΔN and over-fertilization: plateau line is for data where OF < 50 kg N.ha^{-1}, linear line is for data with OF>50 kg N.ha-1. R^2 represents the coefficient of determination of the linear regression. A R^2 with *** is significant at p< 0.001 level*

Diagnosis of the effects of current agricultural practices on soil mineral nitrogen content and kinetics in the Douaisis territory: survey and modelling approach

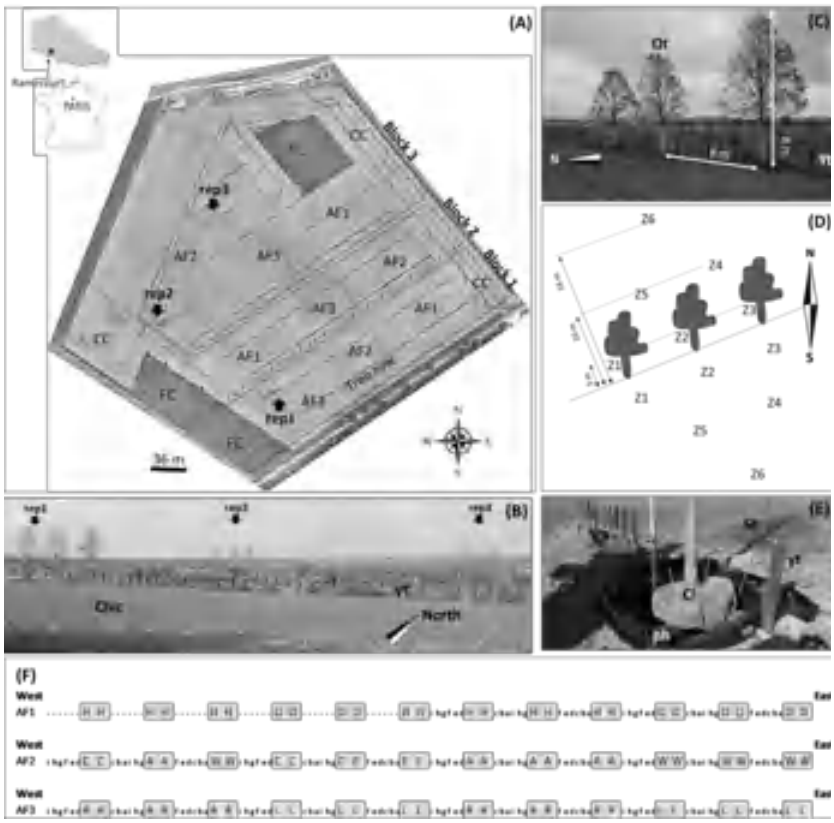
The aim of this project was to evaluate, to model and to diagnose the effects of the current agricultural practices on the soil mineral nitrogen (SMN) stock and fluxes at Douaisis territory. From 2017 to 2020, surveys were done with 25 farmers covering about 97 plots and the SMN was measured in the same plots three times a year at crop harvest, in autumn and at the end of winter. Stocks and fluxes of SMN were estimated at plot using STICS model. Except for legumes and rapeseed, farmers applied higher N fertilizer levels than the recommended doses for all crops. This overfertilisation led to high amount of SMN at harvest for potatoes and corn but was well valorized by sugarbeet and cereals. The SMN significantly varied with crop year and the sampling dates but values measured at the end of winter of year 1 were positively correlated to those measured in autumn of year 0, itself correlated to those measured at harvest of year 0. At harvest and at the end of winter, SMN was the highest for potatoes (150 kg N ha-1), legumes and corn, the lowest for cereals (80 kg N ha-1) and intermediates for others crop. At plot scale, the STICS model underestimated SMN but values followed the same overall trend as measured SMN. The crop successions presenting the highest risk of N leakage in the air and groundwater were monocrop of maize, sugarbeet/maize, legume/cereals without catch crop and potatoes/cereals. After legumes crop, the sowing of catch crop for long duration or rapeseed reduces N leaching. Same results were also observed for potatoes when N fertilizer application was split at different periods to fit with the plant needs. Further experiments should be done to validate these proposed agronomical innovations.



Environmental performance of some 2 year crop successions recorded in 25 farms in Douaisis territory. CC means catch crop. Data are simulated from STICS model and performance thresholds are inspired from the work of Reau et al. (2021). The N leaching was calculated during the intercrop and the volatilization during the last crop.

Agroforestry in the Hauts-de-France – A Research and Demonstration. Experimental Site in Ramecourt

As the current agricultural practices in the Hauts-de-France region result in soil erosion, nitrate leaching and a decline in biodiversity, agroforestry systems (AFs) may be an alternative to conciliate productivity with lower environmental impact (Dupraz and Liagre, 2008). We set up the first AF experimental site to study its agro-economic and environmental performance in local agro-pedoclimatic conditions. The experimental site was established in autumn 2018 on an 18-ha plot in Ramecourt on a deep luvic cambisol with a silt loam texture developed on a flint clay. Due to a high silt content (73% silt) and a low organic matter content (2%), as well as a slope of 8%, the plot is highly affected by channel erosion. Young (1 year old) and adult trees (25 years-old) were planted. Modalities with or without nitrogen-fixing trees in AF treatment are compared with sole-crop (CC) and pure-forest control (FC) plots (Figure A) according to a randomised block design with 3 replicates. Tall trees in rows are intercalated with 9 species of shrubs (Figure F) and will be intercropped in AFs by sugar beet, potato, wheat, barley and flax. The tree density is 50 and 430 trees ha-1 for AFs and FC respectively, and the average size of the microplots is 0.9 ha. Using this equiped experimental site, we hypothesised that AFs should limit soil erosion, restore soil fertility and biodiversity, improve natural-resource use efficiency and water quality, reduce inputs and increase farmers' incomes.



Schematic representation of the experimental site: (A) plot location and experimental design; (B) spatial disposition of the three replicates of adult trees experiment; (C) zoom on adult tree experiment (example of replicate 1); (D) spatial distribution of pyranometer, thermometer and hygrometer around the 3 adults tree per replicates (Z1 to 6 correspond to 6 area defined at different distances from adults tree rows) ; (E) picture of adults tree at plantation ; (F) tree sequencing within rows in AF1, AF2, AF3 and FC. In each block, three alley-cropping modalities AF1, AF2 and AF3 are compared with pure-forest (FC) and sole-crop (CC) control plots. For tree sequencing, letters in upper and lower case represent the 6 tall trees (O = oak, H = hornbeam, L = black locust, A = alder, W = hybrid walnut, C = wild cherry) and 9 species of shrubs (a. Castanea sativa, b. Cornus sanguinea, c. Acer campestris, d. Euonymus europaeus, e. Corylus avellana, f. Tilia cordata, g. Ligustrum vulgare, h. Salix alba, i. Viburnum lantana) respectively. Sigles mean : chic = chicory; pb = plastic bag;rep1 to 3 = replicate 1 to 3; Sh = tree shade ; yt = young trees.

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1.2 Biocontrol and crop bioprotection

Looking for alternative methods of plant protection in order to promote agroecology and to reduce the dependence of agricultural systems on conventional pesticides is strongly encouraged (national plan Ecophyto and EU directive 2009/128/EC). Biocontrol, based on the use of safe and renewable natural resources to bioprotect crops against bioaggressors, is considered as one of the most promising ecofriendly tools to reach such a societal challenge. Biocontrol compounds can be beneficial microorganisms, plant or microbial extracts, or even biosourced compounds from byproducts released from biomass transformation. They may act against bioaggressors through a direct antimicrobial activity or indirectly by activating the plant immune system.

Our research topic (part of the Transborder Research Unit INRAE 1158 BioEcoAgro) deals with this context and aims at investigating the efficacy and the modes of action of biocontrol compounds from diverse origins (plants, beneficial microbes, etc.) on phytopathogenic agents of major agroeconomic interest, including Venturia inaequalis, Phytophthora infestans, and Zymoseptoria tritici, causing apple scab, potato late blight, and Septoria tritici blotch of wheat, respectively. The works are carried out in vitro and/or in planta (and in field conditions with partners) using phenotypical, cytological, biochemical, and molecular tools based on targeted or non-targeted (omics) approaches. The research is undertaken in the framework of regional, national and international projects and performed in collaboration with recognized academic, technical, and industrial actors of plant bioprotection.

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Hop (*Humulus* lupulus L.) specialized metabolites: extraction, purification, chemical *characterization* and in vitro evaluation of anti-oomycete activities against Phytophthora *infestans*.

Plant extracts represent a promising source of metabolites in the search for new biofungicides. In this context, this study aimed at evaluating the in vitro antimicrobial activity of hop (Humulus lupulus L.) extracts and metabolites against Phytophthora infestans, an oomycete causing late blight disease in Solanaceae such as potato. Crude hydro-ethanolic extracts and dichloromethane sub-extracts of different parts (cones, leaves, stems and rhizomes) were characterized by UHPLC-UV–MS and some cone specialized metabolites were purified by CPC and preparative HPLC. A commercial hop cone essential oil was also analyzed by GC–MS. All extracts succeeded in inhibiting mycelial growth and spore germination with morphological alteration of the mycelium. Extracts of leaves showed a significant anti-oomycete activity compared to the extracts of cones, stems, and rhizomes. Moreover, no difference was noticed between the crude hydro-ethanolic extract and the dichloromethane sub-extract activity, except for leaves, with the apolar sub-extract being more active than the crude one. The extracts of cones succeeded in inhibiting more P. infestans than the essential oil, which appeared to be the less active evaluated modality. Some purified prenylated phenolic compounds also inhibited P. infestans although copper sulfate, a mineral fungicide control, was still more active. This study highlights the potential use of hop by-products as biofungicides to biocontrol P. infestans.

Illustration of the potato late blight (left) and the anti-oomycete activity of hop extracts (CHE) and sub-extracts (DHE) on Phytophthora infestans mycelial growth (right). (A) Anti-oomycete activity levels of the compounds, showing that the extracts from hop leaves (especially DHE) are the most active. (B) illustration of the mycelium growth inhibition by DHE on solid medium at a range of concentrations (250 to 0 mg.L–1) after 10 days of incubation.

Antifungal activities of lipopeptides from the beneficial bacterium Bacillus subtilis towards two Venturia inaequalis strains with different levels of sensitivity against the azole fungicide tebuconazole.

Lipopeptides are biosurfactant biomolecules produced by a broad range of beneficial microorganisms. To assess their potential as biocontrol compounds against the apple scab, we assessed the antifungal activity of three lipopeptides (fengycin, F; surfactin, S; mycosubtilin, M) from the bacterium Bacillus subtilis against two field strains of Venturia inaequalis

possessing different levels of resistance towards the fungicide tebuconazole, an active substance from the triazole family. The biomolecules were tested in a liquid medium using 96-well microplates, alone or in binary (FS, FM, SM) and ternary (FSM) mixtures against the phytopathogen, and in different concentrations to calculate the half-maximal inhibitory concentration (IC50) for each molecule or mixture. In the bioassays involving the sensitive strain, all lipopeptide modalities exhibited antifungal activity. Moreover, modalities involving fengycin and its mixtures exhibited the best antifungal activities; the activity of fengycin alone being very similar to that of tebuconazole. Interestingly, regarding the strain with reduced sensitivity to tebuconazole, surfactin and fengycin alone were not efficient while mycosubtilin and the different mixtures showed interesting antifungal activities. For both pathogenic fungal strains, microscopic observations revealed important morphological modifications in the presence of fengycin (formation of vesicle-like swollen structures; see picture below) and at lesser extent in the presence of surfactin but not in the presence of mycosubtilin. Overall, this

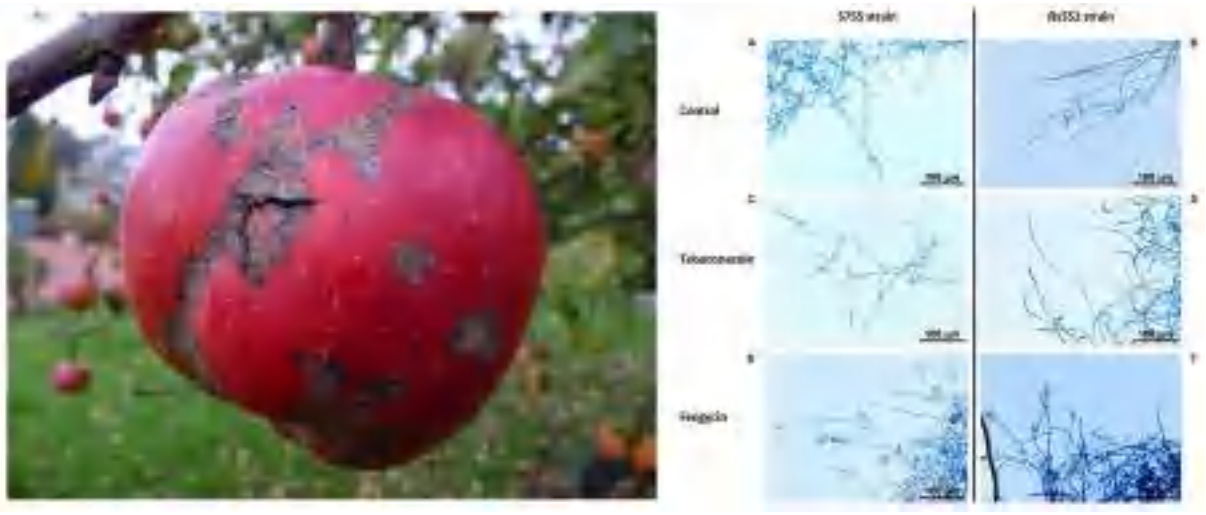


Illustration of the apple scab (left) and the effects of tebuconazole (fungicide) and fengycin (lipopeptide) on the morphology of Venturia inaequalis mycelium (right) assessed in vitro on the two strains S755 (sensitive) and rs552 (with reduced sensitivity). (A) S755 control; (B) rs552 control; (C) S755 treated with tebuconazole; (D) rs552 treated with tebuconazole; (E) S755 treated with fengycin; (F) rs552 treated with fengycin.

study highlights the diversity in mode of action of lipopeptides on apple scab and their potential development as biocontrol compounds against field strains of this major disease of apple.

Deciphering immune responses primed by the Bacillus subtilis lipopeptide mycosubtilin in wheat towards Zymoseptoria tritici.

Plant immunity induction with natural biocontrol compounds is a valuable and promising ecofriendly tool that fits with sustainable agriculture and healthy food. Despite the agroeconomic significance of wheat, the mechanisms underlying its induced defense responses remain obscure. We reveal here, using a combined transcriptomic, metabolomic and cytologic approach, that the lipopeptide mycosubtilin from the beneficial bacterium Bacillus subtilis protects wheat against Zymoseptoria tritici through a dual action mode (direct and indirect) and that the indirect one relies mainly on the priming rather than on the elicitation of plant defense-related mechanisms. Indeed, the molecule primes the expression of 80 genes associated with sixteen functional groups during the early stages of infection, as well as the accumulation of several flavonoids during the period preceding the fungal switch to the necrotrophic phase. Moreover, genes involved in abscisic acid (ABA) biosynthesis and ABA-

associated signaling pathways are regulated, suggesting a role of this phytohormone in the indirect activity of mycosubtilin. The priming-based bioactivity of mycosubtilin against a biotic stress could result from an interaction of the molecule with leaf cell plasma membranes that

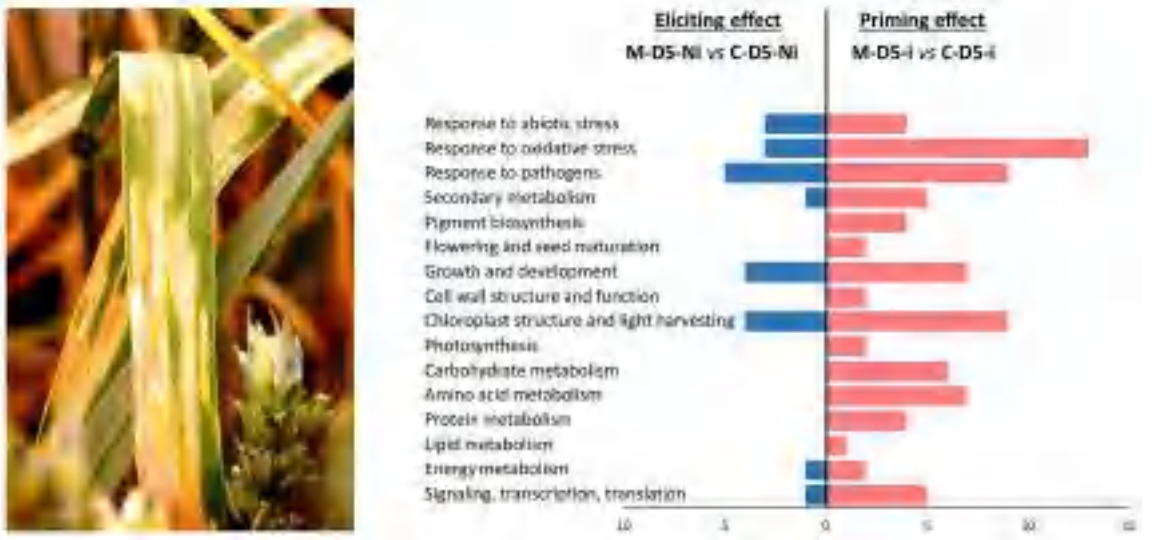
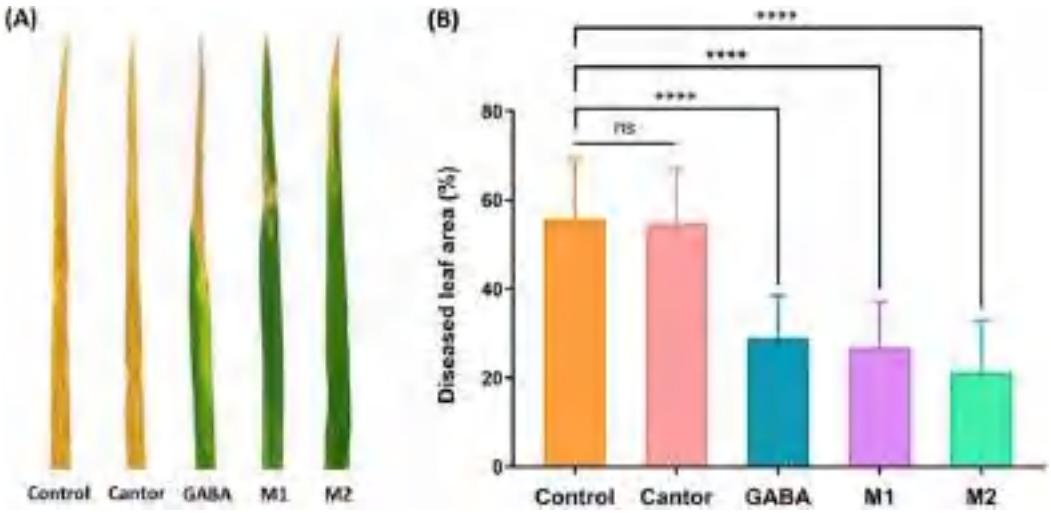


Illustration of Septoria tritici blotch of wheat disease (left) and the effect mycosubtilin (lipopeptide) on the wheat transcriptome highlighted with microarray (right). The plant genes expressed in eliciting (defense activation directly after plant treatment) and priming (defense activation in treated plants only after pathogen arrival) modalities are highlighted in blue and red, respectively. Functional groups of expressed genes were performed based on NCBI GenBank and related-gene physiological processes were assigned with NCBI, AmiGO 2 Gene Ontology and UniProt.

may mimic an abiotic stress stimulus in wheat leaves. This study provides new insights into induced immunity in wheat and opens new perspectives for the use of mycosubtilin as a biocontrol compound against Z. tritici.

New plant immunity elicitors from a sugar beet byproduct protect wheat against Zymoseptoria tritici.

The current worldwide context promoting agroecology and green agriculture requires the discovery of new ecofriendly and sustainable plant protection tools. Plant resistance inducers, called also elicitors, are one of the most promising alternatives fitting with such requirements. We produced a set of 30 molecules from pyroglutamic acid, bio-sourced from sugar beet byproducts, and examined for their biological activity on the major agro-economically pathosystem wheat-Zymoseptoria tritici. Foliar application of the molecules provided significant protection rates (up to 63% disease severity reduction) for 16 among them. Structure-activity relationship analysis highlighted the importance of all chemical groups of the pharmacophore in the bioactivity of the molecules. Further investigations using in vitro and in planta antifungal bioassays as well as plant molecular biomarkers revealed that the activity of the molecules did not rely on direct biocide activity towards the pathogen, but rather on the activation of plant defense mechanisms dependent on lipoxygenase, phenylalanine ammonia-lyase, peroxidase, and pathogenesis-related protein pathways. This study reports a new family of bio-sourced resistance inducers and provides new insights into the valorization of agro-resources to develop the sustainable agriculture of tomorrow.



Disease severity on wheat plants against Zymoseptoria tritici treated with water (control), the adjuvant Cantor (0.15%), the reference molecule γ-aminobutyric acid (GABA), and M1 and M2 molecules (biosourced at Junia from sugar beet byproducts) at 5 mM. (A) Representative third leaves from the control and each treatment. (B) Means scored on wheat leaves from the control and each treatment. Disease symptoms (in A and B) were recorded at 21 days post-inoculation by scoring the percentage of the third leaf area covered with lesions bearing pycnidia.

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1.3 Farm Animal Welfare

Rearing environment of farm animals is often bare and insufficiently complex. This inhibts their physiological and behavioural needs, their sensory stimulation, their cognitive abilities and consequently their welfare. A growing interest for welfare assessment from the different stakeholders in animal productions has been observed over the past years. The concerns related to farm animal welfare are to find objectified ways for assessing welfare in different types of animal productions and also levers for improving the level of farm animal welfare. Rearing enrichment is one lever able to improve animal welfare. This enrichment is described as an intentional increase of the environmental complexity. Our works are focused on poultry and fish with physical enrichment (increase of complexity thanks to additional supplies such as objects and structural modifications) and cognitive enrichment named as well occupational or psychological enrichment. This cognitive enrichment leads animals to actively interact with their environment using their cognitive abilities

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Personality and cognitive abilities, ways to explain the different levels of range by chickens reared in free range systems

A great variability in the use of range(outdoor open space beyhond the barn) by chickens reared in free range systems is often reported. Indeed some chickens are known to never leave the barn while others visit more or less extesively the range. For sanitary , welfare and commercial purpose it is important that chickens use the available range more frequently and homogenously. It has already been shown that range use depends on external factors such as weather and plant cover as well as internal factors such as breed and sex. However, these results do not fully explain why flocks submitted to the same environmental conditions still present important variations between individuals in the range use. During some of our experiments (related to the PPILOW Project) we focused on the search of early and stable behavioral signs of range use. Chickens, were reared from 2 flocks (during 2 seasons: spring and fall) under same conditions, were followed continuously from young age until slaughter age, through behavioural observations. Our results shows that foraging (pecking and scratching at the ground) and range use were the 2 behaviours that showed consistency across the rearing periods within both seasons. Moreover foraging was the only behaviour correlated to range use for the 3 rearing periods independently of the season. This suggests that range use and foraging are likely to be part of same personality trait : exploration. In some of other studies about chickens reared in free-range we showed a link between the level of range use and cognitive abilities. Cognitive abilites mean how chickens perceive, process, and memorize information from their environment. Hence , we observed that low-ranger chickens (less exploratory) performed better during a spatial memory task and exhibited increased inhibitory control compared to high-ranger chickens (more exploratory).

Chickens individually identified to follow their range use in free-range system (picture credit@JUNIA)

Cognitive enrichments to improve rainbow trout welfare

The concern about fish production welfare is recent. Environmental enrichment (EE), used in other animal productions, appears as a promising strategy to improve fish welfare. EE may take several forms, such as cognitive enrichments. Indeed, a potential way to improve animal welfare is to give them opportunities to actively interact with their environment by meeting moderate challenges, controlling some aspects of the environment, or anticipating specific events, thereby mobilizing their cognitive abilities. Allowing animals to predict events (e.g. feeding) offers them the opportunity to gain knowledge about their environment and to better cope with possible environmental change. Feeding predictability is one of the most studied cognitive enrichment strategies. In a recent study we aimed to determine which feeding predictability would be most appropriate for rainbow trout and what the consequences might be for their welfare. We tested four feeding predictability conditions: temporal (based on time of day), signalled (based on bubble diffusion), temporal + signalled (based on time + bubble diffusion), and unpredictable (random feeding times). Our results showed that rainbow trout

can predict five daily feedings with time as the only predictor. However, this temporal predictor alone also increased aggressive and stereotypic behaviours, suggesting that the use of time as the sole predictor of feedings may be detrimental to fish welfare. The combination of temporal and signalled predictability elicited the highest conditioned response and the level of pre-feeding aggression and stereotypies tended to be lower than for temporal predictability alone. Rainbow trout were also successfully conditioned to use bubbles as the sole predictor of feeding, and this condition resulted in fewer pre-feeding agonistic and stereotypic behaviours than in the temporal predictability condition. Interestingly, we also found that bubbles were highly attractive regardless of the conditions

Bubbles as a feeding predictor: promising enrichment for farmed rainbow trout (picture credit@JUNIA)

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1.4 Sustainability of agricultural sectors and territories

Territories are facing many challenges today, and must reinvent themselves to respond to transitions (agro-ecological, digital, etc.). All stakeholders want to move towards more sustainable practices from production to consumption, and new approaches are emerging in the territories (urban agriculture, local supply chains, sustainable agriculture practices, etc.). The objective is to analyse the place of agriculture and farmers in relation to socio-economic and territorial issues at different geographical scales (territory, farm, agricultural practices). We try to answer the following question : How does agriculture participate and adapt to the development of territories and vice versa?

The investigation target three major sub-topics:

The first focuses on territorialized food systems, i.e. the analysis of the place of agriculture in its territory and its link with it, in particular through the prism of local food policies. The second deals with the sustainability of farms, and how farms find strategies to adapt to their environment. Finally, the third deals with the analysis and socio-economic impact of agricultural and territorial projects, or the analysis of agricultural practices and projects with regards to sustainable development issues.

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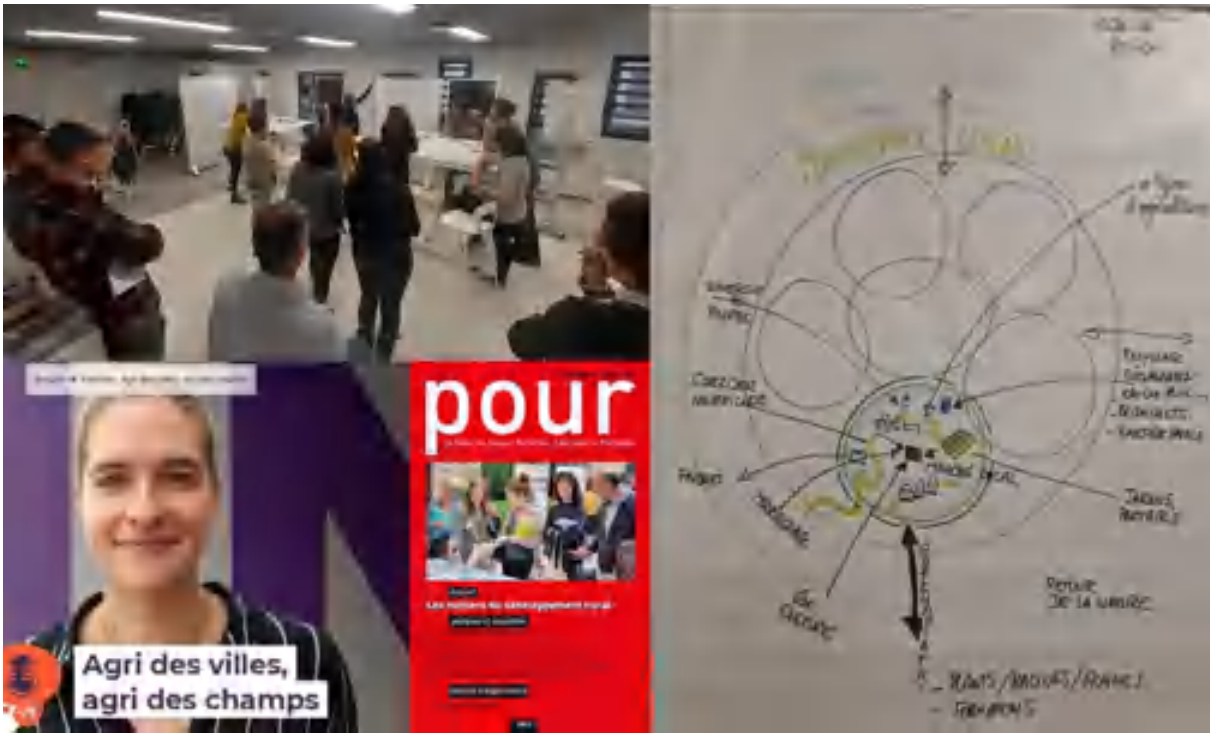
Recognition of all forms of agriculture in the territories



From left to right, bottom to top : Consultation work between urban and rural farmers/representation of the city and its links with agriculture resulting from the consultation work/Marie Stankowiak, contributor to the podcast/Extract from the magazine cover POUR

Demonstrator of tomorrow's agriculture and food

From left to right, bottom to top : Hydroponic production in the greenhouse of the Fives urban farm / Tree planting on the agroforestry demonstration site in Ramecourt / 3D perspective of the future rotunda of the Palais Rameau

Health for Dairy cows (H4DC)

Cryptosporidium is a major cause of waterborne disease outbreaks worldwide. In cattle farms, this common disease causes stunted growth, high mortality and increases the weakness of these animals which further threatens the economic viability of a sector which already faces frequent crises. In humans, this pathogenic agent is considered the second cause of fatal severe diarrhoea for children under 2 years old in Africa and Asia. In Europe, Cryptosporidiosis outbreaks are frequent, an outbreak which occurred in 2013 in Ireland had an estimated economic impact of 19 million euros.

Fighting Cryptosporidium excretion in farms will not only lead to reduced economic impact in calf production but also reduced risk to human health as stated by the One Health approach.

H4DC (Health 4 Dairy Cows) is an European project, led by Junia, which consists in working on this disease by reducing the impact of cryptosporidiosis in farms. Indeed, the project aims to increase farm productivity in a number of different countries, making these businesses more efficient and successful, with a lower impact on human health.

From left to right, bottom to top : Survey of one farmer from the panel of pilot farms/Dissemination of good practice to control cryptosporidium in calves/Annual conference in September 2022 between H4DC project partners in Canterbury

For this purpose, 57 farms have been surveyed in Belgium, France, and the Netherlands over the year 2018 and 2021 to evaluate the economic implications of the Cryptosporidiosis disease in those dairy husbandries.

Using the same method of calculation as Gunn and Stott in their 1997 study, we estimated in 2020 that the economic impact of the disease at an average of €180/affected calf in France, €153 in the Netherlands and €142 in Belgium. Taking into account the evolution of the economic context of agricultural production (fall in the sale price of veal, increase in health costs and labour costs) in 20 years, we concluded that the contribution of the labour cost is undoubtedly the greatest burden on the expenditure related to the management of the disease.

Integrated and territorialized management of late blight risk in potato crops

Potato cultivation is very pesticide-intensive, largely due to potato blight. A project was therefore built around this issue in a territory located in the heart of the Hauts-de-France region, in order to limit dependence on phytosanitary products, their impacts and the risks for local residents and their environment. The objective in this project was to identify risky practices and the obstacles to change through surveys of farmers and gardeners, since the latter represent one of the main sources of primary inoculum for their neighbouring farmers. We found that farmers are aware of their environmental impacts and that the risk is generally under control. However, there is a need to continue to raise awareness of good practices and to create synergy in the agricultural world. At the same time, the surveys showed a rather individualistic farming world, making it difficult to gather around a project. Despite this isolation, many farmers would like more interaction with the non-farming world, which they feel does not understand the reality of their work. Farmers are dependent on the requirements of the sector, making change towards more environmentally friendly practices slow and difficult. Economic partners seem to have an important role to play in change. Farmers evolve according to the obligations they have to meet. Their obstacles to change are mainly economic.

Our results show a less controlled risk of mildew among gardeners, due to the lack of information and knowledge of gardeners on the subject. It seems necessary to raise their awareness by disseminating good practices to limit the disease, and this in different forms in order to reach the maximum number of people. A real accompaniment must be created around the gardeners.

Our work will serve as a basis for developing actions that are better adapted to farmers and gardeners, in order to remove the obstacles to change and reduce risky practices.

From left to right, bottom to top : Survey of a potato producer/Potato plot of a project partner/Collective intelligence session with project partners and local producers

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Smart Systems and Objects

Integrated Circuits for Communication Systems

Microelectronics Technology

Distributed Artificial Intelligence

Smart Image Analysis

Cooperative Robotics

Intelligent objects combine various functions together with communications and advanced computing and data analysis capabilities, often through the use of artificial intelligence (AI). Research on intelligent objects aimes reduced energy consumption and cost for the processing, higher integration levels, increased functionality and interaction beween systems and between the system and the users. Topics include microelectronics technologies, integrated circuits for communication systems, distributed artificial intelligence, Smart image analysis, and cooperative robotics are explored.

Microelectronics technologies play a key role in the development of smart objects, as a foundational research theme. Research at JUNIA is focussed on smart packaging and integration as well as thermoelectric micro-sources and microthermics.

Integrated circuits for communication systems are essential for enabling smart objects to communicate with each other and with external devices and systems. Research is focused the design of high-speed and low-power digital RF transceivers for various applications, including body coupled communications targeted at body-area networks.

Distributed artificial intelligence targets ultra-low-power AI embedded in smart objects. The research addresses both the design of ultra-low-energy AI hardware, as well as boosted perfomance through cooperation of multiple intelligent objects in a local network.

Smart image analysis is an important area of research for smart objects so that the objects can interpret their surroundings particularly for the interaction with users.

Finally, cooperative robotics allows the objects to team up and perform tasks that would be impossible for a single object to accomplish on its own. The research focuses particularly on the design of soft and adaptive robots for delicate objects grasping and cooperation of robotic systems with humans.

Associated research units : iemn CRIStAL Unité Mécanique Lille UML

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2.1 Integrated circuits for communication systems

The main objective of research in the area of integrated circuits for communication systems is to design and develop high-performance, low-power, and cost-effective circuits and systems for various communication applications. This includes designing circuits and systems for a wide range of frequency bands, such as radio frequency (RF), microwave, and millimeter-wave, as well as for various communication standards, such as Bluetooth, Wi-Fi, cellular, and satellite, or non-standardized protocols, such as in wireless body-area networks.

One of the principal research challenges in this area is the design and optimization of RF and microwave circuits and systems to meet the stringent performance requirements of modern communication systems, while leveraging recent digital-centric CMOS technologies. This includes the design of high-speed and low-power digital RF transmitters, RF-DACs, digital delta-sigma modulators, digital mixers, ultra-low power ADCs as well as the design of integrated filters. Another challenge is the integration of multiple functions onto a single integrated circuit.

Overall, research in the area of integrated circuits for communication systems aims to enable the development of advanced communication systems that can meet the increasing demand for high-speed, low-power, and reliable communication.

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Ultra-low-power transmitter for the Human Intranet

The Human Intranet refers to a network of sensors, devices and actuators on the human body for various applications such as health monitoring, rehabilitation, augmented human, medical, and wellness applications. We have explored and studied many aspects that cover heart-beat-based MAC protocols [Sol20], system-level considerations [Ben20], and circuit implementations of heartbeat detectors [Gau20] and digital transmitters [Toc21].

A particular focus of the Human Intranet deals with capacitive body-coupled communications. One of the main challenges in designing such devices is the limited power budget, as they are typically powered by small, low-capacity batteries or energy-harvesting systems. Therefore, it is important to minimize the power consumption of the transmitter to extend the battery life of the device and enable energy-efficient communications.

The research result detailed here [Toc22b] is a transmitter implemented in 28 nm FD-SOI CMOS technology from STMicroelectronics, which allows for low-power operation. The highly-duty-cycled transmitter operates at 0.5 V and the switched-capacitor power amplifier is able to transmit at data rates from 0.1 to 27 Mb/s in the 450 MHz frequency range using pulse-based signaling. One of the key features of this design is the exploitation of body biasing techniques for efficiency optimization [Toc22a] and frequency calibration of a free-running ring oscillator.

This transmitter demonstrates flexible data rates, while consuming less than 100 µW of power, which compares favorably with other WBAN transmitters in the literature. This work has obtained the best industrial paper award during IEEE RFIC 2021.

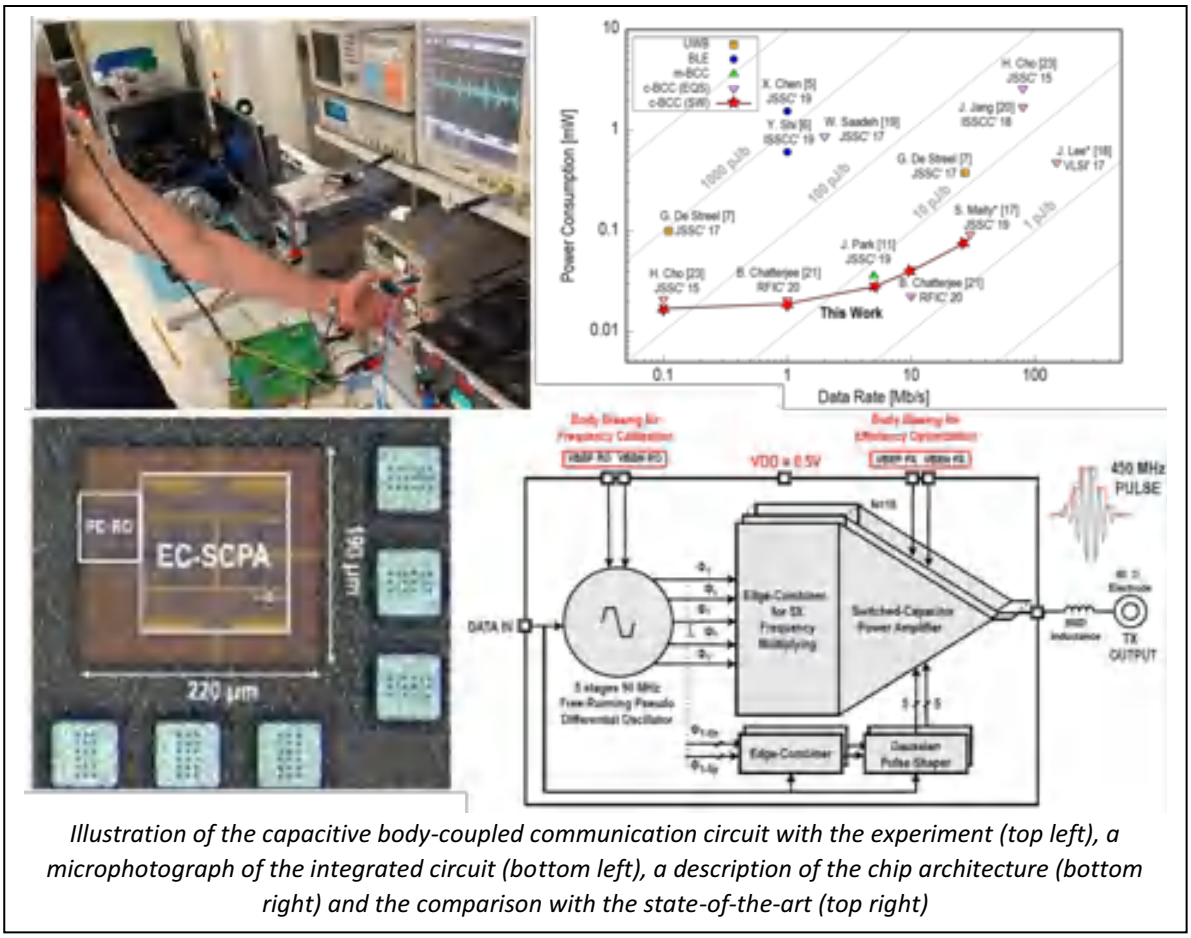

Illustration of the capacitive body-coupled communication circuit with the experiment (top left), a microphotograph of the integrated circuit (bottom left), a description of the chip architecture (bottom right) and the comparison with the state-of-the-art (top right)

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2.2 Microelectronics Technology

Microelectronics Technology covers research from device to systems with deep connections to industrial R&D (ST-IEMN common laboratory), high-risk research topics (ERC, ANR) and deep commitment in advanced processing platforms (EQUIPEX LEAF). Current activities are organized as follows:

1 - Smart packaging and integration
Aiming at advanced integration solutions in line with the so-called 'System Moore' paradigm. It is based on the observation that the largest performance and functionality margins cannot be obtained anymore at the device level but rather at the system level where the package does not only realize the simple function of encapsulation but becomes a functional part of the system. In that perspective and in the framework of the LEAF EQUIPEX project that we coordinate, the use of laser micromachining has offered a unique opportunity as this technique is coming to age to penetrate the domain of semiconductor packaging, assembly and heterogeneous integration.

2 - Thermoelectric micro-sources and microthermics
Leveraging non-conventional thermal effects at nanoscale in order to modulated heat transfer, one can artificially enhance the thermoelectric efficiency of otherwise poor thermoelectric materials. This approach comes with device fabrication and characterization. Thermal characterization techniques, are also used to foster modeling and development of thermal devices such as PCMRAM.

This work has received support from : i) the EQUIPEX LEAF project ii) the ST-IEMN Joint Laboratory and the NANO2017/NANO2022 development programmes iii) ERC-UPTEG Starting Grant 338179 iv) projects HANIBAL ANR-20-CE42-0019 and EFFICACE ANR-20-CE09-0024 v) French RENATECH network.

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Functional packaging for millimeter wave (mmW) communications

The future telecom network infrastructure is expected to support applications ranging from immersive reality to haptic sensing and actuation without neglecting the real-time, ultra-low latency and reliability requirements for mission critical communications involving e.g. vehicle traffic control, automated critical process management, assisted and remote surgery... Beyond the current commercial deployment of 5G, this implies that 6G is bound to continue its relentless expansion into frequency bands covering the 100-300 GHz spectrum. Obviously, the success of 6G is intimately tied to the performance of transistors and circuits to meet the requirements in terms of frequency rise, available gain, output power and noise figure needed to compensate for higher path losses in the millimeter wavebands (mmW). Advanced silicon technologies (e.g. STMicroelectronics BiCMOS) aiming at fT/fmax cut-off frequencies above 400GHz will allow the design of circuits in the 140-220GHz frequency range (G-band). To enable proper circuit design, it is crucial to measure the figures of merit of these devices, in particular the noise figure. However broadband instrumentation such as noise sources, noise receivers,

impedance tuners and power receivers are currently not commercially available to meet this demand over this frequency range [1]. For the first time, a compact packaged noise source based on a SiGe BiCMOS technology operating in G-band has been fabricated and measured. The chip packaging strategy is based on low-cost organic substrates embedded in a split-block with a transition of propagation modes between a grounded coplanar line and a rectangular WR5 hollow waveguide. Laser micromachining has been a key technology to achieve assembly accuracy without performance variability. The excess noise ratio (ENR) has been measured in G-band, showing record levels at such frequencies with up to 24 dB associated to a flatness better than 2 dB and constant output matching.

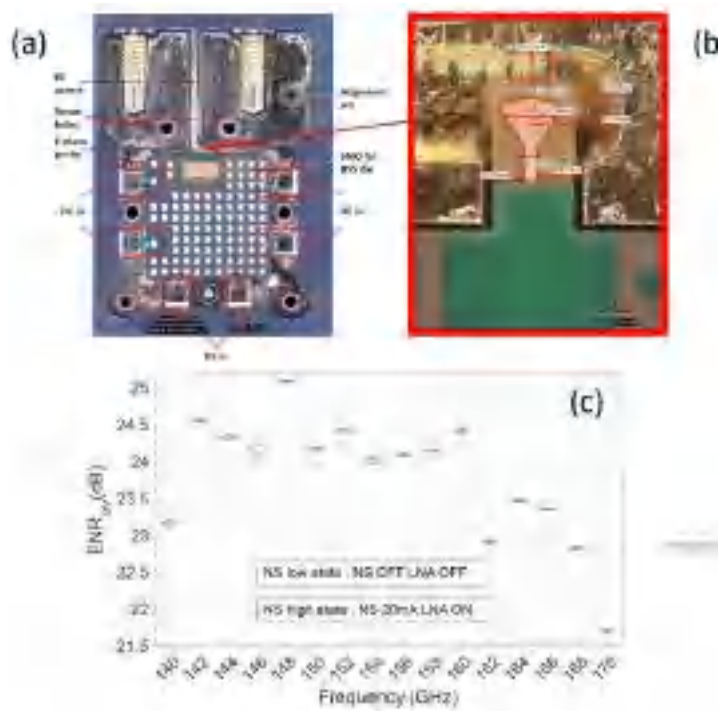

Fig. 1 : Packaged noise source in G-band (140-200 GHz) (a) Internal view of the split-block package showing the BiCMOS die flip-chipped onto an organic substrate for signal propagation to a WR5 rectangular waveguide (b) Zoom on the E-plan probe used for mode conversion (c) ENR measured at the package output.

Augmented RF performance of CMOS technology by localized substrate micromachining

RF front-ends used in mobile handsets are constantly evolving to support new communication standards leading to increasingly stringent specifications in terms of loss and linearity. As a result, RF designers continually need technology options to meet these challenging specifications. RF switches are important components of the RF frontend as they allow to selectively propagate the signal through transmit/receive pathways using antenna-swapping, power and diversity switches. Here, the application targets the fabrication of suspended membranes of SOI-CMOS RF circuits/functions on SOI substrates. Despite the presence of a buried oxide layer (BOX), the substrate holder degrades electrical performance by providing a parasitic coupling path to RF signals. The motivation for such a membrane process has been to achieve a significant increase in RF performance by reducing dissipative losses, lowering substrate-induced non-linearities and decreasing capacitive cross-talk within the device or between devices. These three improvement drivers therefore have a major impact on the performance of RF circuits for mobile communications. A femtosecond laser assisted micromachining and etching (FLAME) process was therefore developed to suspend in membrane the RF functions integrated on an SOI substrate [2]. RF characterization performed on different suspended RF functions (RF switches, inductors and LNAs) reveals a systematic improvement of the figures of merit: i) for the RF switch, 23 dB and 6 dB improvement of the second and third harmonics, ii) near doubling of the Q (50) quality factor of integrated inductors and iii) reduction of the noise figure by ~0.1 dB (1.35 dB at 6 GHz) of a low noise amplifier (LNA) [3]. These results demonstrate the significance of local substrate removal methods using laser

micromachining and open up new avenues for RF designers to evaluate ultimate circuit performance in the absence of substrate-induced dissipative losses and non-linear effects.

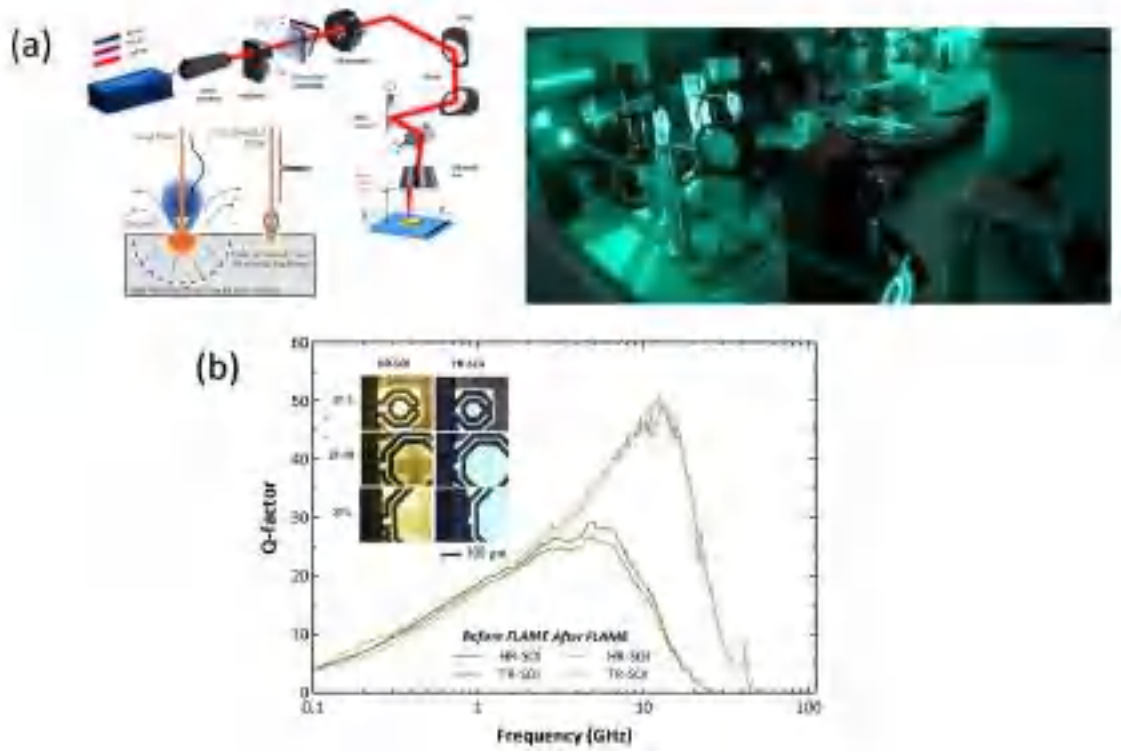

Fig. 2 : Improvement of the quality factor of integrated inductors in SOI-CMOS RF technology: (a) Schematic illustration and optical path view of the laser micromachining set-up used for the membrane suspension (b) Comparison of the quality factor (Q) of inductances before and after application of the membrane suspension process.

Thermoelectric energy harvesting based on silicon nanostructures

The developmement of the Internet-of-Things has not reached the level expected ten years ago. Among the major causes : energy supply of the numerous autonomous, high performance, power hungry electronic devices. Autonomy could be brought through local energy harvesting, among which, thermal to electric conversion is a very interesting source owing to the wide variety and availability of local heat sources. However, thermoelectric modules remain low efficiency converters and use rare or toxic materials (Pb, Sb, Te). They feature low compatibility with low-cost mainstream microelectronics production lines. Our goal is thus to leverage original physical phonomena to artificially enhance silicon as a thermoelectric material. To that end, a new process was developed to fabricate fully suspended silicon thin films patterned at the nanoscale following the concept of phonon engineering. This concept uses a pattern of holes at the right length scale to hinder the heat flow while preserving electrical current conduction, resulting in augmented thermoelectric performance of the material. This approach leads to several remarkable results. First, we simulated, estimated and designed thin-film planar converters architectures. We then developed a versatile process that enables the fabrication of a variety of devices fully compatible with silicon MEMS technologies. In addition, we quantified heat transport at nanoscale using three complementary methods, namely: Electro-thermal,

Raman thermometry and Scanning Thermal Microscopy. Not only the results show the consistency of these methodologies for the first time, they also demonstrate that heat conduction has been divided by a factor 15. From the fundamental point of view, these artificial materials could solve the well-known "phonon glass, electron crystal" dilemma faced in thermoelectricity. Finally, a demonstrator was fabricated and characterized that shows the efficient heat gradient management and power generation [4].

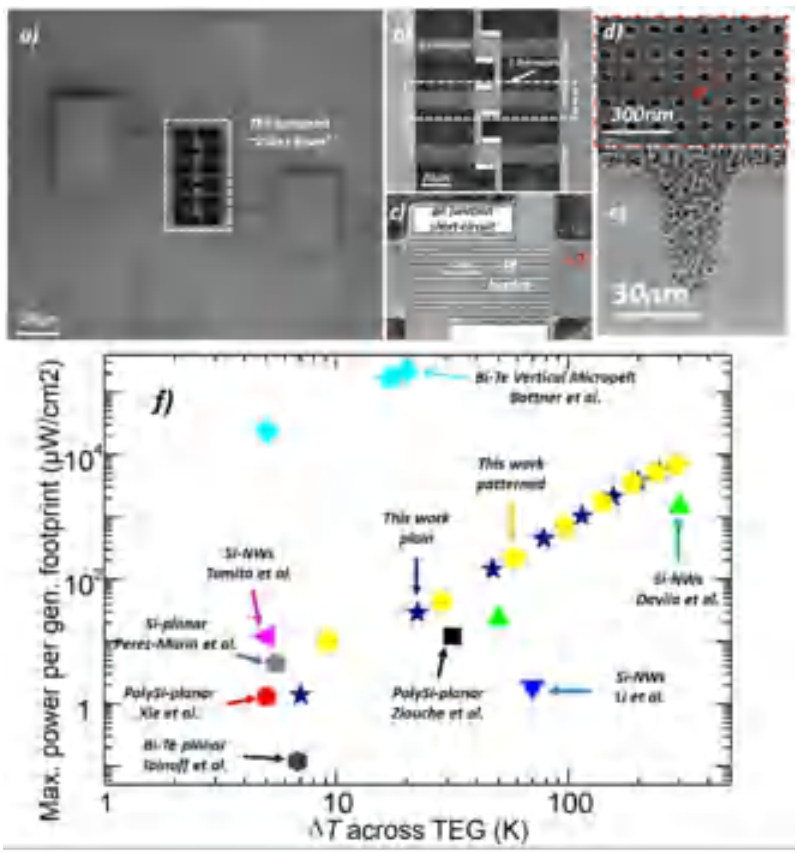

Fig. 3: *(a) Scanning Electron Micrograph of a thermoelectric device made of 5 suspended thermopiles. (b) Close-up view of three thermopiles. (c) Platinum resistive heater. (d) Detail of the membranes pore patterns. (e) Cross section Transmission Electron Micrograph of the membrane. (f) State-of-art of thermoelectric micro-harvesters showing maximum output power per footprint area as a function of the temperature difference.*

Microthermics characterization and modeling for ICT

Heat dissipation in microelectronics is a key issue owing to the tremendous power densities reached in typical ICs (~100W/cm²). Thermal management is thus taken into account at several design stages and scales from chip floor planning to system packaging. At the microscopic level, the shrinking sizes of devices reveal the impact of thermal effects such as balistic heat transfer of thermal boundary resistance which are commonly ignored. Additionnaly, some components make an active use of heat as a part of their working principle, this is typically the case of resistive Phase-Change Materials non-volatile memories. (PCRAM). Thus, thermal metrology of quantities such as the thermal conductivity or thermal boundary resistance becomes critical for accurate thermal modeling in support of technology development. Our goal is twofold : i) We make use of a non-contact thermometry method based on the temperature-dependent Raman spectrum to achieve measurements of thermal conductivity in relevant material stacks. ii) We used lumped sum of Finite Element Method to model the operation of thermally operated devices. Fig. 4 illustrates the principle of the Raman thermometry technique. With this methodology the contrast of thermal conductivity between the amorphous (off) and crystalline (on) states in PCM stacks can be measured [5].

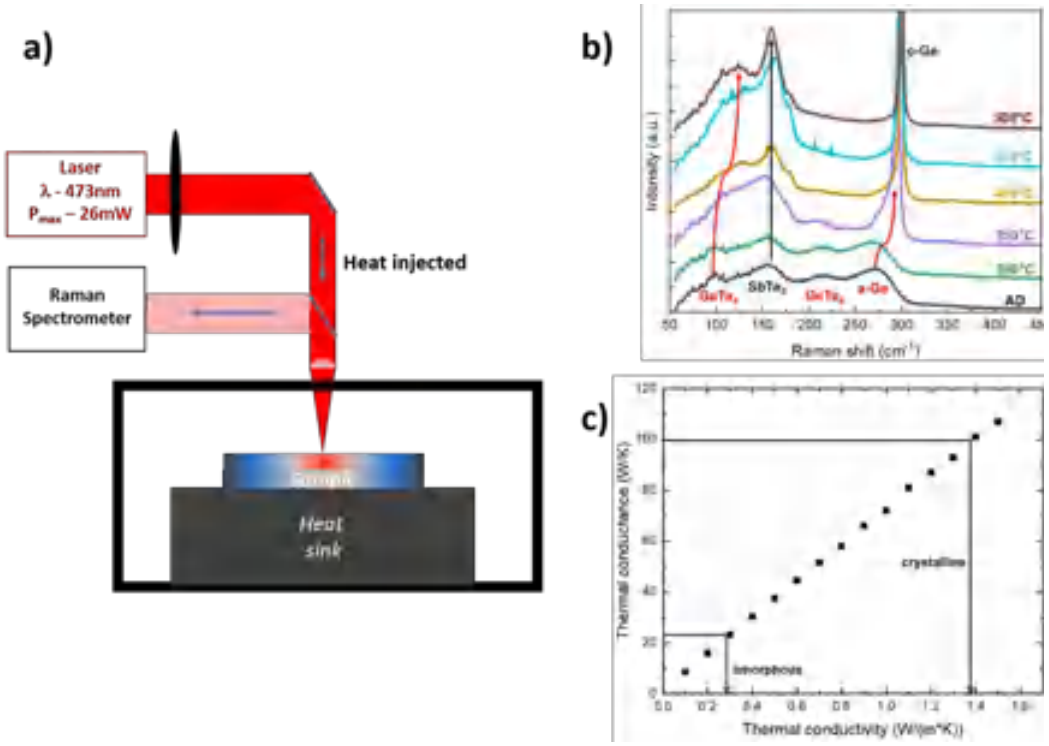

Fig. 4 : a) Schematic of the Raman thermometry setup. A calibrated variable density filter is added on the probe laser path. The sample is studied under vacuum conditions. b) The Raman analysis can be carried out as in a conventional experiment. c) Power variation measurements allow for extraction of the hot spot temperature as a function of the power density which in turns give the stacks thermal conductance.

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2.3 Distributed artificial intelligence

The main objective of the "Distributed Artificial Intelligence" research field is to design ultra-low-energy systems - or systems of systems - implementing high performance artificial intelligence-based algorithms. The targeted systems range from application-specific integrated circuits to microcontroller-based objects in applications like audio signal processing (Keyword Spotting, Speaker Identification, etc.) or biomedical signal processing (Cardiac Arrythmia Classification, Sleep Apnea Detection, etc.).

The main challenge of this reasearch work is to enable ultra-low-energy consumption while achieving a minimal classification accuracy relevant to the targeted application. For this purpose, several computing paradigms are explored, such as event-driven computing (data is processed only when an input event has occurred) or in-memory computing (computing blocks are integrated in the memory to limit data exchange).

The demonstrated concepts ultimately aim at being integrated in wireless sensor networks, autonomous embedded systems for the targeted applications (vocal assistants, body monitoring sensor networks, etc.).

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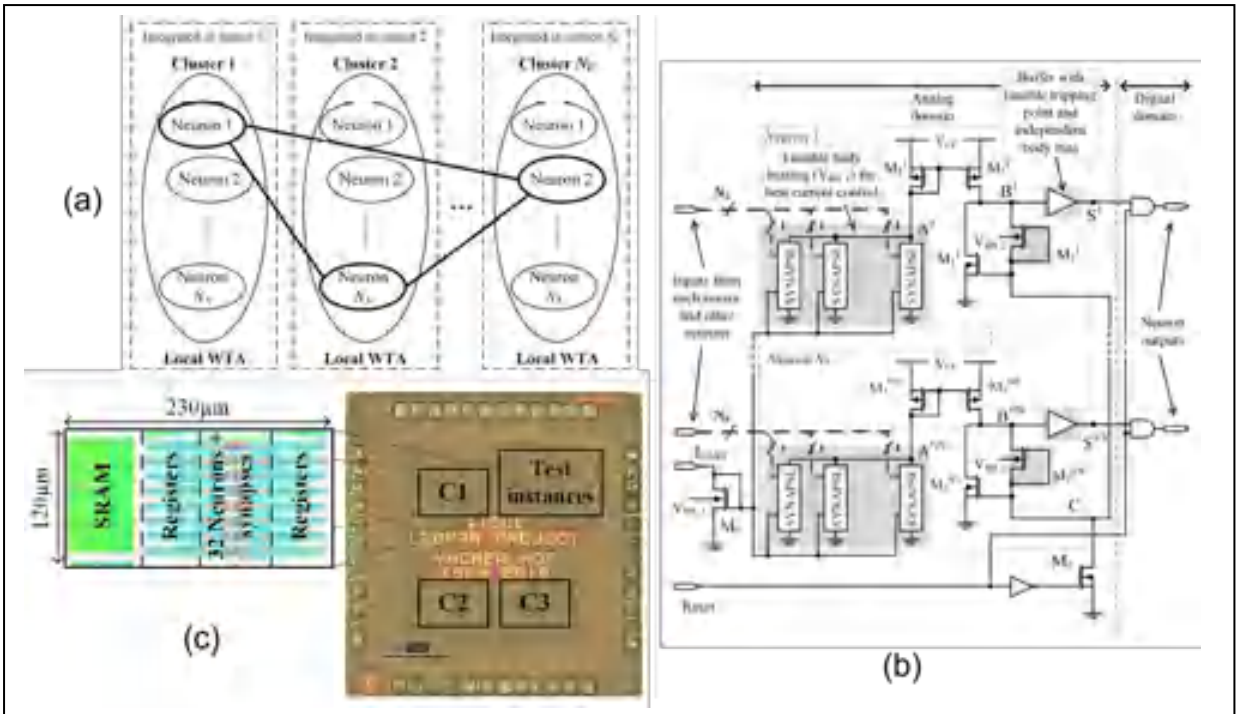
Distributed Clique-based Neural Networks

Clique- *based Neural Networks (CBNNs) refer to a specific type of artificial intelligence (AI) engine, focusing on stored pattern recognition. Instead of a probable class learnt from thousands of training samples, which is the case for most AI-based engines, CBNNs output the closest (in terms of Hamming distance) pattern from a set stored a priori. This operation, derived from error-correcting codes, is particularly efficient for recovering registered information from noisy inputs, such as body posture recognition from imprecise sensors, word detection from incomplete sentences, etc.*

The main challenges of the research topic are: (i) implementing on silicon the theoretical algorithm of a CBNN with ultra-low energy consumption, and (ii) provide an architecture that can adapt to multiple use-case scenarios, including the case where several units have to be implemented on different physical objects and exchanging information wirelessly.

A circuit, fabricated using 28-nm FD-SOI CMOS technology process from STMicroelectronics, has demonstrated an energy consumption of 43pJ per operation of pattern recovery, which is 6.5 times lower than the state-of-the-art [Lar21]. This implementation concept has also been proven for the case of an autonomous operation for an entire pattern recognition in a global system, or distributed with a single sensor and communicating with similar objects to form a recognition system for body posture recognition [Lar20a][Lar20b].

This work has received a Best Paper Award in the IEEE AICAS 2020 conference;



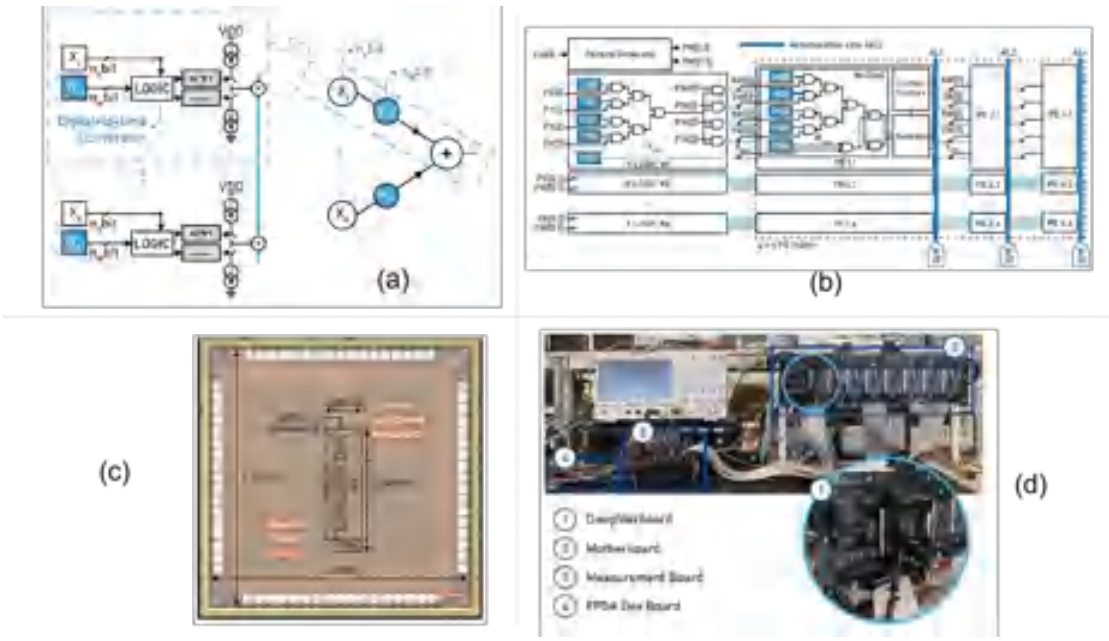
Top-level illustration of a clique-based network distributed among different sensors (a); Circuit schematic of a CBNN cluster (b); Photograph of the 28-nm FD-SOI fabricated chip and the designed instances (c).

Time-based Matrix-Vector Multiplication Unit

In the case of embedded AI-based systems, the total energy consumption is dominated either by a main processor able to execute complex operations, or a communication interface sending data to be processed to an external system (e.g. the Cloud). To reduce the overall power of the system, the energy-hungry blocks could be put in sleep mode most of the time and wake them up only when relevant by an ultra-low power pre-processor specific to the targeted application.

The main challenge is to achieve the ultra-low energy operation in the pre-processor while maintaining acceptable classification accuracy for the targeted task [Her21]. The central operation in neural networks is the Multiply-and-ACcumulate (MAC) task. A novel architecture of the MAC operator has been developed that exploits the low data rate in the targed applications for intensive reuse of resources throuht time domain multiplexing and bit-wise operation in the analog domain. This results in a compact and ultra-low-power operator that can be integrated directly with the weight memory to further reduce power [Her22a].

A proof-of-concept circuit has been fabricated in 28 nm FD-SOI CMOS from STMicroelectronics. Operating at 0.8 V, the circuit is able to achieve an efficiency of 99.2 TOPS/W for an implementation in a classifier using inputs and weights coded on up to 5 bits [Her22b]. This bitwidth is sufficient to perform audio classification operations such as voice-activity detection or keyword recognition with an accuracy over 90% [Her21].



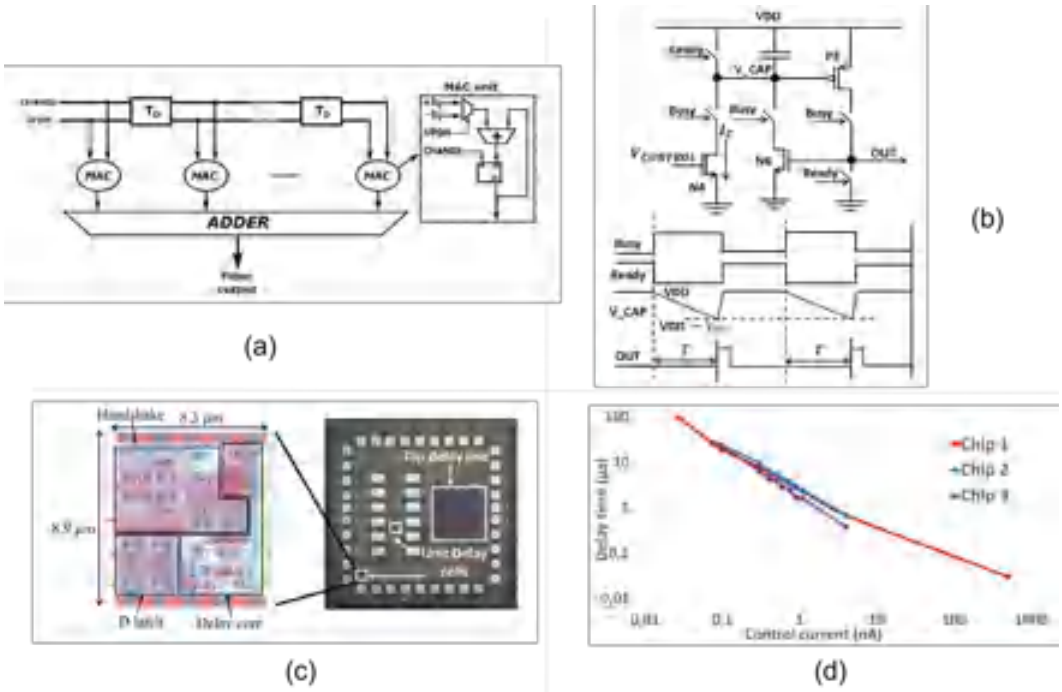
Schematic of the implementation of the proposed time-based MAC operation (a); Top-level schematic of the expanded Matrix-Vector Multiplication unit (b); Photograph of the prototype fabricated in 28-nm FD-SOI technology (c); Photograph of the circuit test-bench, including parallel operation of multiple chip instances (d).

Event-driven feature extraction for audio signal classification

For operations like voice-activity detection or keyword recognition, information contained in audio signals are sparse in time but usually the whole data are used for analysis and most of it is classified as irrelevant by the processing unit. This leads to a high energy consumption, harming the battery lifetime in embedded systems. A solution explored by our research team is to sample the input signal only when a new event is detected.

The main challenge of this approach is that the signal is non-uniformly sampled, and thus keeping track of the time between samples becomes crucial. Moreover, the standard framework for design and simulation of digital systems is not compatible with such an approach because it relies on a uniform clock signal. A solution to tackle both challenges is to replace this signal by pulses generated in an event-driven fashion and propagated through the processor by a chain of highly configurable delay cells connected by an asynchonous handshaking protocol.

The circuit implementing a chain of 96 delay cells ranging from 30ns to 100µs under 0.7V has been fabricated using 28-nm FD-SOI CMOS process from STMicroelectronics [Gon20]. The energy consumption per event is 15fJ, which is 3 times better than the state of the art while implementing a hazard-free handshaking protocol. The delays and the concept of event-driven computing have also been demonstrated in an applicative use-case of feature extraction for keyword recognition in [Mou21].



Block diagram of a continuous-time FIR filter based on pulse propagation by delay cells Td (a); Internal simplified schematic of a delay cell (b); Photograph of the delay chain prototype fabricated in 28-nm FD-SOI technology (c); Measured graph of the dynamic range of the output delay depending on the value of the control current, from 30ns up to 100µs (d)

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2.4 Human centered smart image analysis

Three main subjects will be developed in this domain :

Facial landmark detection is an essential task for a large number of applications such as facial analysis (e.g., identification, expression, 3D reconstruction), human-computer interaction or even multimedia (e.g., content indexing and retrieval). Although many approaches have been proposed, performance under uncontrolled conditions is still not satisfactory. The variations that may impact facial appearance (e.g., pose, expression, illumination, occlusion, kinetic blur) make it a difficult problem to solve.

Another issue is related to automatic facial expression recognition. This recognition is useful to create applications in various domains such as health, road safety or marketing where feedback on user state is relevant. Despite very good results in controlled settings (frontal face, no occlusion, good illumination), facial expression recognition is still today challenging under unconstrained environment. Among the different challenges, occlusions are particularly difficult to handle as they add noisy elements on the images and hide parts of the information.

Finally, in addition to facial analysis, whole body analysis allows to understand poses, actions and dangerous situations. The objective is also to understand interactions between a user and a robotic system for home autonomy assistance, based cameras sensors and embedded deep learning models. The majority of behaviors recognized are of the personal environment type. The typical situation is an elderly person living alone. The main objective is to increase safety through intelligent monitoring by detecting dangerous situations (domestic accidents, falls, discomfort, dangerous postures, immobility, etc.

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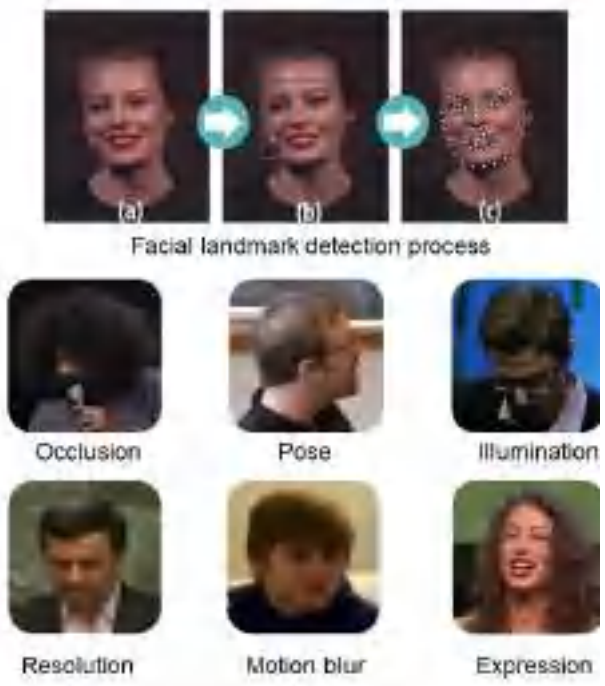
Facial landmark detection in uncontrolled environment based on local and global motion modeling

A contribution to the analysis of the performance of current approaches and the modeling of temporal information for video-based facial landmark detection was made. Experimental studies were conducted using a video dataset to measure the impact of pose and expression variations on landmark detection. This evaluation highlights the most difficult poses and expressions to handle. It also illustrates the importance of a suitable temporal modeling to benefit from the dynamic nature of the face.



Facial landmark detection process and major challenges encountered under uncontrolled conditions

We focused on improving temporal modeling to ensure consideration of local motion in addition to global motion. Several architectures were designed based on the two main models from the literature: coordinate regression networks and heatmap regression networks.

Experiments on two datasets (SNaP-2DFe and 300VW) confirmed that local motion modeling improves results (eg. in the presence of expressions). These experiments were extended with a study on the complementarity between spatial and temporal information as well as local and global motion to improve the design of the proposed deep architectures. By leveraging these complementarities more effectively, competitive performance with current state-of-the-art approaches is achieved, despite the simplicity of the proposed deep neural network models.

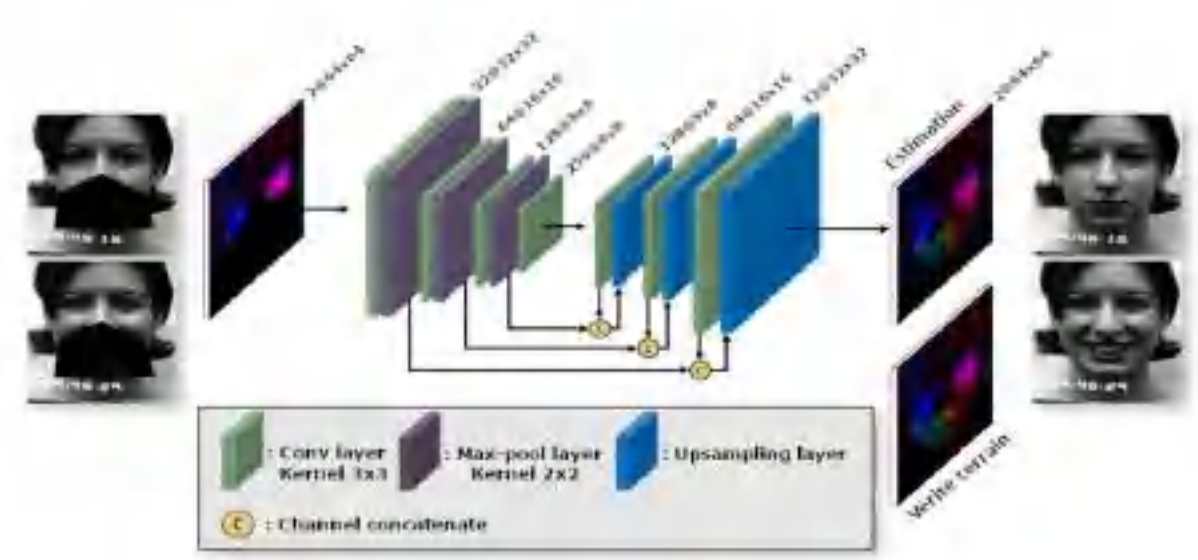
Automatic recognition of facial expressions in the presence of partial facial occultations

The automatic recognition of facial expressions still faces various challenges in natural environments. The presence of partial facial occlusions is considered one of the major challenges in recognising facial expressions. Various solutions have been proposed in the literature to address this problem. These solutions can be grouped into two main categories: solutions that focus on the visible areas of the face and those that reconstruct the hidden areas.

These solutions are mainly based on texture or geometry descriptors. However, motion seems to be adapted to address the problem of occultations due to some properties. The motion properties that we put forward are motion propagation, which allows to keep information related to facial expression in spite of occlusions, and the similarity of motions related to inter-personal facial expressions, which allows to abstract from the identity of the person on the one hand and, on the other hand, allows to rely more easily on similar data to be able to reconstruct the hidden areas of an occluded data.

We have proposed a first solution that focuses on the visible regions of the face by computing optimised facial models. This first solution relies on a motion descriptor in order to take advantage of the motion propagation property, which allows to keep information on the visible regions despite occultation.

We proposed a second solution based on a reconstruction of the corrupted optical flow computed from occluded face images. This second method is based on a denoising auto-encoder architecture that allows to reconstruct an unnoised optical flow by an occultation.



Facial expression reconstruction autoencoder based on optical flow maps

Human action recognition for active assisted living

Understanding human actions is still an important task in artificial intelligence. It finds its applications in different fields such as smart surveillance, content indexing or human-machine collaboration and interaction. Computer vision-based approaches are the most widely used techniques and lead to different sub-tasks such as: human detection, body part segmentation, pose detection, human action recognition (HAR) and human action segmentation (HAS).

The diversity of videos in available HAR datasets makes it difficult to identify efficient architectures. Most approaches consider human action recognition as a video classification problem and focus on global analysis of image sequences instead of targeting human subjects.

In this context, we developped an approach for human action recognition adapted for assistive robotics and active assisted living. The main objective is to increase safety through intelligent monitoring by detecting abnormal and rare situations (domestic accidents, falls, discomfort, dangerous postures, immobility, etc.).

To deal with optical flow limitations, we replaced the pre-processing step by a human body segmentation. The approach is interesting from the point of view of multi-task networks that are embedded in assistive robots.

The model based on the fusion of RGB and segmentation sequences proves to give the best results since it keeps the contextual information. It also demonstrates interest of semantic segmentation in the analysis of static and low/partial motion actions and motivates the development of more efficient models.

Semantic segmentation of human body on different situations: (Top) Normal situations, (Bottom) abnormal situations

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2.5 Cooperative robotics

An increasing number of large-scale and complex systems including robots and cobots are deployed in different life environments: transportation, industries, hospitals, institutions, etc. These autonomous and heterogeneous cyber-physical systems usually operate in isolation from each other and must be brought to collaborate to achieve one or more common missions. Such a configuration is referred to as a system of systems (SoS), where each entity (robot or other system) is a system component. A key problem is how to design, model and control such a system of systems.

Research contibutions are at various levels :

- The integrated design of complex and new components or robots

The robot as a system component (micro level) is more and more autonomous and performs more and more complex tasks, such as gripping deformable objects, realizing complex trajectories and shapes, etc. The challenges here is to propose integrated design architectures allowing to model and control these increasingly complex systems by optimizing several parameters (material, shape, strain, etc).

- Investigation and modeling of failure mecanisms of elastomers aiming at increased lifetime of such elastomers used in soft robotics.

- The collaborative management of a set of components given to achieve a mission.

The issue here is the development of decision support tools for the collaborative management of a system of systems.

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Integrated design of a soft and adaptive gripper for delicate objects grasping

JUNIA researchers have set a manufacturing process to develop bio-inspired soft fingers, based on the octopus or tongue motion. The aim is to exploit the complete mechanical structure of the fingers for grasping while taking advantage of the good properties offered by hyper-elastic materials.

Soft gripper for mushroom harvesting

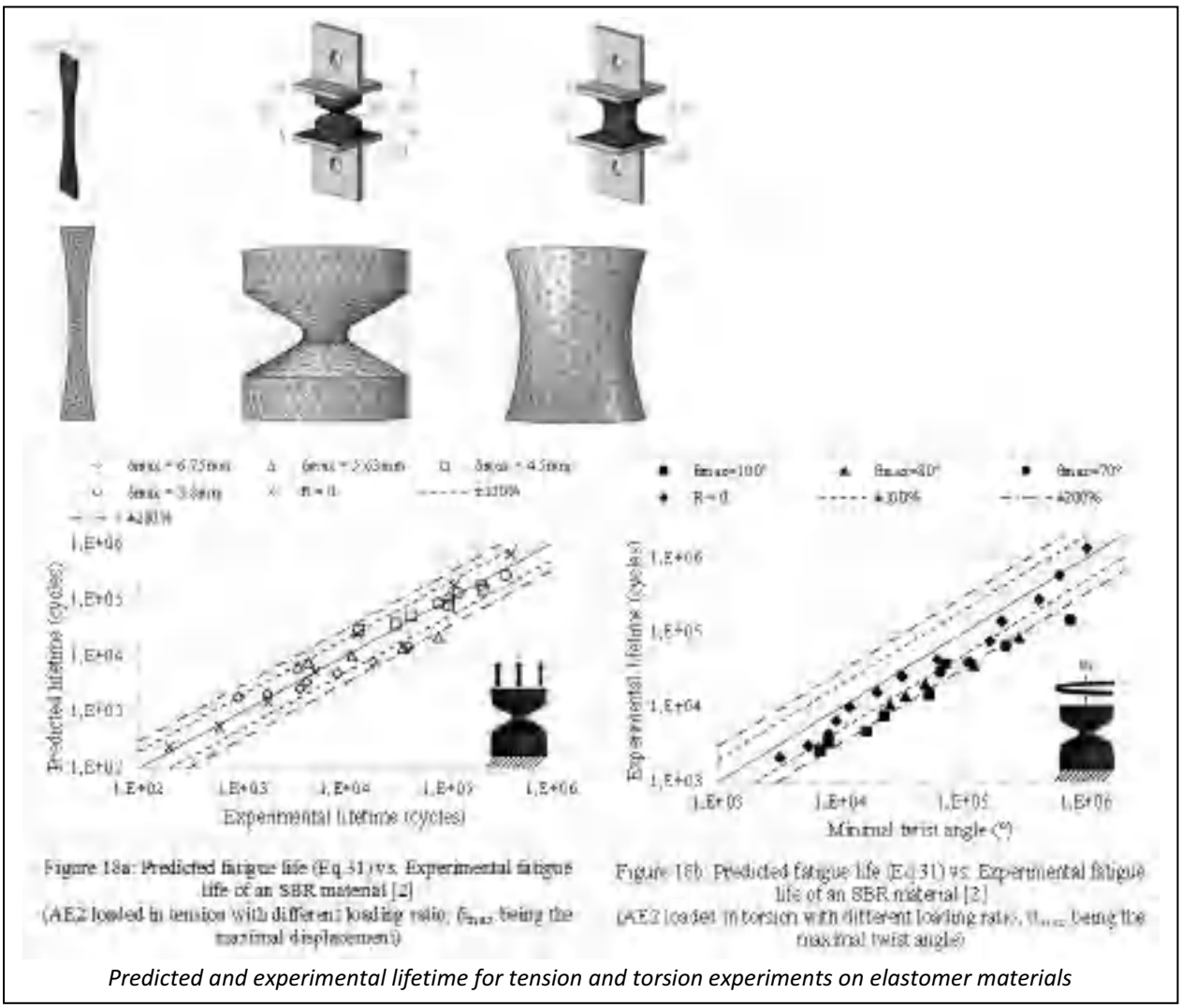
The resilience of these materials in soft gripping is a fundamental aspect that allows a wide range of applications, including agricultural applications in the particular case of our application: mushroom picking.

They are made of elastomer fluid actuators distributed along their shape. Thus their kinematics replicate in a natural way, the anatomical behavior of biological agents. They are essentially actuated by air or any other fluid.

Material investigation: thermomechanical fatigue of elastomers

The study of the hyperelastic behavior of elastomers is of increasing interest to the scientific community due to their growing use in industry, including flexible robotics. Among these, we distinguish thermomechanical fatigue which is induced by damage due to repeated solicitations. Therefore, a precise characterization of the material including the minimization of the uncertainty on the material, the implementation of a mathematical and numerical model, would allow to predict its life. In addition, topological optimization allows us today to make important gains in materials for eco-design.

The study of elastomers requires the consideration of the different energies involved in mechanical loadings. This study, which refers to the internal thermodynamics of these materials, is quite complex to formulate in order to derive generalized behavior laws. We are particularly interested in developing a criterion of lifetime based on continuous damage with consideration of the phenomenon of self-heating and physical-chemical aging and which is universal (ie valid for any type of polymer). We have carried out an important test campaign to characterize two grades of elastomers filled with carbon black and developed multiple models and numerical simulations in order to obtain reliable behavior models. Finally, we propose a criterion of lifetime prediction which gives good results in comparison with the realized tests.

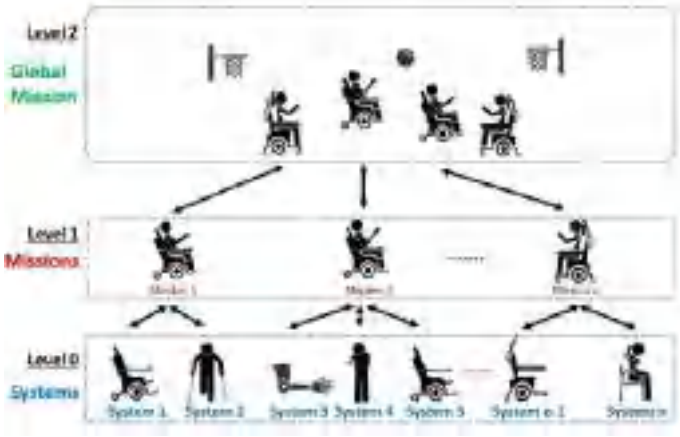


Predicted and experimental lifetime for tension and torsion experiments on elastomer materials

Collaborative management of a system of systems

This work aims at the development of decision support tools for the collaborative management of a system of systems. The target is the management of collaborative system components evolving on a large scale and having the following organizational properties: operational independence, managerial independence, cooperation, geographical dispersion and evolutionary development.

In such a paradigm, each equipment or person is a communicating object interacting with the other system components. Here the scientific problem is the collaborative management of a set of given components to achieve a given mission. We are developing this work as part of the RITMEA project in collaboration with a startup company.



System of systems to improve the autonomy of people with reduced mobility.
Level 0, component level; Connected wheelchair, connected orthesis, flexible gripper, etc. Level 1: Local missions; Autonomous navigation, obstacle alerting system, etc.
Level 2: Global mission; Handisport, etc.

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Nanomaterial Engineering

2D Nanomaterials

Characterization Tools for Micro and Nanotechnology

Electrospinning of Fibrous Materials

When crystalline dimensions are reduced to nanometre sizes, new structures and properties emerge. For example, synthesizing semiconductor materials with nanometer sizes restricts the electron motion and leads to a discrete atom-like electronic structure, which makes light absorption widely tunable, enables the bright emission of pure colors and significantly alters chemical functions because of the large surface-to-volume ratio. Our goal is to synthesize or grow one-dimensional and two dimensional nanomaterials and characterize their properties with potential applications in photovoltaïcs, quantum computing, neuromorphic, catalysis and sensing. Narrow band gap semiconductor nanowires, semiconductor nanoplatelets, two-dimensional Mott-insulators, metal-oxide nanofibers, piezoelectric nanofibers are among the most valued nanomaterials of our current research activities.

To reach a fundamental understanding on how atoms and molecules assemble into nanomaterials or to extend the traditional approaches to patterning and microfabrication, we develop tools that are able to deal with the nanoscale. They are used not only to grow nanomaterials, but also to characterize their physical properties. We see the current state of the art of these characterization techniques as a multidimensional parameter space in which trade-offs are made between spatial resolution and sensitivity, chemical speciation and sampling volume, speed of data acquisition and detection limits. To push the limits of what can be realized in terms of spatial resolution, chemical sensitivity and time resolution, we work hand in hand with key industrial players in instrumentation.

A more applied research is performed in the field of nanofibrous non-woven membranes which are prepared by electrospinning from polymer solutions. The elaborated materials are used to solve specific issues in areas such as biomedical applications (i.e. protection against acute respiratory syndrome), air filtering (sensors for the detection of filter clogging) and energy harvesting through piezoelectric polymeric nanofibers.

Associated research units : iemn gemtex

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3.1 2D Nanomaterials

Two-dimensional (2D) nanomaterials are a new class of nanomaterials with sheet-like structures and transverse dimensions larger than 100 nm, while the thickness is a few nanometers only. The success of graphene with fascinating properties such as excellent transparency, high electrical/thermal conductivities, large specific surface area, and extraordinary mechanical properties has ignited interest for other ultrathin 2D nanomaterials. 2D nanomaterials are very special materials as they possess large surface and anisotropic physical/chemical properties. Our main goal is to synthesize 2D semiconductor nanomaterials and study their electronic and optical properties with application prospects in electronics, photonics, sensors, energy production and storage.

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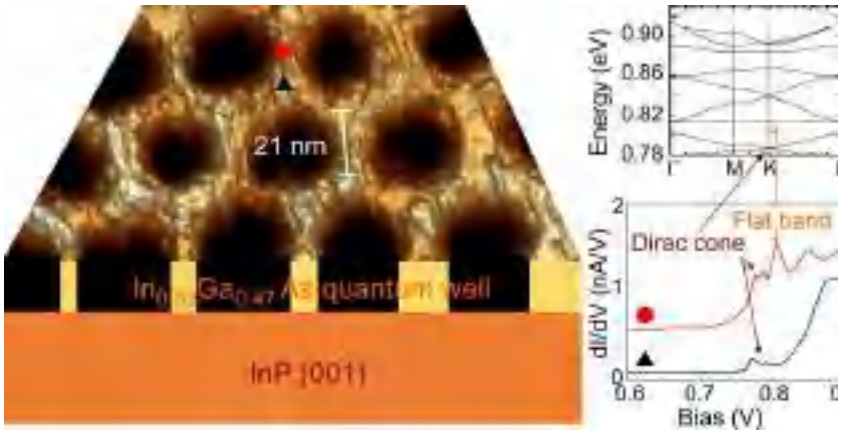
Design of semiconductor quantum materials with unusual band structure

When a crystal is reduced to two dimensions, electrons have unusual and counterintuitive quantum properties. In some materials such as graphene, electrons can behave as relativistic massless particles, much like photons. Conversely, in other materials, electrons can occupy flat electronic bands, giving them an infinite mass. These flat-band electronic systems are currently attracting considerable interest from physicists. Indeed, since electrons have zero kinetic energy, very original quantum phases can be formed, for example the superfluid phase.

Can these effects be induced in artificial materials, whose properties would result from the design of a two-dimensional lattice with specific geometries? This is the question that we have addressed in the research project Dirac III-V funded by the National Research Agency [1]. In collaboration with two other french research laboratories and with the Debye Institute in Utrecht, we have considered a typical semiconductor quantum well in which electrons are originally free to move in two dimensions. Thanks to the application of a lateral periodic potential, the electron waves are scattered by the potential, leading to the creation of particular band dispersions under the effect of quantum interference. This approach requires to structure the free electron gas with a periodicity close to the electron wavelength, corresponding to a few tens to a few nanometers only depending on the chosen semiconductor materials [2,3]. Tunneling spectroscopy measurements at low temperature demonstrated a



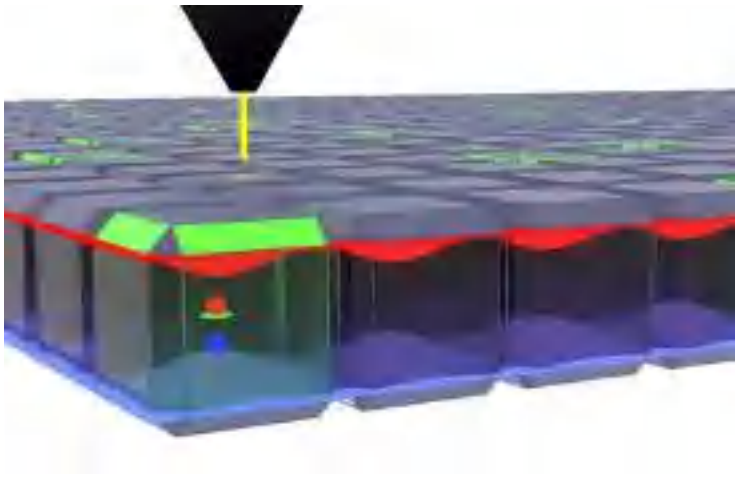
Scanning tunneling microscopic image of a honeycomb lattice nanoperforated in an InGaAs quantum well and tunneling spectra showing key features related to the creation of a Dirac cone and a flat band in the band structure.

profound modification of the electronic band structure, as predicted. In particular, despite the disorder effects inherent to nano-lithography, the spectra showed the signature of a flat band with a very high density of electronic states [4]. This feat, which required pushing the limits of current lithography techniques, opens the way to the generation of non-trivial quantum phases in the most common semiconductor materials.

Quantum dot acceptors in two-dimensional epitaxially fused *PbSe* quantum dot superlattices

Oriented attachment is becoming a key technique to generate two-dimensional crystals from the controlled assembly of quantum dots. By playing with the chemistry of the quantum dot facets, single crystals with different geometries, leading to distinct electronic structures, can also be produced. To fully deploy the potential of such superstructures as electronic materials, the next milestone consists in controlling their conductivity.

In collaboration with the university of Ghent, low temperature scanning tunneling spectroscopy of individual quantum dots was used to study two-dimensional epitaxially fused PbSe quantum dot superlattices and explore the physical mechanism at the origin of the doping in superlattices with a square geometry [5]. The experiments revealed the existence of a minority of defective QDs randomly distributed in the superlattice, that exhibited deep levels. These states, which arise from the surface chemistry of the unbound facets and not from imperfect epitaxial connections, trap electrons and leave behind weakly bound holes. Essential to account for the doping efficiency is the electronic coupling that was measured between the hole ground states of the majority of sound quantum dots, contributing to their substantial broadening. Based on Fermi-Dirac statistics, we showed that a broadening of 70 meV is large enough to provide free holes to the superlattice even at a low temperature of 77 K.



Schematics of a superlattice of PbSe *quantum dots studied with scanning tunneling microscopy, where the green quantum dots hold a deep level and act as acceptors*

Our study provided a thorough understanding of the efficiency by which defective quantum dots introduce charges in the superlattice, behaving as acceptor quantum dots in analogy with foreign atoms incorporated in semiconductor crystals.

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3.2 Characterization tools for micro and nanotechnology

Advances in fundamental nanoscience, design of nanomaterials and ultimately manufacturing of new nanotechnology-based products all depend to some degree on the capability to accurately and reproducibly measure properties and performances characteristics at the nanoscale. Fields such as electron microscopy, scanning probe microscopy and optical spectroscopy share common challenges of improved sensitivity, better discriminationn, faster data acquisition and analysis, and improved resolution. It is widely accepted that no single technique is able to provide all of the critical metrology for nanoscale systems. The ability to develop a breadth of capabilities that allow the broadest spectrum of analyses to be addressed is therefore of paramount importance. The vision includes tools that can measure statistically significant information and are capable of point-by-point characterization. They must offer correlation of multiple physical characterization, fast, non invasive subsurface/volumetric measurement capability, and 3D-resolved, nondestructuve evaluation of the chemical, physical, electrical, optical and other properties with the highest spatial and time resolutions.

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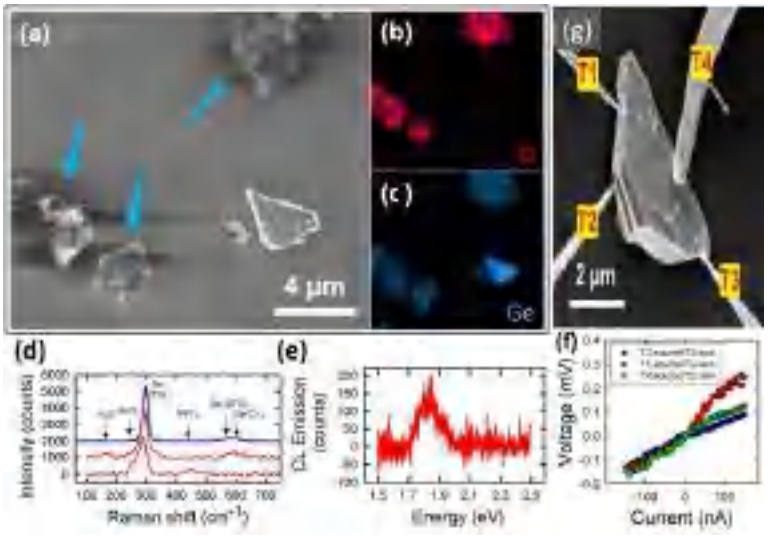
Multiphysical characterization of germanane

Germanane, the 2D graphane analogue, in which the germanium atoms arrange in a puckered honeycomb layer, belongs to the promising 2D materials with potential integration in electronic technologies. So far, the major way to synthesize germanane relies on the topochemical transformation of Zintl-phase CaGe2, which requires the subsequent functionalization of the germanane layers to strongly improve their resistance to oxidation. Despite the demonstration of the successful methylation of germanane, additional side effects arising from the layered

structure have been recently found and metrics such as scalability, sheet resistance and CMOS compatibility are still missing for making inroads into the conventional semiconductor industry. In-depth understanding of the fundamental properties of germanane calls for the development of multiphysical characterization tools including analyses of the crystal structure, chemical composition and electrical resistivity.

By combining scanning electron microscopy with either Raman spectroscopy and cathodoluminescence developped within the joint team Horiba-IEMN, or multiple tip scanning tunneling microscopy developped within the Excelsior Equipex project, we were able to identify oxygen-free crystallites and measure resistivity smaller than 1 Ohm.cm. Along with the high purity of the crystallites, the good thermal stability of the electrical resistance up to 280 °C makes methyl-terminated germanane suitable for complementary metal oxide semiconductor back-end-of-line processes.

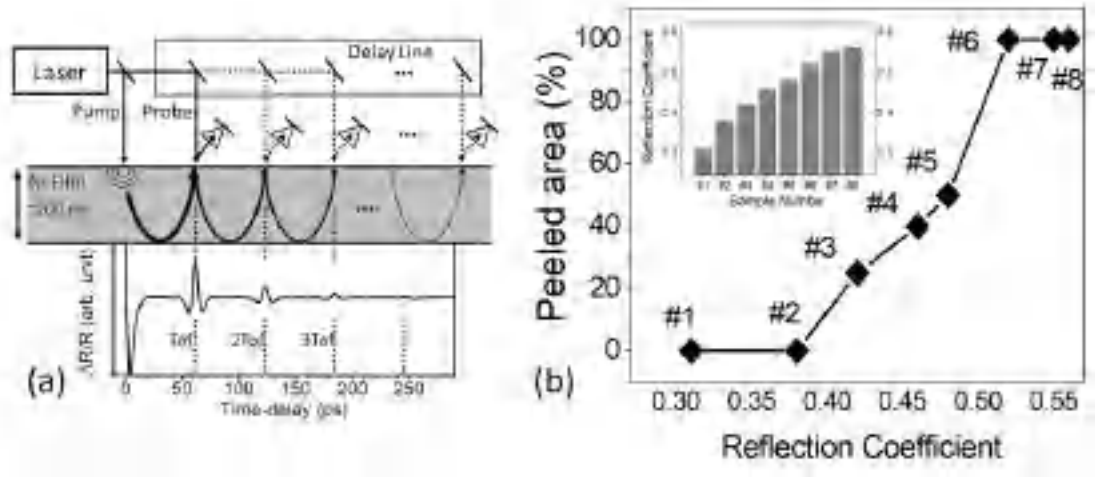


Multiple-physical characterization of germanane flakes performed with (a) scanning electron microscopy, (b) and (c) energy-dispersive X-ray spectroscopy, (d) Raman spectroscopy, (e) cathodoluminescence, (g) and (f) 4-probe scanning tunneling microscopy.

Thin-film elasticity and adhesion using the Colored Picosecond Acoustic technique

Colored Picosecond Acoustics (APiC) is a unique combination of optics and acoustics that implements a pulse-echo technique at the nanoscale using a tunable ultrafast laser. From the experimental point of view, it is a fully optical setup, acoustics taking place in the sample only. Very high frequency acoustic waves (up to several hundreds of GHz) are emitted and detected using ultra-short laser pulses. The first application of APiC is the thickness measurement of thin-films (range a few nm to a few µm) and complex stacks made of various materials (dielectrics, metals, semiconductors…). It can also be used to measure elasticity of thin-film materials. A large number of methods have been developed to characterize the adhesion of a thin film to a substrate. Among them, tape test is still one of the most popular methods. Acoustic waves and especially ultra-high frequency acoustic waves are also sensitive to adhesion defects as they affect the way acoustic waves are reflected at such an interface. To demonstrate the capability of APiC to characterize the adherence of a thin-film on a substrate, we first prepare a series of identical thin-film samples with a variable adhesion at the interface between the film and its substrate. To modulate adhesion of some samples, an ultrathin gold layer is deposited on the substrate before thin-film sputtering. Ion implantation is also used to reinforce locally gold adhesion. The samples are then characterized using two very different

techniques: APiC for measuring thickness and acoustic reflection coefficient (R) at the interface and scotch tape test to have an independent evaluation of the adhesion through the peeled area (P). An excellent correlation is found between R and P: high |R| value samples are easily peeled off and P is large. That work demonstrates the capability of Picosecond Acoustics to perform adhesion tests in a totally non-destructive manner and furthermore locally.



(a) Principle of acoustic measurement at the nanoscale using a fully optical setup and typical signal measured on a 200 nm thick Ni layer deposited on silicon. Tof means Time of flight. Thickness is deduced from the time of flight (tof) combined with Ni sound velocity. Adhesion is characterized through the reflection coefficient. (b) Correlation between acoustics and scotch test regarding thin-film adhesion. Weak adhesion is correlated to a large reflection coefficient.

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3.3 Electrospinning of Fibrous Materials

Different processes can be used to produce a textile surface such as weaving, knitting, braiding or electrospinning. Electrospinning makes it possible to fabricate non-woven polymerous membranes (synthetic or natural) with diameters varying from a few nanometers to a few micrometers. The technique is very similar to additive technologies (3D printing type). During the electrospinning process, a high electrical potential (between 5 to 30 kV) is applied to the droplet of the polymeric solution extruded from the spinneret. This electrostatic charge accumulates on the surface of the liquid droplet and deforms it into a cone called a Taylor cone. When the electrostatic force opposes the surface tension of the liquid, the jet is stretched and split into ultrafine fluids. Ultrafine fibers will be collected on the conductive collector (randomly or aligned) as the solvent evaporates and the fluids solidify. Pore size distribution and large-scale manufacturing are areas where further development is needed.

Electrospun membranes have potential for a variety of applications. The work at JUNIA focusses more particularly on:

- Development of an aerosol filtration membrane for the fight against airborne diseases,
- Development of piezoelectric textiles,
- Development of textile sensors for the detection of respiratory diseases,
- Development of textile sensors for the detection of filter clogging.

Lille is the historical center of the textile industry in France and there is a significant industrial potential for developing electrospinning technology in a wide range of applications. This research topic aims at enhancing development and innovation capabilities at the regional level.

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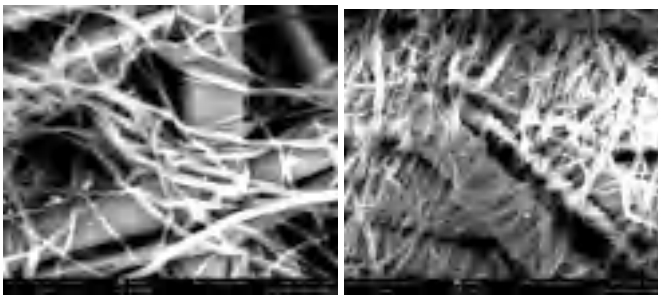
Development of an aerosol filtration membrane for the fight against airborne diseases

Since the beginning of this century, we have witnessed several epidemics of airborn diseases, the most recent of which is the severe acute respiratory syndrome caused by Corona Virus 2 (SARS-CoV-2). The aim of this project is to develop a high-quality alternative mask for the public, dedicated to the fight against pandemics, while being comfortable, washable, with high filtration performance, and manufactured on an automatic machine. In France, there are factories producing spunbond and meltblown nonwovens dedicated to other applications (hygiene for example) however their production lines are not capable of manufacturing a media for masks. The idea is therefore to develop a media by using the existing non-woven technologies like carding and spunlace processes. These technologies are more versatile with high production capacity (more than 0.5



(a) (b)

SEM images of electrospun thermoplastic polyurethane membrane on a nonwoven substrate (a) 45min (b) 90min of electrospinning

million m² per day and per line) and allow the use of blends of fibers with multiple properties for moisture management, control of the rigidity of the mask, the dimensional stability following washing, etc. The developed mask, which is in between cloth masks and medical masks, should filter the aerosols smaller than 3 µm and have a good washing resistance. This washable mask will be composed of three layers. The two exterior layers are made of non-woven textiles encompassing inside an electrospun membrane. The electrospun membrane is used to improve the filtration efficiency of the mask which should filter particles equal to or less than 3µm (cloth masks) or even meet performace criteria of medical masks (Type I). Different polymers (PA-6, TPU,…) have been experimented for electrospinning on a optimal non-woven substrate. The membranes have then been characterised to analyse their filteration efficiency and their permeability. This project is a collaboration between JUNIA and ENSAIT.

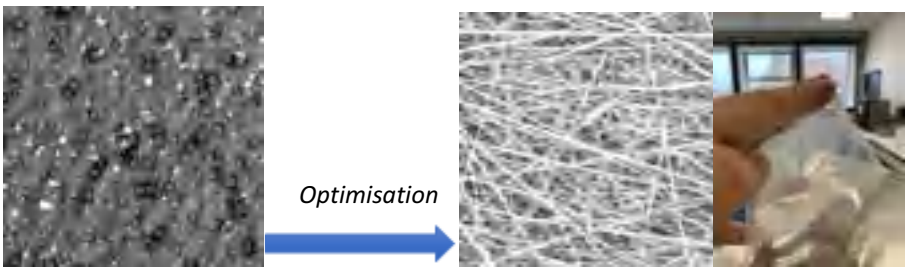
Development of piezoelectric textiles

In recent years, energy shortages are getting worse. The use of non-renewable energy resources based on fossil fuels such as oil, coal and natural gases are sources of various environmental concerns. One of the alternatives to solve these questions is the use of renewable energies. The daily power associated with human body movements represent up to a few tens of watts. The goal of this study is harvesting a tiny part of the energy dissipated during the various movements that could be enough to power some electronic elements. This kind of energy harvesting is based on direct piezoelectric effect: when a mechanical stress is applied on piezoelectric materials, the materials generate electrical charges across their boundaries.PVDF ((-CH2-CF2-)n) is a thermoplastic semi-crystalline polymer with high purity, lightweight and flexible, solvent resistance, and electrical field stability. The PVDF crystalline structure exhibits five different polymorphs, α-, β-, γ-, δ-, and ε- phases. The polar β- and γ-phases of PVDF show good piezoelectric responses because of the high dipolar moment per unit cell. Thus, the piezoelectric performance of PVDF is mostly related to the content of polar crystalline phases (FEA). In this study, electrospun method is used to prepare PVDF-based PENG because electrospun technology can significantly improve the FEA in PVDF. There are three methods tested in this study to improve the piezoelectric properties of PVDF PENG:

1. Increase piezoelectric coefficient (d33) of PVDF. The FEA in PVDF is improved in the following methods: Nanofiber structure and optimizing the parameters during electrospinning process.

2. Adding piezoelectric nanoparticles BaTiO3 to improve the piezoelectric performance of PVDF nanofibers.

3. Fabricating PVDF PENG with novel multilayer structure



F_{EA} = 68,32 ± 1,19% F_{EA} = 94,2 ± 0.4%

This photo demonstrates that the content of electroactive phase (FEA) of samples is increased by optimizing the electrospinning parameters.

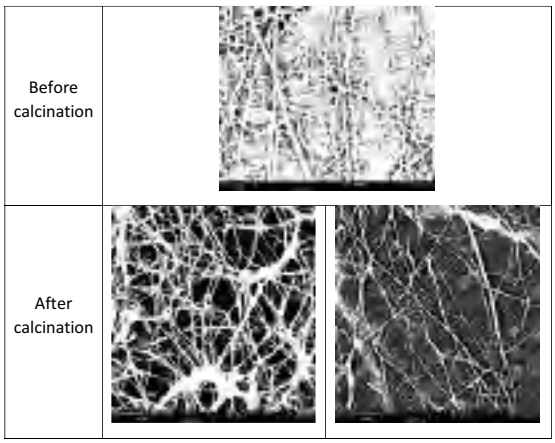
Development of textile sensors for the detection of respiratory diseases

Asthma is a major noncommunicable disease (NCD), affecting both children and adults, and is the most common chronic disease among children. Asthma affected an estimated 262 million people in 2019 and caused 455000 deaths. Most asthma-related deaths occur in low- and lower-middle-income countries, where under-diagnosis and under-treatment is a challenge. Traditional methods for detecting asthma are expensive, so trying to find a less expensive way to diagnose asthma in an early stage helps patients to spend less money for not only diagnosis but also treatments. The focus of this work is on developing gas sensors to detect nitric oxide (NO) gas, a main bio marker of asthma, by using metal oxides and electrospinning process. Detecting gas using metal oxide-based gas sensors is based on interaction between molecules of gas and materials of sensing membrane. High sensitivity of the detector is crucial for early stage diagnosis. The sensitivity is directly related to the density of available oxygen vacancies on the surface of sensing membrane. We developed an open structure and porous sensing membrane based on metal oxide and nanofibers. Metal oxides are not spinnable directly. Therefore, metal oxides need to rely on the use of precursor solutions followed by a high temperature step to form the oxide from their melted states. Our method consists of three major steps:

(i) Preparation of an organic precursor solution containing an alkoxide of metal or metal salt with a polymer matrix.

(ii) Electrospinning of the prepared solution to produce the composite nanofibers, which also contain the polymer matrix or solvents.

(iii) Calcination or sintering of electrospun nanofibers at elevated temperatures



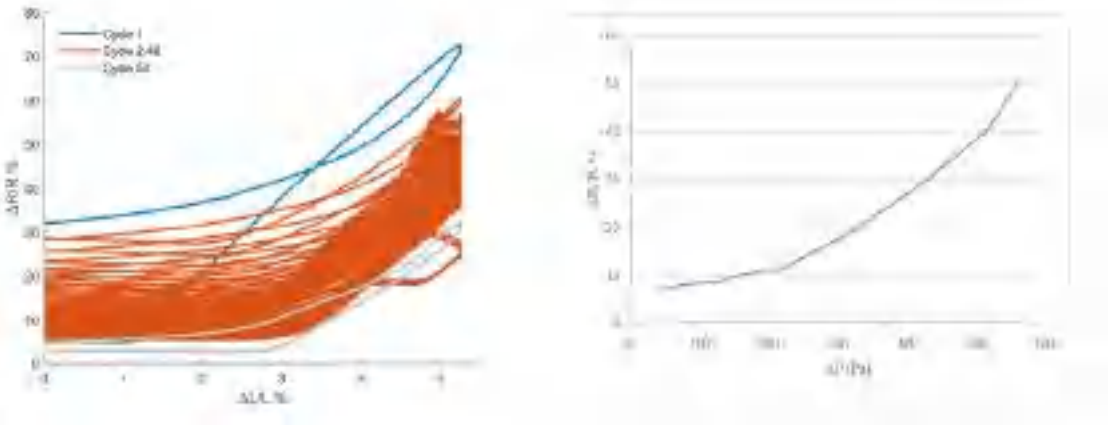
SEM images of rGO/ZnO nanofibers before/after calcination to be used as sensors in a developed gas chamber (sensing characterization is under process)

Development of textile sensors for the detection of filter clogging.

Nowadays, many people suffer from respiratory diseases, the global burden of diseases indicates that air pollution is the fourth most important risk after high blood pressure, dietary risks and smoking. The French Health Safety Agency (ANSES) has announced recommendations for Indoor Air Quality (IAQ) for concentrations of certain molecules such as formaldehyde (10 µgm-3 (8 ppb)) and chloramine (300 µgm -3 (60 ppb)). To meet these rates, filters play an important role in air purification, especially in enclosed public places such as swimming pools or shopping malls. One of the recurring problems with air filters is the detection of their clogging by particles in order to change or clean them. Clogging occurs when the deposition of particles blocks part of the filter. The pressure drop increases causing a strong increase in electrical consumption of the motor and drop in filtering efficiency.

The aim of our project (SAFIRS, funded by the National Research Agency (ANR)) is to avoid the problems of filter clogging by relying on the skills of two companies (Titanaire and ETT), which manufacture industrial air filters and labs of IMT Atlantique and Mines Saint-Etienne which deal

with electrical connections and the detection of VOCs and ENSAIT which focuses on the detection of filter clogging. The use of a sensor based on an electrospun textile membrane sensors is tested.In this study, thermoplastic polyurethane (TPU) nanofibers were produced using optimal electrofilling parameters (distance: 15 cm, voltage: 12 kV and flow rate: 1.5 ml/h) and DMF/THF as solvents. Then, carbon-based inks were printed on the surface.



a) The cyclic test curve (50 cycles) for printed membranes (pattern: straight line) b) The ΔP (Pa)/ΔR % curve (pattern: zigzag)

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Acoustics and vibrational systems

Underwater Acoustics

Acoustic Metamaterials

Multimodal Perception

The “Acoustics and vibrational systems” theme focuses on the link between acoustic waves and the mechanical, electrical and biological systems used to generate, perceive or transform these waves. It concerns both the design, manufacturing and test of acoustic and vibratory devices developed for the different sub-topics (materials, transducers, sensors, panels, microsystems, etc.) and the study of psychophysical effects related to sound and tactile perceptions.

The objectives of the theme are twofold: 1) to provide new knowledge on the properties of acoustic waves and their perception; 2) rely on this new knowledge to develop innovative acoustic devices that meet new needs of civil society (disability, environment, energy, art) or industry (communications, marine technologies, instrumentation) .

The "Underwater acoustics" sub-topic concerns acoustic devices deployed in the oceans, mainly sonar systems used to detect objects, to provide images of the seabed or to communicate information. Other investigations study acoustic screens aimed at making ships discreet or stealthy and mitigating ocean pollution by human-made noise.

The “Acoustic Metamaterials” sub-topic focuses on the development of structured materials with unusual properties with respect to acoustic waves. Bio-inspiration and multi-scale structuring can contribute to their design and new additive manufacturing technologies to their realization.

The “Multi-mode perception” sub-topic introduces the human factor into the equation by addressing sound perception, tactile perception and auditory display.

Associated research unit : iemn

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4.1 Underwater Acoustics

Most detection, visualization and communication systems using electromagnetic waves must be completely redeveloped using acoustic waves to be functional under the surface of the oceans. Pratical applications are mainly based on two systems: sonar, which emits and receives acoustic waves to detect objects, build images of the seabed or communicate; acoustic screens that reflect or absorb waves to make ships discreet or stealthy and reduce anthropogenic noise pollution.

Main current issues and problems in the ocean concern frequencies between 10 and 1000 Hz, i.e. acoustic wavelengths in water between 1.5 m and 15 m. Knowing that the interaction of an object with a wave is effective when its dimension is comparable to the wavelength, the miniaturization of underwater acoustic systems for the production and control of acoustic waves appears to be a major challenge. Two main themes are addressed in our research:

- the design and manufacturing of compact piezoelectric transducers used as sound sources in water involving electrical, mechanical and acoustic effects which require expertise in multi-physical couplings and specific numerical models;

- the study of acoustic screens based on acoustic metamaterials that artificially structure a medium to acquire unusual properties with respect to acoustic waves and in particular the ability to interact with wavelengths much larger than their size.

Specific measurement methods are also developped for these undewater devices.

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New concept of low frequency and broadband underwater acoustic source

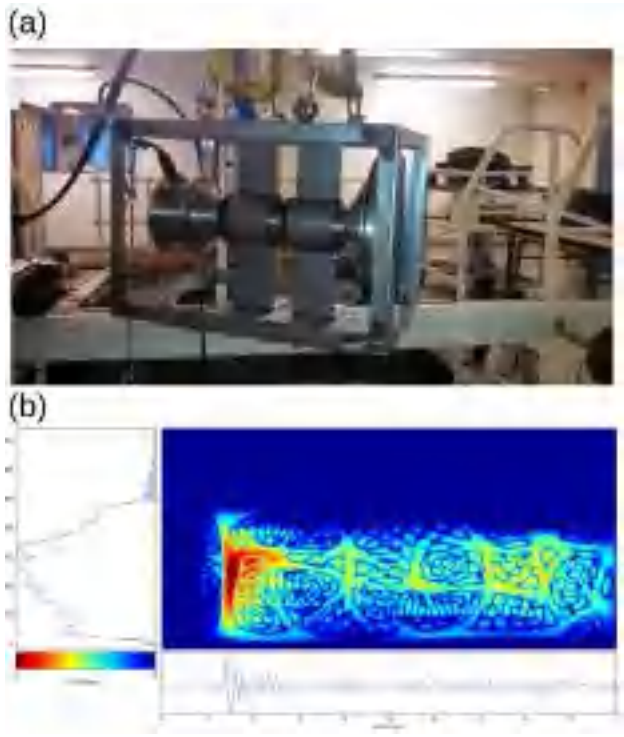
Seabed imaging requires the development of both low-frequency (to be able to reach the seabed and penetrate the sediments) and broadband (to improve image resolution) acoustic sources. These sources must be light and compact when they are deployed on a zodiac or an autonomous underwater drone.

To achieve these goals, the classic Tonpilz transducer concept has been revisited. The Tonpilz transducer is a resonator made up of two masses, a light headmass on the front face allowing the radiation of the wave in water and a heavy tailmass, connected by a pillar of piezoelectric ceramics serving both as a source of vibration through electro-mechanical coupling and as spring element for the resonator. This solution is bandwidth-limited due to two characteristics: the use of a single resonance and the use of a single vibrating surface. In addition, the presence of the tailmass weighs down the transducer without directly contributing to acoustic radiation.

The structure of this transducer has been reworked by replacing the classic solid tailmass with a light tailmass/housing/horn assembly. This new lightened element plays both the role of tailmass and sealing box and introduces additional resonances in the frequency band and secondary radiating surfaces. The result leads to a transducer (figure a) that is more compact, lighter (29 kgs instead of 48 kgs) and usable in a wider frequency band (1000-8000 Hz instead of 1000-4500 Hz).

Unlike the classic sonar transducer characterized only by its frequency response, the use in imaging also requires temporal response characterization via a time-frequency representation (figure b. This analysis shows that a strong reduction of the pulse duration from 5 ms to 1.4 ms is obtained with the new transducer.

Collaboration (SOACSY, Naval School of Brest)



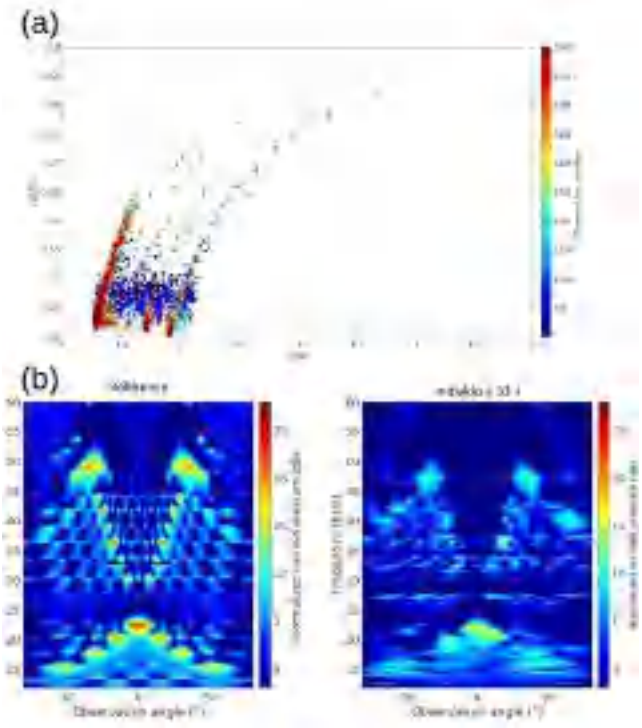
(a) Prototype of low frequency broadband sonar transducer under test in Junia acoustic tank
(b) Measured time-frequency response of the prototype transducer highlighting frequency bandwidth and time resolution of the emitted acoustic signal

Stealth and discretion of underwater structures

The acoustic discretion of a ship describes its ability to lower the intensity of the noise it radiates into the water. Stealth refers to its ability to reduce echoes when insonified by an incident acoustic wave. In both cases, the performance of the ship is evaluated by energy information, the level of radiated noise for radiation, the target index for stealth. We study here the possibility of completing the overall energy objective of reducing the radiated power with an objective of optimizing the spatio-temporal distribution of the acoustic fields.

The hulls of ships are reinforced by stiffeners which strongly contribute to the distribution in space and time of the radiated or diffracted acoustic fields. When the distribution of the stiffeners is periodic, the angle-frequency representations of these fields highlight the presence of high intensity patterns that can be associated with this periodicity (figure b).

In the RAMSES project (ANR Astrid), the solutions studied to reduce the intensity of these patterns consist in disturbing the periodicity of the stiffeners by introducing a slight variation in the geometry of each stiffener. Two original aspects have been implemented in that research work:



(a) Representation in criteria space of individuals over generations during an optimization process with the genetic algorithm
(b) Frequency-angle representation of the acoustic field radiated by the ribbed plate submitted to a prescribed force: reference plate (left) and optimized plate (right)

- the use of coupling between simulations by physical models and metaheuristics (figure a) to identify spatial distributions of disturbances optimizing a criterion of radiation (figure b) or stealth in a given frequency band. This approach has also been extended to the case of simultaneous optimization of discretion and stealth;

- the integration of coherent detection processing in the stealth criterion to exceed the energy criterion and take into account the loss of coherence between incident and diffracted signals provided by the solutions implemented.

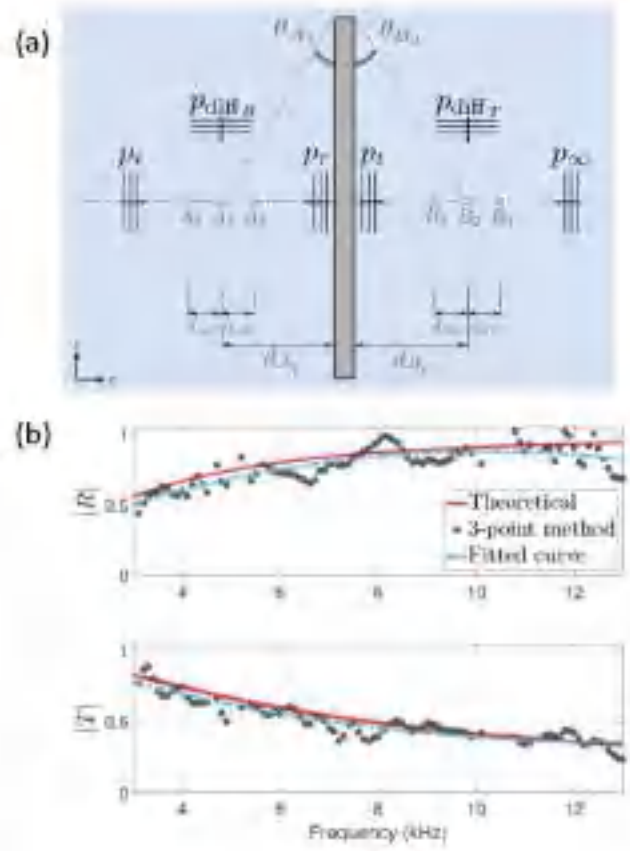
The extension of this work to the case of structures covered with anechoic or masking panels is addressed in the CLEOPATRE project (ANR ASTRID).

Collaboration (LOMC, Thales DMS, Thales R&T)

New method for measuring reflection and transmission coefficients of a composite panel in a tank

The material properties or acoustic performance of submerged composite structures must often be determined or verified experimentally. For underwater applications, a panel can be characterized in an acoustic tank equipped with a source and two hydrophones, one being used for the reflected signal and the other for the transmitted signal. However, if one wishes to characterize the intrinsic performances of the material, the panel measurements can be strongly disturbed by the waves diffracted by the edges of the panel. It is therefore crucial to evaluate or reduce the contribution of the diffracted pressure.

The so-called "3-point" method has been developed and fine-tuned in the acoustics laboratory thanks to the work of 2 theses (P. Meresse (2015) and L. Roux (2021)). It is a technique that decomposes the total pressure into four contributions : incident, reflected, transmitted and diffracted on the edges. These different contributions are determined by measuring the total pressure at three positions close to each other and to the panel (figure a). The reflection and transmission coefficients can thus be obtained by removing the contribution of the waves diffracted on the edges, in order to compare them directly with those obtained theoretically for a panel of infinite lateral dimensions (figure b).



(a) Schematic representation of the measurement setup
(b) Frequency variation of reflection and transmission coefficient through a panel: comparison between theoretical results and measurements using 3-points method

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4.2 Acoustic Metamaterials

Controlling the propagation of waves (elastic, acoustic or electromagnetic) is a fundamental problem that has arisen for a long time in several fields of physics and mechanics. The main challenge is to develop a class of materials with complex dynamic behavior over wide frequency ranges, while presenting realistic structural requirements, such as being small, compact, light and efficient under structural constraints for practical implementation.

In this context, "acoustic metamaterials" have recently attracted renewed interest in addressing this scientific challenge through the use of composite structures (i.e. made of several materials) periodic (i.e. composed of unit cells that are repeated in space). The main problem is to understand and identify the interaction between material properties and their spatial arrangement (architecture) in the periodic units that lead to the desired dynamic behaviors.

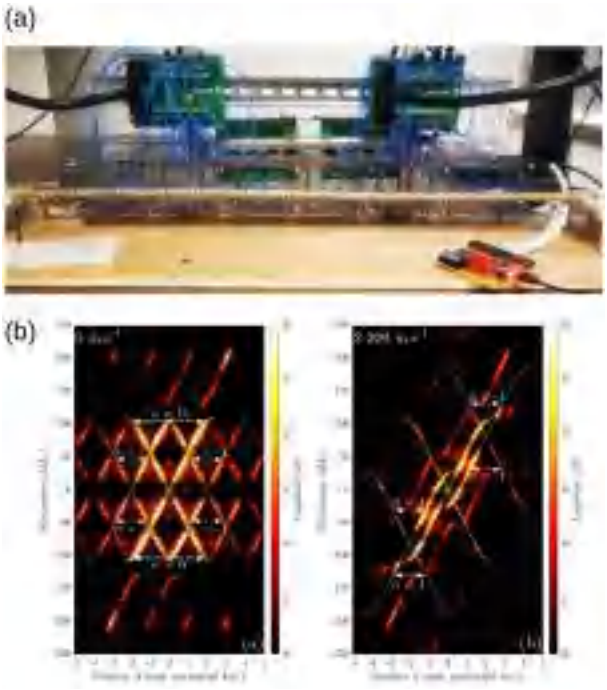
The "geometry" aspect plays a fundamental role in determining the properties of "acoustic metamaterials". If at the beginning of the 2000s the explored shapes of unit cell inclusions were rather canonical (circular, square, triangular, etc.), more and more complex geometries have since started to be explored, including for example bio-inspired hierarchical geometries.

The main scientific approaches of the laboratory in connection with this subtopic concern (i) the development of new calculation methodologies adapted to periodic structures based on analytical and numerical models and (ii) the experimental characterization of their dynamic behavior through the reconstruction displacement fields (scanning laser-vibrometric scans) and transmission tests in the largest underwater acoustics tank in an academic environment.

Contact : Marco MINIACI, marco.miniaci@junia.com

Space-time modulated piezoelectric phononic crystals

Wave propagation in media with spatio-temporally modulated material parameters is widely studied for several years. Nevertheless, simple experimental realizations are diffucult to achieve, as significant and rapid changes of the parameters are difficult to produce. Sarah Tessier's PhD thesis focuses on modulated piezoelectric phononic crystals in which it is possible to affect the propagation of acoustic waves by simply modulating the electrical conditions on a periodic set of electrodes. Thus, it is possible to control modulation through electrical circuits with a fairly simple experimental implementation and allow for high modulation speeds.
The experimental study is conducted on a phononic crystal composed of an assembly of piezoelectric rings separated by electrodes which can be grounded or left in a floating potential condition (figure a). Dispersion curves (relating acoustic wavenumber to frequency), obtained by measuring electrical potential of the electrodes in space and time, exhibit exepected frequency band gaps periodically connected to the ground.
When periodic groundings are shifted in time at subsonic modulation speeds, an asymmetric shift of the band gaps is observed, associated to a non-reciprocal propagation of the elastic waves (figure b). For faster modulation speeds corresponding to sonic and supersonic regimes which include a crossing of line of sound, multiple interactions between propagation modes and unstabilities are highlighted. This work was part of ANR JCJC project MEANDRE.



(a) Experimental setup allowing space-time modulation of electric boundary condition applied to a piezoelectric phononic crystal
(b) Dispersion curves of acoustic waves in the piezoelectric phononic crystal without modulation (left), with subsonic modulation at 2200 m/s (right)

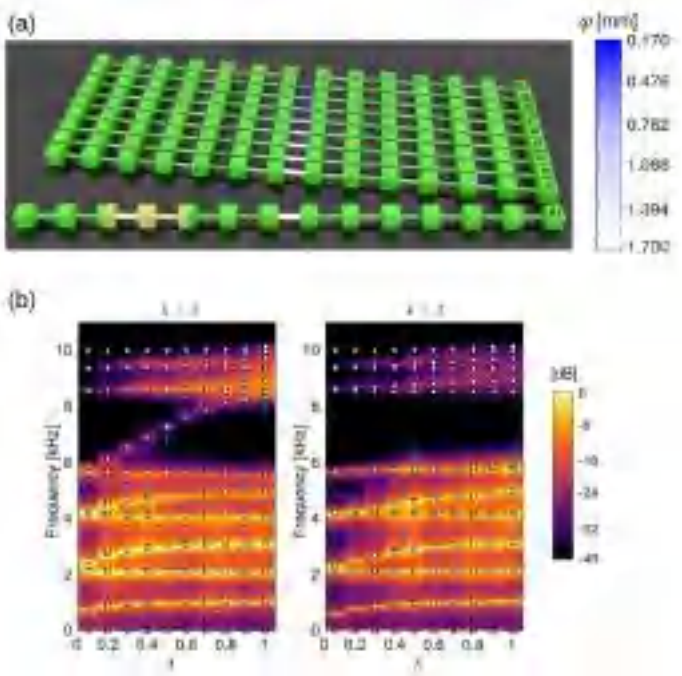
Spectral flow of localized mode in elastic media

Localization of waves, i.e., a phenomenon for which the deformation energy instead of propagating over extended regions remains confined in small portions of the original domain is a fundamental problem arising in multiple areas of physics, including elastic systems. This can occur in periodic, quasi-periodic or totally random media.

In this context, we investigate the interplay between local properties (material composition / geometry) and architectural defects to realize the aforementioned nontrivial mode localization.

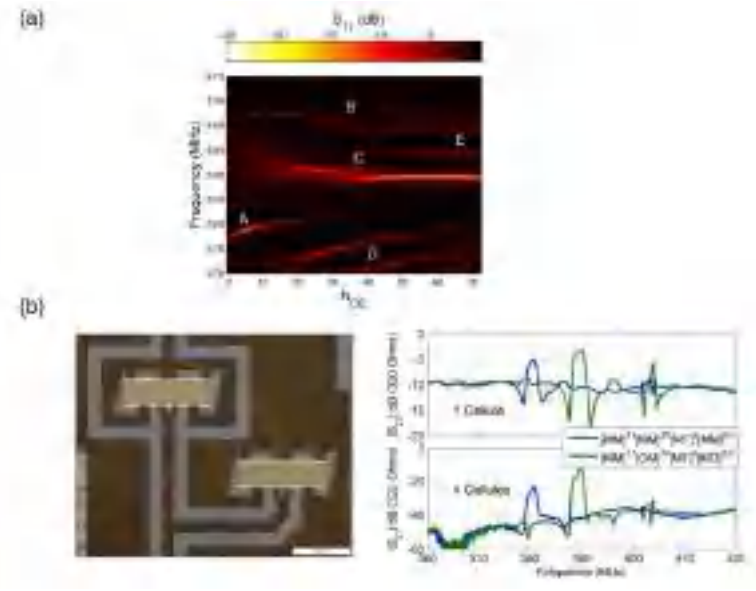
Our idea is to take inspiration from the theory of « fractional electronic charges » to achieve localized modes in continuous elastic media without involving (i) changes over substantial portions of the structure nor (ii) ad-hoc contextual modifications that do not translate into a general design paradigm.

Shown here in the playground of 3D printed structures (figure a) and elastic plates, such localized modes (figure b) open new avenues in elastic wave-based applications in architected elastic solids.



(a) Three-dimensional rendering of the experimental samples for which stiffness modulations of central beam indicated as #1 – #10 are considered
(b) Measured frequency response functions in the 0 – 11 kHz frequency range for the two classes of elastic chains. In the first case, a spectral flow of the 8th mode from the lower to the upper bulk band is clearly observed

Tunable Surface Acoustic Wave resonators and filters for radio-frequency



(a) Simulated s_{11} coefficient magnitude of the SAW resonator as a function of frequency and number of floating electrodes in each mirror N_{oc}
(b) Tunable SAW filter: microscopic image of fabricated signle L cell filter (left), measured frequency response of s_{21} coefficient magnitude for two different conditions on mirrors electrodes (right)

Modern telecommunication systems are expected to be operational in extended frequency ranges which imposes an increased number of filter components present in these systems. It is thus of practical interest to develop telecommunication circuits with a limited number of filter components without reducing the functionality of emission/reception circuits.

The objective of Ricardo Alcorta-Galvan thesis is to achieve this goal by developing tunable/switchable surface acoustic wave (SAW) filters for telecommunications applications. This type of filter is composed of a series of periodic electrodes on a piezoelectric substrate. External

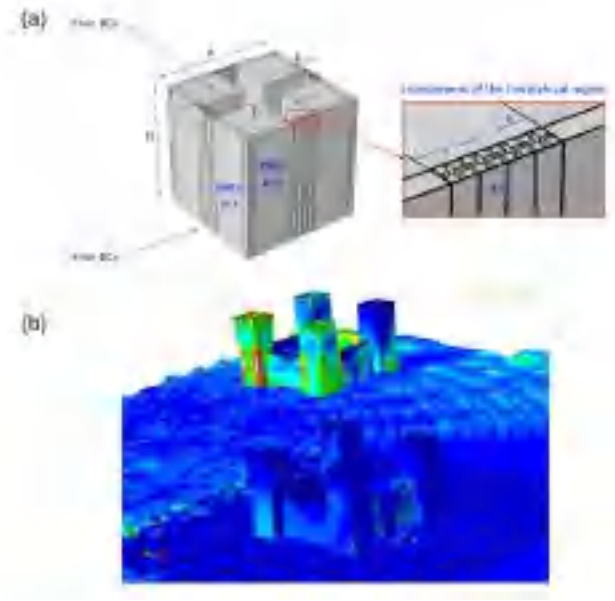
electrical signals are applied on the electrodes, inducing surface acoustic waves that propagate on the substrate. Periodic metallizations are also used to control surface wave propagation and delimit acoustic cavities acting as phononic crystals. Partial reflections of surface acoustic waves from the electrode edges open Bragg bandgaps.

The strategy in this work is based on the fact that the width and the center frequency of the bandgap can be controlled by modifying the electrical condition on the mirror electrodes (figure a). Using this approach, SAW resonators are designed, fabricated and electrically characterized with a 2,2% relative resonance frequency shift. These resonators are then used to develop a lumped element filter whose pass-band center frequency depends on the electrical condition of the electrodes of each resonator (figure b). This topic was also addressed in the FORMOSA ANR ASTRID Maturation project (collaboration: Thales R&T, frecnsys, AMCAD).

Bio-inspired and hierarchical metamaterials for acoustic and vibration control

The aim of the EU-funded BOHEME project is the technological development of a new class of mechanical metamaterials, drawing inspiration from Nature for their design. Exploiting knowledge from various disciplines (from biology to mathematics, from ocean engineering to materials science), we start from the innovative assumption that the working principle behind metamaterials is already exploited in nature and that through evolution this has led to optimised designs for wave and vibration control and impact damping. BOHEME will take a disruptive approach for applications over various wavelength scales, from non-destructive testing to noise reduction to low-frequency vibration control (including seismic waves), to coastal protection or energy harvesting from ocean waves.

In this context, so-called "seismic shields" have been proposed for the protection of large areas where other isolation strategies (e.g. dampers) are not workable solutions. The feasibility of an innovative design based on hierarchical design of the unit cell, i.e. a structure with a self-similar geometry repeated at different scales has been investigated (figure a). Results show how the introduction of hierarchy allows the conception of unit cells exhibiting reduced size with respect to the wavelength while maintaining the same or improved isolation efficiency at frequencies of interest for earthquake engineering (figure b). This allows to move closer to the practical realization of such seismic shields, where low-frequency operation and acceptable size are both essential characteristics for feasibility.



(a) Hierarchical large-scale metamaterial (the inset provides an enlargement of the region where the second hierarchical level is introduced)

(b) Simulated displacement field produced by an incident seismic wave on Siena Castle without (top) and with (bottom) hierarchical seismic shield

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4.3 Multimodal perception

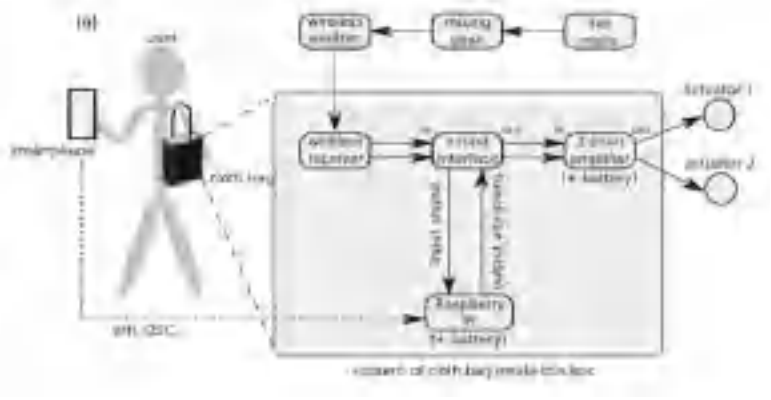
This research theme aims to develop experimental methods and protocols to meet scientific challenges in the field of sound perception, and to integrate them into a theoretical framework at the crossroads of acoustics, psychology and linguistics. The issues we are interested in are:

a) to integrate in the field of sound perception, recent research results showing that perception is multimodal and involves several sensory modalities which interact in a complex way (multimodal integration),
b) to overcome the unrealistic nature of perception experiments in laboratory conditions by studying how we perceive and interpret sound in the context of multimodal perception, based on the implementation of "ecologically valid" experimental approaches, where the participant interacts with his environment in a usual way.
Conversely, sonification offers a representation of data (traditionally represented via the visual channel) via the auditory channel. Such alternative representations have the potential to provide radically new methods of exploring and analyzing data: listening to the data, instead of looking at it, highlights different aspects of the data and potentially offers new approaches. In order to strengthen the currently developed sonification methods and foster their potential wider use within the scientific community, there is a need for a systematic evaluation of the sonification techniques in question, using a psychological framework.

Contact : Arthur PATÉ, arthur.pate@junia.com

Touch the Music: Displaying music into vibration

This work "TOTEM" (TOuch ThE Music), an INTERREG micro-project, aims at finding inclusive solutions to foster the d/Deaf's (persons who have become deafened or hard of hearing in later life, after they have acquired a spoken language) participation to live music concerts. A portable device has been developed that transforms live music signals into symbolic vibrations is described (Figure a). A co-construction, user-centered approach supplied a list of specifications adapted to the d/Deaf and hearing users' needs. The specifications were iteratively implemented and discussed over the course of the project, alternating between developments in the lab and in situ tests during live music concerts.



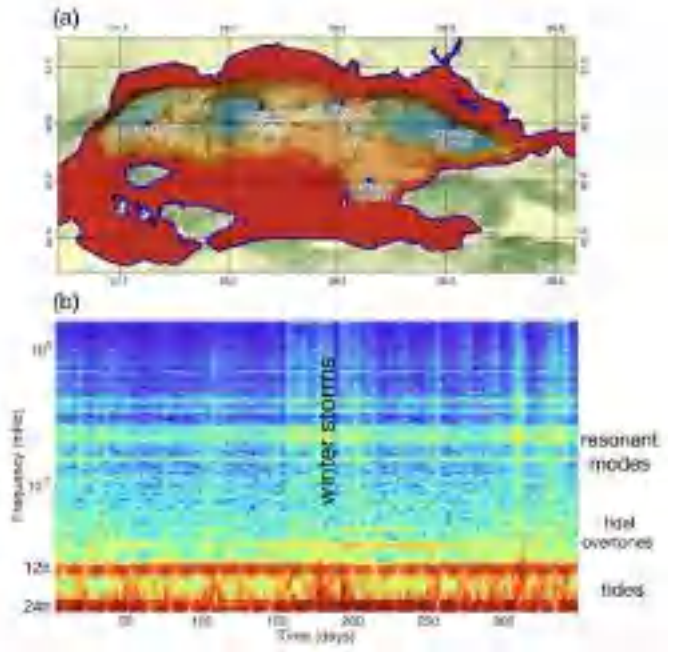
Schematic view of the hardware part of the portable device transforming live music signals into symbolic vibrations

Collaborations:

Aéronef, Hovertone

Spatialized sonification of meteorological data

The seiches, resonant oscillations of the surface of a closed sea or a lake, are one of the phenomena useful to understand tsunami formation. They can be triggered by earthquakes or by meteorological events. Recent deployments in the Sea of Marmara (Turkey, figure a) have collected recordings pressure (figure b) on the seabed at several sites at depths sufficient to overcome wave noise, allowing the detection of long period (10 to 120 minutes) and low amplitude (< 1 cm) oscillations related to seiches of meteorological origin.



(a) Sensor deployment area in the Sea of Marmara (Turkey)

(b) Examples of measured data to be sonified by a combination of audification, sonification, spatialization and acoustic zoom

The objective of this work is to combine signal processing and listening tests to clarify the relationships between meteorological events and observed resonant phenomena (seiche), via an analysis of their representations as sound and a search for temporal correlations between recorded signals and variations of the events parameters that triggered them: atmospheric

pressure, speed and direction of the wind at the surface, shear stress applied by the wind on the surface of the sea.

The sonication methods proposed here combine audification (acceleration of seabed pressure recordings), sonification by mapping data parameters to audio parameters, data-controlled sound spatialization, acoustic "zoom" in order to overcome the limits of audification (the waveform acceleration factor being constrained by the need to obtain a sonified signal at audible frequencies) and to be able to change the time scale analysis, and listening tests.

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Consumer and user sciences

Consumer and user behaviour in context

An object, product or service can have the most innovative technologies or all the unimaginable creativity, if it is not adopted by the consumer or user, it will not see the day. The success of a product or service cannot be achieved without its acceptability by the consumer or user. This is why the opinion of the latter must be taken into account from the beginning of the design of the product or service, and even upstream during the proof of concept, to match the product to the needs and expectations of the consumer or user. Thus, our researchers study consumer behaviors in order to integrate the latter at the heart of reflections during the design of a product or service in various fields of application such as food, health, materials, energy...

Whatever the field of application: energy, city, building, food... the behavior and expectations of the consumer or user are varied, and it seems essential to understand his individual motivations. Understanding the expectations and behavior of the consumer or user requires skills in consumer sciences, sensory evaluation, cognitive psychology and statistics. It involves declarative methods such as focus groups or questionnaires, but also observational methods such as the study of body expressions, the implementation of physiological measurements or eye tracking. Since 1995, the team has developed an expertise in sensory evaluation through its standardized sensory analysis laboratory. In addition, the research team has set up an "immersive" room in its laboratory in which a 360° video projection, a diffusion of odors, temperature and humidity control as well as spatialized sound allow the consumer to be immersed in a given environment without having to move. All these methods allow to capture the opinions, expectations, beliefs, intentions of use and behaviors of the consumer or the user.

Associated research unit : BioEcoAgro

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5.1 Consumer & User Behavior in Context

In a context of transitions (economic, energy, food, ...), with consumers more and more involved in their choices, it seems essential to develop products or services for and with the final consumers in order to meet their expectations. Moreover, with an increasingly internationalized world and growing global exchanges, transnational cultural flows are becoming inevitable. It has been established that factors such as culture, familiarity, habits and beliefs influence consumer choices. It is therefore essential to integrate all these dimensions into consumer behavior and choices studies to optimize the consumer experience. Also, the environment in which the consumer finds himself shapes his choices.

This environment can be physical (a place for example) and all five senses are needed to apprehend it. Vision is the first sense that is sollicited in a product's evaluation. Somaesthesia is the sense for thermal and tactile sensations as well as proprioception, necessary for evaluating objects based on their texture or shape for example. Olfactory and gustatory senses are mainly dedicated to food and cosmetic perception but olfactory can also play a role on well-being sensation. Last but not least, hearing takes a prominent place in everyday life. An annoying noise or a classical excerpt can modulate consumer's mood. Finaly, there are interactions between the five senses, which constitute key factors to explain consumers behavior. Therefore, taking into account all these dimensions is essential to understand the consumer.

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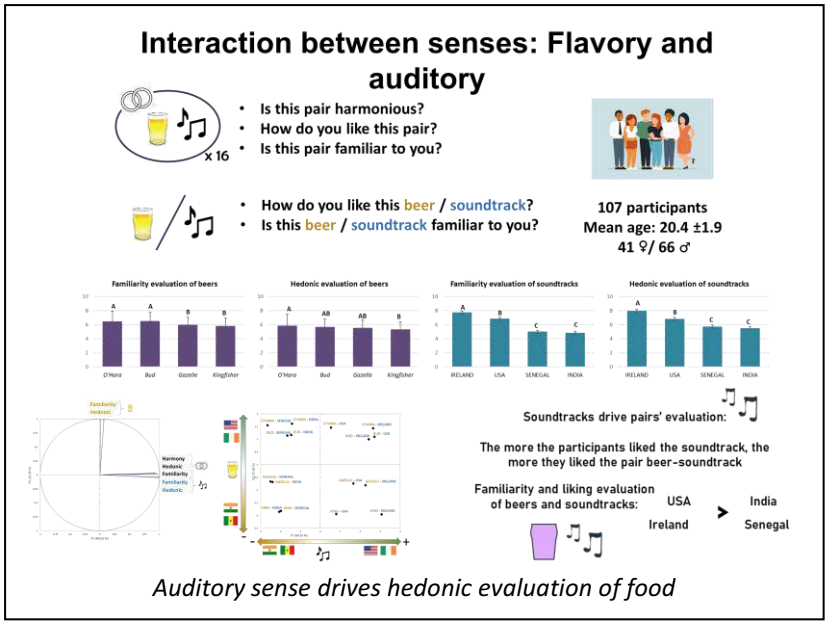
Evaluation of senses interactions in context: auditory versus flavory perceptions

In French gastronomy, food and beverage pairing is a traditional practice set down by pairing principles. Among these, some studies highlighted the principle of "geographical identity": pairing two products related to the same area. While this concept has been explored for food-food and food-beverage paring, there are less investigations across different senses e.g. auditory and flavory; specifically when flavory stimuli belong to the same food category. Yet it is well known that the auditory environment interacts with food behavior. We can wonder whether the pairing principles identified for food and beverage are relevant for a soundtrack and a beverage and more precisely whether the shared geographical identity of a beverage and a soundtrack drive their association.

In a study aiming at exploring multisensory interaction through the investigation of geographical identity association between a complex beverage – a beer – and a complex soundtrack, we showed that familiarity and hedonic evaluation of pairs as well as of soundtracks were strongly correlated to harmony evaluation of pairs while familiarity and hedonic evaluation of beers were correlated together. In addition, it seems that soundtracks dominate the evaluation of pairs. The present study attempts to demonstrate that pairing multisensory stimuli is complex and the related principles refer to some of the already highlighted pairing principles for food-food pairing: geographical identity but also perceptual principles.

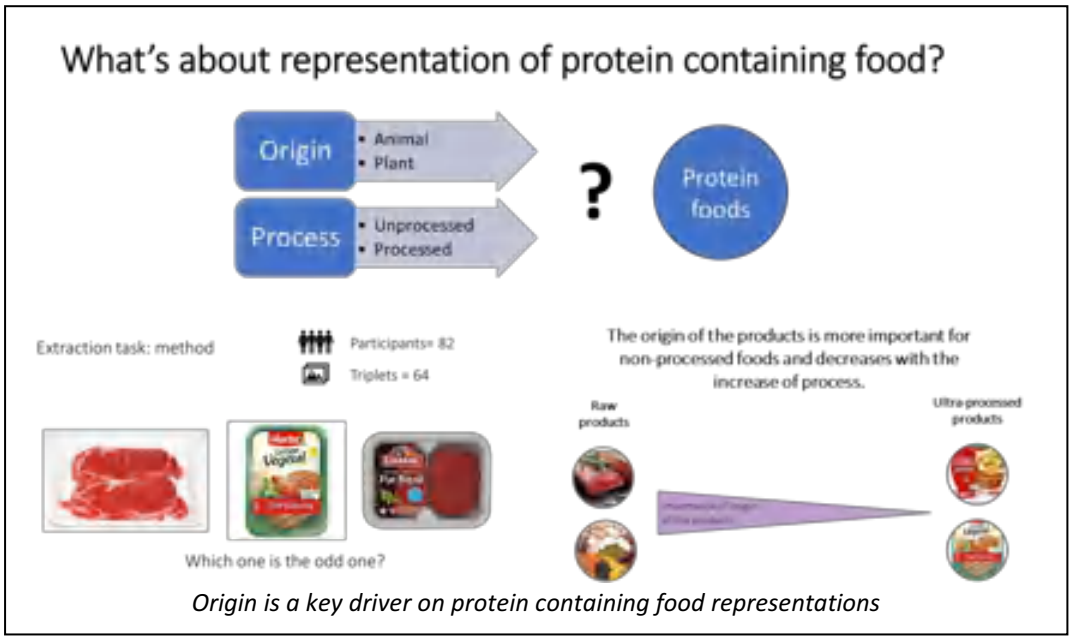
The next step will be to know if this sensory dominance of sound over taste still persists when the consumer is immersed in a congruent environment with a particular sense (bar for flavory and auditorium for auditory).



Auditory sense drives hedonic evaluation of food

Consumer representations towards protein

Protein intake for humans is a major issue as the production of meat is contributing to the excess of greenhouse gas emissions and loss of biodiversity. To cover the upcoming protein demand in a sustainable way, a shift from animal-based food items to plant-based ones will be necessary. We studied the representations people have of protein containing food and more specifically, the role of origin and process in these representations. Our results showed that, globally, the origin dimension is preponderant, except for ready-to-eat dishes for which the process dimension is more important. While plant and animal unprocessed foods are clearly two distinct categories with specific properties, plant-based and animal-based ready-to-eat dishes share a large number of properties and thus could be a potential way of decreasing meat consumption by substituting one by the other.



Origin is a key driver on protein containing food representations

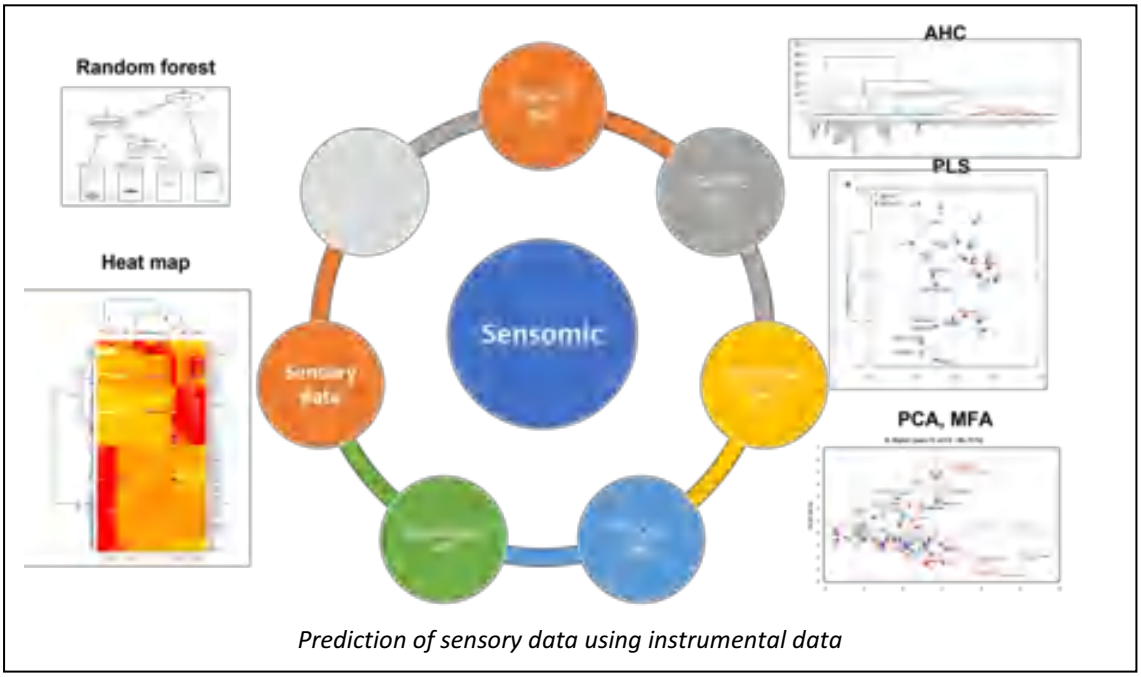
Relations between peptidic composition and bitterness of dairy hydrolysates

Our studies on consumer behavior allow us to acquire expertise in sensory evaluation methodology and statistics. This expertise is used for studies linking sensory data to physicochemical, microbiologica, peptidomic, process, genetic data (Sensomic).

In collaboration with the company Ingredia, we have highlighted processes for obtaining non-bitter hydrolysates with specific functional properties. In this study we have connected

the presence or absence of peptides and their intensity over time compared to the different sensory characteristics of hydrolysates by using heat maps, random forests and regression trees. We identified the peptides susceptibly responsible for bitterness intensity and predict the main sensory feature of micellar casein enzymatic hydrolysates.

Another example of this type of work concerns a study of wild hop varieties in Hauts de France. In this study we tried to link genetic, chemical and geographical data of different hops with sensory data of beers made from these same hops. The first results show that wild hops constitute a huge pool of chemical, genetic and sensory diversity of this species.



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Smart Energy Networks

Electrical grids and multi-energy systems

Optimal energy management

The ecological transition, the need to reduce energy consumption and losses, to consume energy more efficiently and to diversify production sources are at the heart of the Smart Energy Networks theme.

The resarch is focused on two topics :

- Electrical grids and multi-energy systems

A major part of the activity concerns energy in the form of electricity: from the production of renewable energy to the management of consumption, via the networks that distribute it (distribution power systems, rail, buildings). New kinds of loads are taken into account, such as electric vehicles, for example.

Coupling of electricity with other forms of energy vectors (sector coupling) such as heat or hydrogen is also explored with the aim of sizing power systems more accurately, by acting on their architecture and energy management.

- Optimal energy management

The new expectations and constraints of the actors interconnected to these systems are integrated into the research work, taking into account regulatory, economic and societal developments. The Researchers in this area is strongly interdisciplinarity with domains such as economics, sociology and ethics. Mathematical and artificial intelligence tools are used to model and optimise power systems, as well as to develop energy supervisors and study new approaches to consumption and exchange of electricity.

Associated research unit : L2EP

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6.1 Electrical networks and multi-energy systems

At a time when energy appears to be increasingly precious, the energy networks that distribute it must increase their efficiency and reduce their climate footprint, by considering two levers of action: the design of architectures and components, and the management of energy flows.

Consequently, this research topic adresses to major objectives :

- Electrical networks and multi-energy systems : Designing energy systems and networks, integrating production and consumption sources and storage systems, with the aim of reducing their environmental footprint, both in design and use.

- Optimal energy management : For a more efficient use of energy, and with the objective of maintaining the quality of service provided to users, or even to provide new services to the actors of networks and power systems, this sub-theme aims at developing solutions for managing energy flows.

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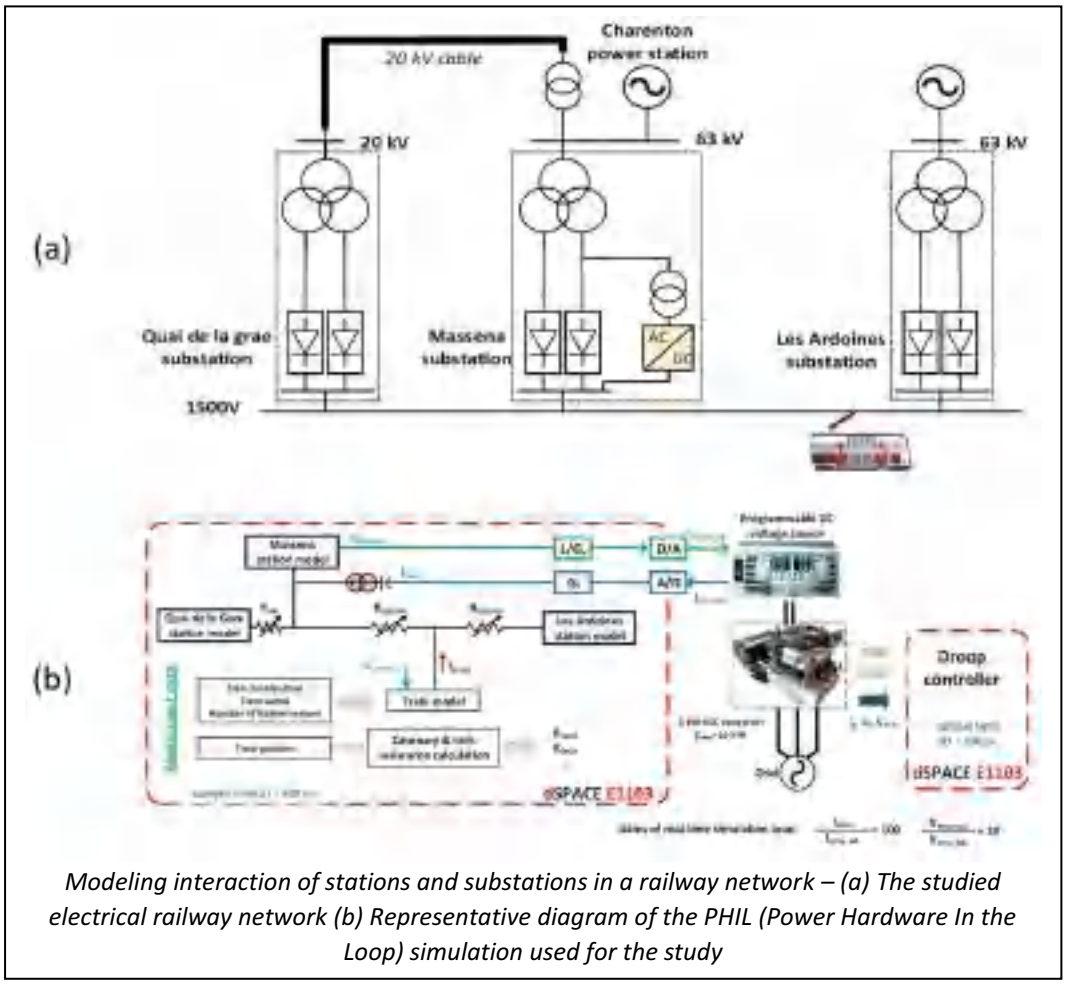
Railway smart grids and systems

Rail traffic is increasing and will continue to do so over the next few years, leading to an increase in the associated electricity consumption. In order to limit the energy bill and the carbon footprint, rail network managers and their research partners are looking at new network architectures, allowing for the integration of renewable energy sources, storage systems and general energy exchanges (projects CONIFER, RACCOR-D). The research work also focuses on the dimensioning of these architectures, as well as on the management of the energy flows that must be associated with them, in order to maintain the quality of service and the reliability of the installations. The recovery of energy during train braking is also being investigated in order to improve the energy efficiency of rolling stock (project MASSENA). New services are also being studied, which could be provided, for example, by the substations developed in this way, to stations and their customers. The question of protecting the installations is of course studied, by envisaging current limitation solutions based on superconducting materials, which could lead to better sizing of the substation components, transformers in particular (project SAFE). Finally, the question of the availability and quality of train consumption data and measurements, as the rolling stock may not be equipped with the latest metering technology, or that this equipment may also be defective (project DECOFER).

Validation methodologies are developed within the research teams, ranging from numerical simulation to full-scale power experiments and the use of experimental platforms (Figure 1)



Modeling interaction of stations and substations in a railway network – (a) The studied electrical railway network (b) Representative diagram of the PHIL (Power Hardware In the Loop) simulation used for the study

Smart grid management: demand side management and integration of user expectations

The environmental challenges we are currently facing require a drastic shifting in our way to consume: the new paradigm should be less, efficently, and with the lowest possible impact on the environment. From the electric grid point of view, energy management is of particular interest to reach efficiency while increasing the penetration rate of renewable energy sources, thus ensuring an environmentally friendly production. To that end, all grid stakeholders must take part in the equilibrium, while having their sensitivities and constraints respected.

To tackle this challenge, as electrical engineering alone does not enable to grasp all the aspects of the problematic, the contribution of humanities and social sciences was introduced (Project ModAICSS, SOREL). The novelty of this exploratory work is to be found in the definition and understanding of electrical grid stakeholders, as well as the integration of their profiles in an energy supervisor. The main result is a 3-steps methodology applicable to each stakeholder of the grid, using a game theory approach illustrated in Figure 2.

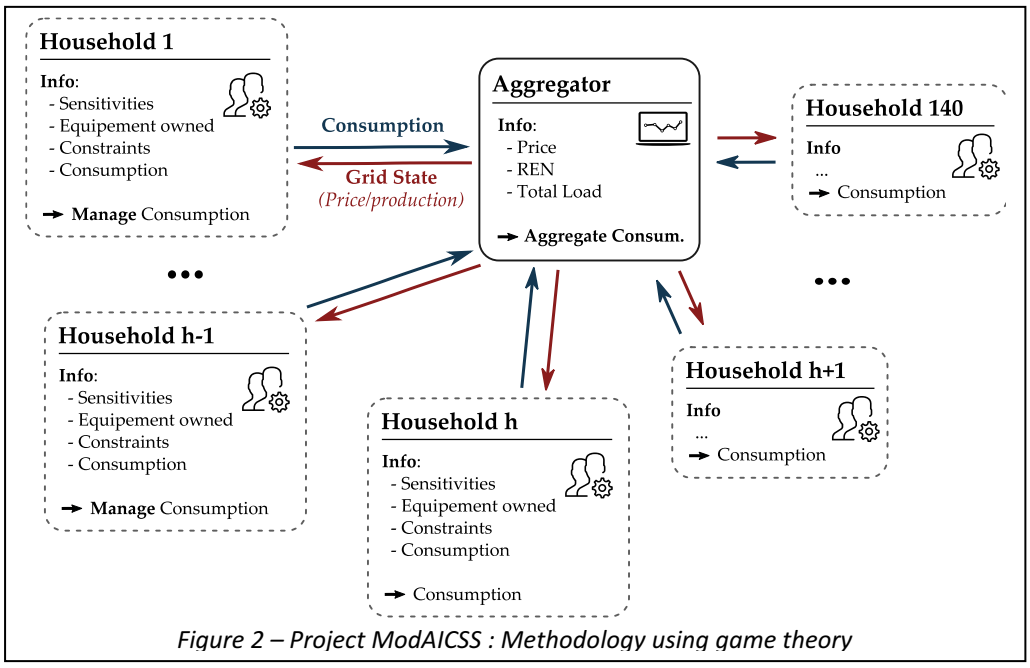


Figure 2 – Project ModAICSS : Methodology using game theory

Smart grid management: Managing the local consumption of renewable electricity production.

The massive integration of renewable generation and new electrical loads like electric vehicles can impact the reliability of current distribution networks as well as their hosting capacity and power quality, mainly because of the high uncertainties and rapid variations introduced in the consumption and production profiles. All these challenges can lead to expensive grid reinforcements for the Distribution System Operator (DSO) as well as a higher electricity bill for the final consumer if no energy management strategies are adopted. The main result is a supervision system (Figure 3) aims to promote the local consumption of renewable energy within distribution grids and optimize energy transmission costs for the DSO. The supervision is also beneficial for the different clients connected to the grid. Avoiding grid reinforcements can simplify the conditions to connect new decentralized producers.

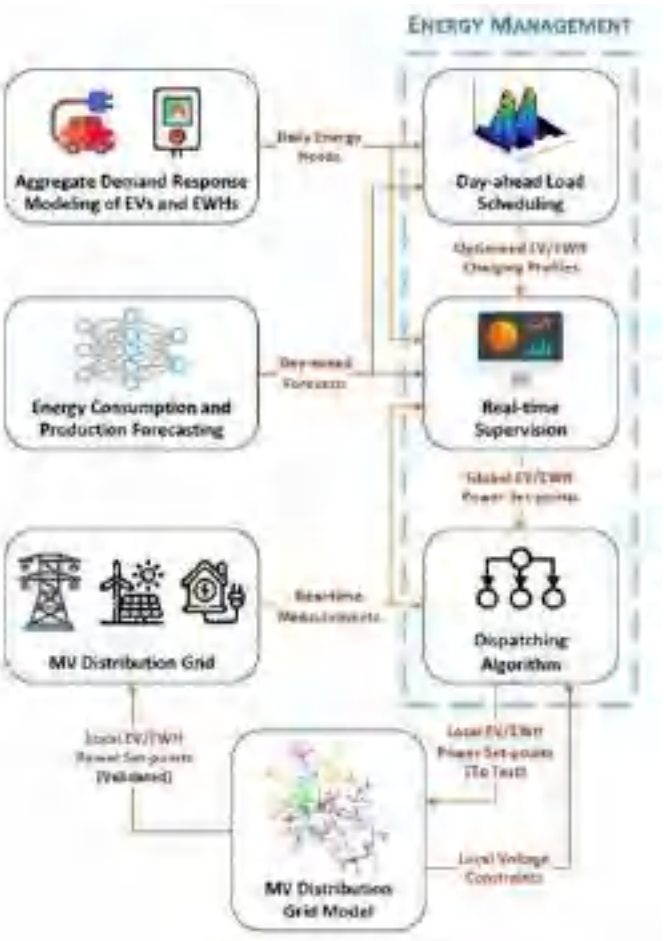


Figure 3 – Project MAESTRO : Global supervision system structure

It can also reduce the consumers' final electricity bill compared to a scenario where they use more EVs without any energy management and require more grid reinforcements. Some algorithms of

this supervisor have been tested on a demonstrator which is a portion of a real distribution network in the department of Deux Sevres.

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6.2 Optimal energy management

Excessive exploitation of fossil energy resources contributes dominantly to climate change as well as to their depletion and consequent increase in energy cost. Alternative energy sources and production and distribution systems are needed. A major focus is put on multi-energy systems with renewable energies and storage in order replace fossile energy sources. These systems must be autonomous, fault-tolerant, reliable, secure and provide good quality energy to satisfy the different actors (producers, consumers, aggregators, etc.). To achieve these goals, efficient, fast and scalable optimisation and control algorithms are needed. These algorithms should be able to process information intelligently and make critical decisions dynamically. Therefore, the main objective of this topic is to develop tools for the intelligent control and optimal energy management of these systems in order to maximise the production of renewable energy sources while achieving an optimised and cost-effective solution in smart grids and buildings. The aim is to develop innovative management approaches for smart grids and buildings based on information and communication technologies in a push for the development of the Internet of Energy (IoE). Transformation of centralised grids into a network of micro-actors that can sell and buy their energy through information technology is a great challenge. End-users could also benefit from specific services and tariff offers, enabling the adoption of ambitious approaches to instantaneous energy demand management and the integration of renewable energies. This increases the adaptability of the network and its resilience

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Joint optimisation of sizing and fuzzy logic power management of a hybrid storage system considering economic reliability indices

This study explores the optimisation of both dimensioning and control system of a hybrid storage system (HSS) associated with photovoltaic panels. The battery (BT) considered as the principal storage organ and a super-capacitor used as the secondary storage system to improve the BT life span makes up the HSS. The main purpose of this study is to

explore a novel optimisation approach to jointly optimise the sizing and the fuzzy logic energy management system (FLEMS). In fact, an optimisation function based on sequential quadratic programming algorithm is proposed. The optimisation methodology has been performed jointly and successfully for the sizing of the BT storage system and the membership functions parameters of the FLEMS in order to decrease the levelised cost of energy with a violation time by 5% of mean absolute percentage error score (<1.5%) throughoutà full year. According to the simulations results, a benefit analysis has been done to assess the associated financial impact.

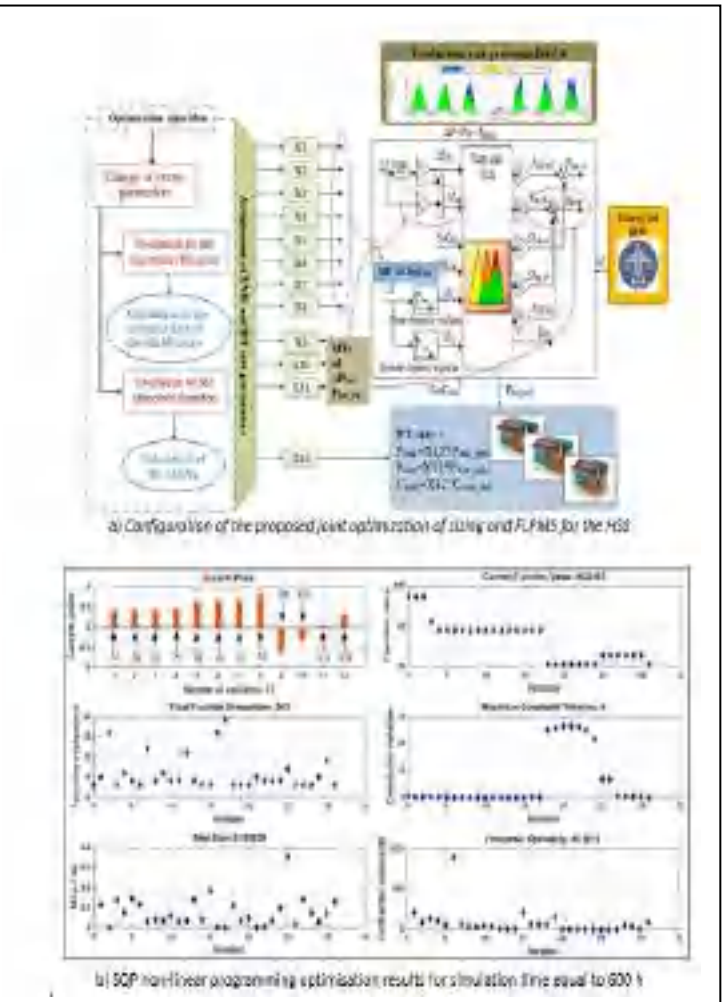


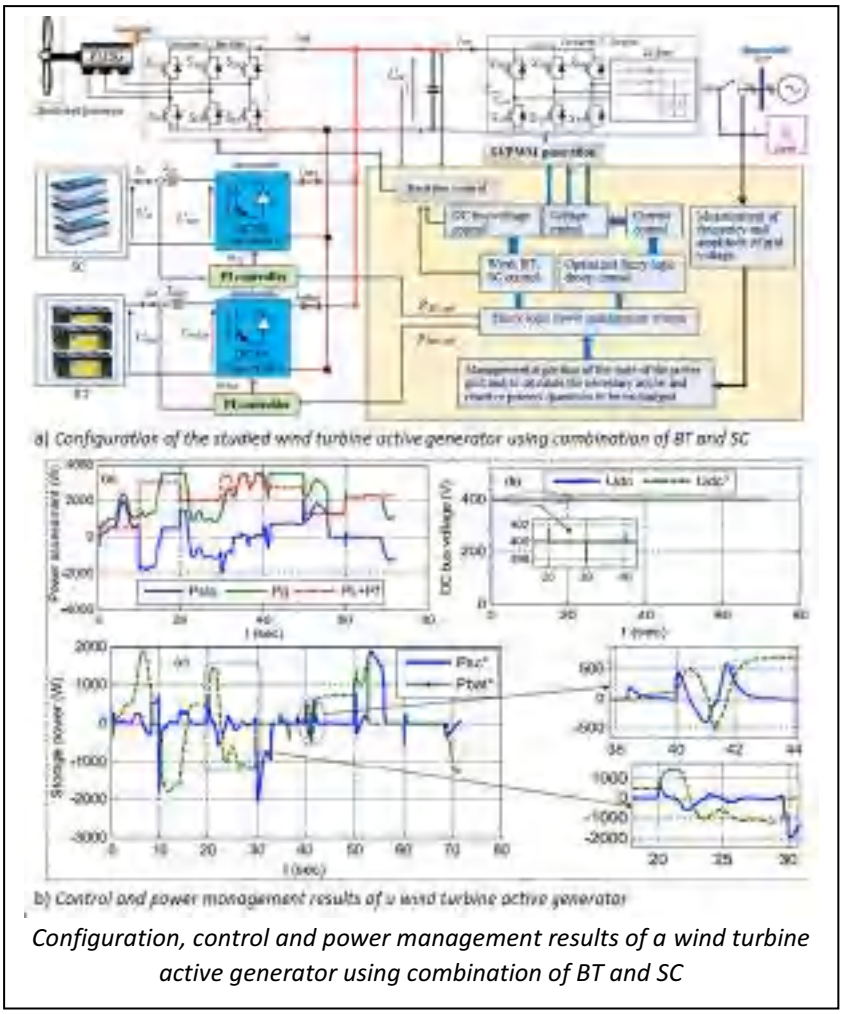
Figure 1: Configuration and results of the proposed joint optimization methodology for sizing and FLPMS for the HSS

Control and power management of a wind turbine active generator for ancillary services under grid instability using fuzzy logic technology.

In this work, a control and power supervisor for a flexible operation of a Renewable Distributed Generator (RDG) is introduced. This RDG consists of a combination of a wind system and a hybrid storage system made up of Batteries (BT) and Super-Capacitors (SC). RDG is associated with a load and a fluctuating grid to form an Active Generator (AG). According to the grid fluctuation, AG can operate in a grid-connected and standalone mode. The objective of this work is to investigate a novel control strategy for AG integrated into the grid in order to maintain its voltage and frequency in an allowable range and to ensure the continuity of the power supply in case of a grid fault. The structure of the proposed control strategy consists of a Fuzzy Logic Supervisor (FLS), an adaptive Fuzzy Logic Droop Control (FLDC) and a Fuzzy Logic Islanding Detection (FLID). FLS is developed to manage

the power flows between the storage devices by choosing the optimal operating mode, thereby ensuring the grid stability and the continuous supply of the load by maintaining the state of charge of SC and BT at acceptable levels and to reduce stresses on BT and improve their life cycle. FLID is used to detect de standalone mode in case of grid failure. Finally, FLDC is used to control the active and reactive powers exchanged with the grid, ensuring its stability by

maintaining its frequency and its voltage in optimal margins. The effectiveness of the proposed control method is validated by simulation results and compared with a generalized control technique.



Configuration, control and power management results of a wind turbine active generator using combination of BT and SC

Development of a tool for urban microgrid optimal energy planning and management

Small-sized variable renewable energy sources (RES) live a large-scale development in urban electrical systems. They increase local high dynamic unbalancing and then can create instabilities on the inertia response. Thus, setting an adequate operating reserve (OR) power to compensate the unpredicted imbalance between RES generation and consumption is essential for power system security. Indeed, effective calculation and dispatching of OR considering inaccurate forecast of both RES and load demand can provide substantial cost reductions. Thus, to facilitate the energy management and system optimization in an urban microgrid (MG), a user-friendly tool for Energy Management System and Operational Planning has been developed. The tool provides a complete set of user-friendly graphical interfaces to study the details of photovoltaic (PV) and batteries, load demand, as well as micro gas turbines (MGTs). Furthermore, this energy management system allows system operators to properly model RES uncertainty. In addition, it could assist operators for the day-ahead energy management with an efficient information system and an intelligent management.

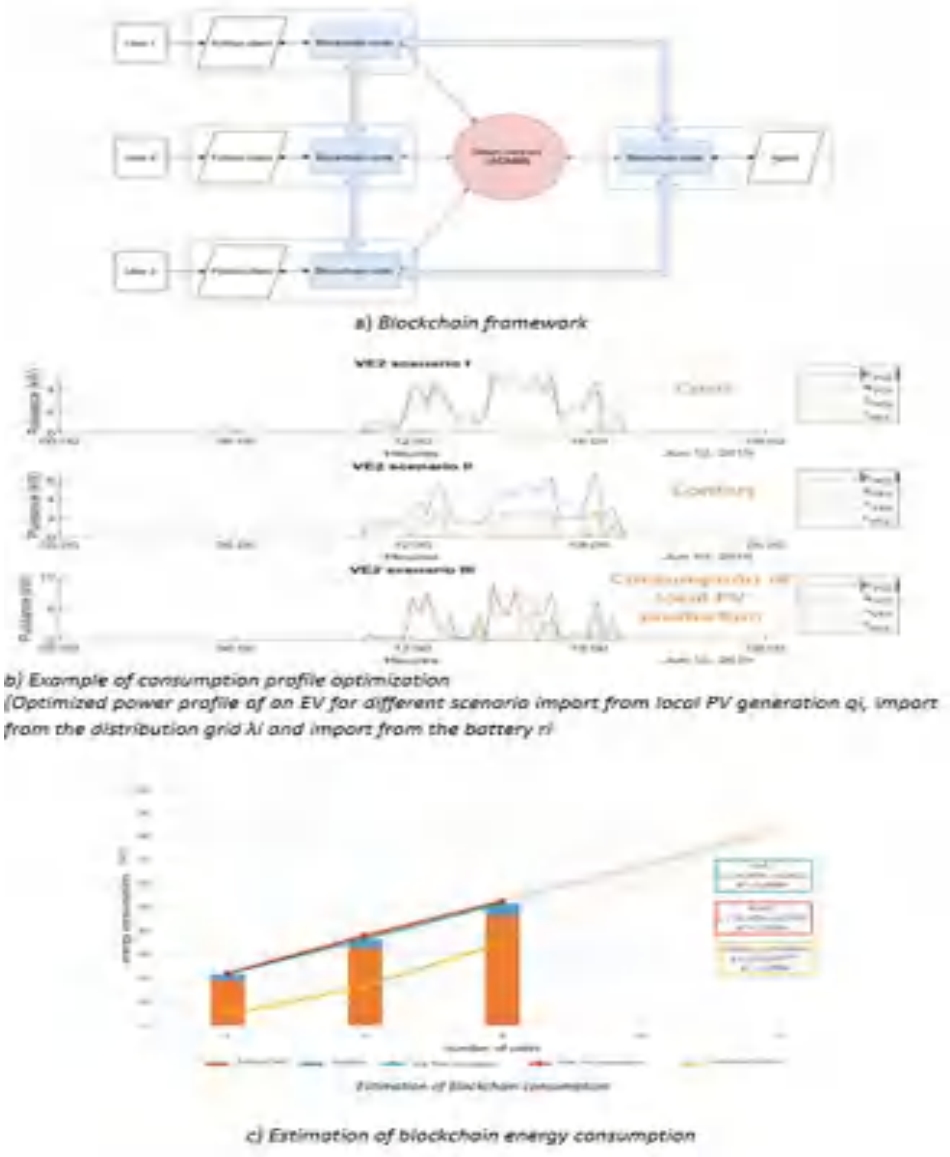
A window of the developed tool: OR dispatching interface

A local blockchain implementation for an energy community

This work presents an implementation of a local blockchain for optimization of energy exchanges in an energy community. The blockchain protects users privacy and ensures a complete distributed optimization, without the intervention of any third party. An ADMM(the

alternating direction method of multipliers) algorithm is used to find a consensus between users. This algorithm uses both Python clients to locally optimize users power profiles and a smart contract, deployed on the blockchain, to check if the global constraints are respected.

The simulations compare two different consensus mechanisms: PoW (Proof of Work) and PoA (Proof of Authority). The energy consumption of the overall blockchain environment is measured and compared to a centralized situation. The results show that for a limited number of nodes, PoA and PoW are similar in terms of energy consumption, and of the same order of magnitude than a centralized solution: for 8 users, they consume only 47% more. For a higher number of nodes, this study suggests that a local blockchain could be even more energy efficient than a centralized solution for optimization



Blockchain framework and some results

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Sustainable cities

Smart cities and smart buildings

Low-carbon building materials and circular economy

The ambition of Junia is to work around transitions in order to respond to technical, energy, climate, environmental and societal challenges. The Sustainable buildings and cities theme focuses on Energy and Urban Transition.

Innovative studies are undertaken in order to provide new solutions for the buildings and cities of tomorrow : Without questioning current uses (cities, spaces, mobility, materials, uses, etc.), it will be impossible to reverse current crises (energy, raw materials, climate) or avoid future crises.

The research activity focuses on 2 topics :

The decarbonization of buildings by materials and systems

- Study and development of the integration of materials from biosourced (hemp, flax,...), Circular Economy (concrete, brick,...) and sediment (river or maritime).
- Use of phase change materials (PCM) to boost specific caracteristics.
- Using artificial intelligence and data to make predictions of temperature, indoor air quality in real time.
- Integration of building users to identify a comfort index.

Urban transformation and sustainable development: smart and inclusive spaces and the city of proximity

- Study of City Information Modeling (CIM) and digital Twins (Development of a CIM Prototype)
- Inclusive neighbourhood (Smart & Inclusive Neighborhood Spaces in Different Urban Contexts)
- Territorial transformation (From Urban to rural: Trajectory of coworking spaces and in Hauts de France.
- Urban resilience: study of leftover spaces and play in dense city fabric) and finally Academic innovation (Efficient use of advanced fabrication 3D model machines for academic benefits)

Associated research unit :

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7.1 Smart buildings and smart cities

Smart and inclusive spaces and the city of proximity are explored in this topic, in particular (1) Building Information Modeling (BIM) & City Information Modeling (CIM), (2) mobility and (3) leftover spaces.

1. CIM is used to build an interactive 3D model of large-scale urban environments. CIM practices are still limited to the collection, integration, and visualization of tangible data. Up to now, intangible data has not been implied in CIM. Limited research is available on citizen participation and integration into the CIM. The main objectives are to (1) define a comprehensive indicator framework for the intangible-related data, and (2) the clarification of the needed methods to create the comprehensive CIM platform.

2. Massive presence of construction sites causes numerous issues to the local communities. Researchers often underestimate the importance of the pedestrians, hence, the problems analysed in this study address the mobility in construction site proximity. The purpose is to analyse the sidewalks comfort and the pedestrian behaviour.

3. National and local governments wordlwide apply a combination of socio-spatial tools that regenerate and transform the city's leftover spaces. Community gardens, cultural centers, and urban developments, through programmed activities, reactivate underused spaces. This research highlights design strategies that domesticate leftover spaces of diverse scales by injecting creative and playful programs.

Urban leftover space becomes meaningful place with a strong local identity, enabling new connections and maximising its socio-spatial potential. This study analyses investigates the roles of local spatial practices in the process of leftovers' identity reconstruction.

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Integration of Tangible and Intangible Aspects in City Information Modeling

This research comprises the comprehensive methodology followed to (1) create the indicator framework and (2) form a CIM prototype. To do so, key activities are followed including: (a) intangible indicators framework build-up, (b) data collection of tangible and intangible layers, (c) data analysis to explore the collected data and create primary findings, and (d) platform build-up including an interactive model creation in a GIS software.

After carefully considering the 2030 Sustainable Development Agenda, The Organisation for Economic Co-operation and Development (OECD) Well-being Framework, and previous researches; the social indicator framework was built including all the required social indicators including mobility, safety and security, education, health, environment, economy, social participation, civic participation, housing, and services.

A preliminary CIM prototype is built for an Area of Interest (AOI) Lille Centre 304. Initially, the neighborhood could be considered residential, but further analysis and literature are needed to correctly reclassify the iris. For this reason, 11 Point of Interest (POIs) have been selected on each road of the AOI, which could be used as an inquiry point. This means that POI could include advantages, disadvantages and improvements related to certain city elements and conditions. This kind of information is to be gathered using interviews, questionnaires and surveys. To highlight the indicators of the social framework, another idea is to create feeling with certain elements. For example, taking the road Solférino on the map, one can get inspired

by the Bio mapping technique of visualizing different values with peaks to display the feeling of mobility or traffic comfort. These curves could also be colored red being the lowest and green being the highest, with different labels and marks.

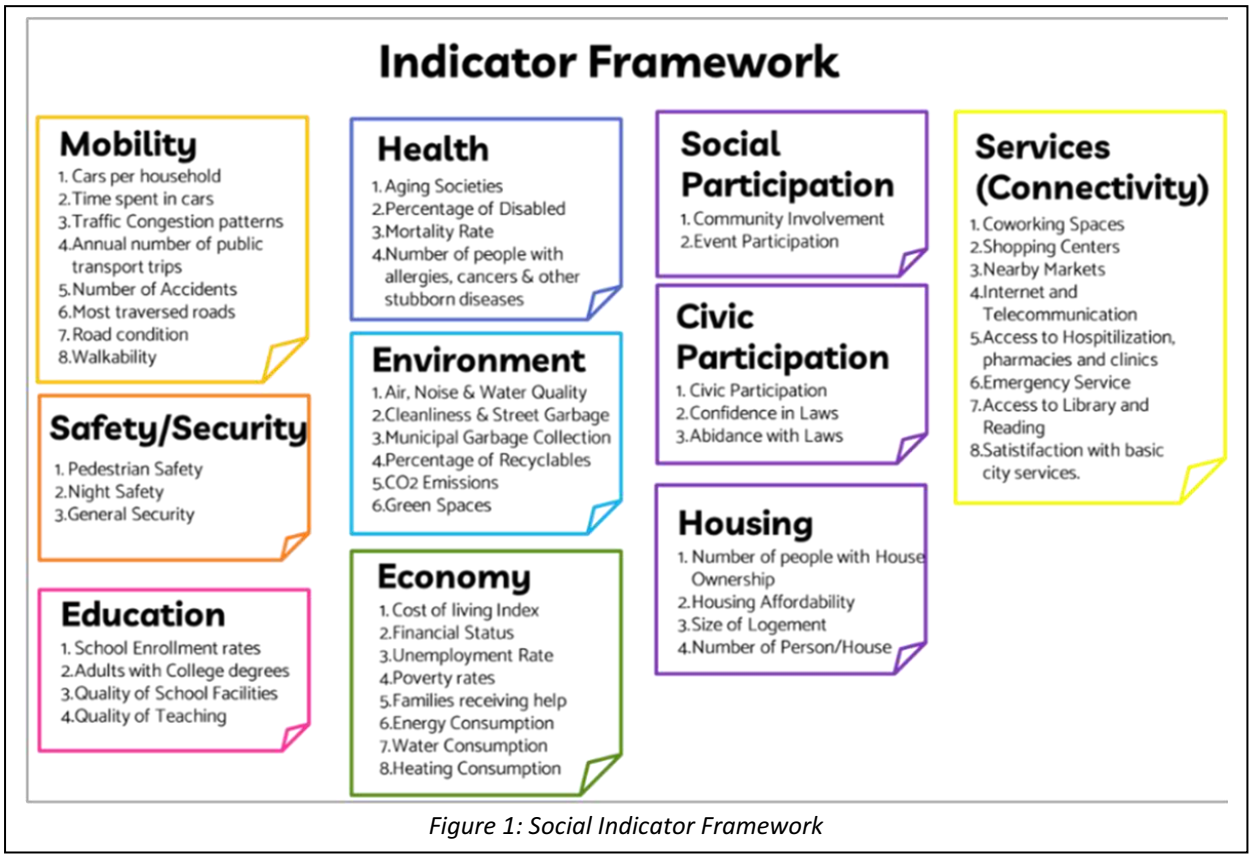

Figure 1: Social Indicator Framework

Pedestrian mobility in proximity of construction sites: an approach to analyse and improve pedestrian experience.

The analysis of pedestrian mobility is conducted in the regional capital Lille including 1) an analysis of the history of Lille's Catholic University and the territory using Geographic Information System (GIS), 2) a Computer Assisted Web Interviewing (CAWI) survey to study the attitude of pedestrians and their opinions about construction sites and 3) an observation of 3 sidewalks located in proximity of construction sites.

The study shows that pedestrian mobility in proximity of construction sites triggers different, often unpredictable, and unsafe behaviours. However, it is obvious from the survey and observations, that respondents are curious about and feeling comfortable in a proximity of construction site. Therefore, walkable spaces in proximity of construction site may be produced with the use of construction elements and machinery, that would allow an extension of sidewalks inside construction sites providing a safe passage for pedestrians. The boundary between construction sites and pedestrian zones would blur, and communication between users on both sides would improve.

As one solution, for the city boulevard sidewalks a more detailed and real-time plan of protected pathways could be established for both pedestrians and workers, who would then more easily apply to these solutions avoiding unsafe behaviours. The plan of pedestrian mobility addressed by the "permisse de stationament" and "permisse a voire" could consider a wider area affected

by the activities on the site, especially considering daily traffic. This could be achieved with a parking plan that includes both permanent and temporary vehicles and machines used on the site. The legislative process for obtaining such a permission could include a plan of pedestrian mobility to compensate the issues caused by the occupation of sidewalks. Moreover, by avoiding narrow and uncomfortable sidewalks, a comfortable mobility through the city which encourages pedestrian mobility would be achieved.

Figure 2: Pedestrian behaviours in construction site proximity

Urban resilience: a study of leftover spaces and play in dense city fabric.

A combination of ethnographic observations and visual analysis is applied as a trans-disciplinary method to investigate small-scale urban leftovers in the traditional urban tissue of the districts in Tokyo.

As a result, In dense urban environments, these playful forms of socio-spatial appropriation become resilience tools that designers develop in relation to the specific spatial context. We identified following design strategies which take different directions, strengthening the relationship between leftovers and activities by:

- Proposing a program to afford outdoor play and informal social play to counterbalance business and commerce. Ultimately, programmed activities facilitate exchange between people and the environment.
- Designing flexible facades in high-rise districts and movable urban furniture which accommodate individual and solitary play. The designer surrenders their authority and becomes an "enabler" rather than a "'decider'".
- Mitigating the interaction of infrastructure and urban tissue, which maximizes affordances and the potential of leftover spaces. As in the historical cases of sakariba—between infrastructure and collective space—and kaiwai—the activity space—this can be a temporary approach within long-term urban development projects.
- Creating and/or leaving confined spaces as intentional voids, which triggers subjective play in proximity to one's residence. This strategy enhances individual maintenance of neglected and non-belonging spaces and strengthens collective identity (as "superfluous spaces," creation of alternative public spaces that accommodate the rituals and meanings of people). The vagueness of space becomes a quality that triggers appropriation and personal expression.

Figure 3: Proposed method for the analysis of leftover spaces

Data driven, anticipatory approach in buildings.

Being the most energy-consuming economic sector, within the framework of the energy

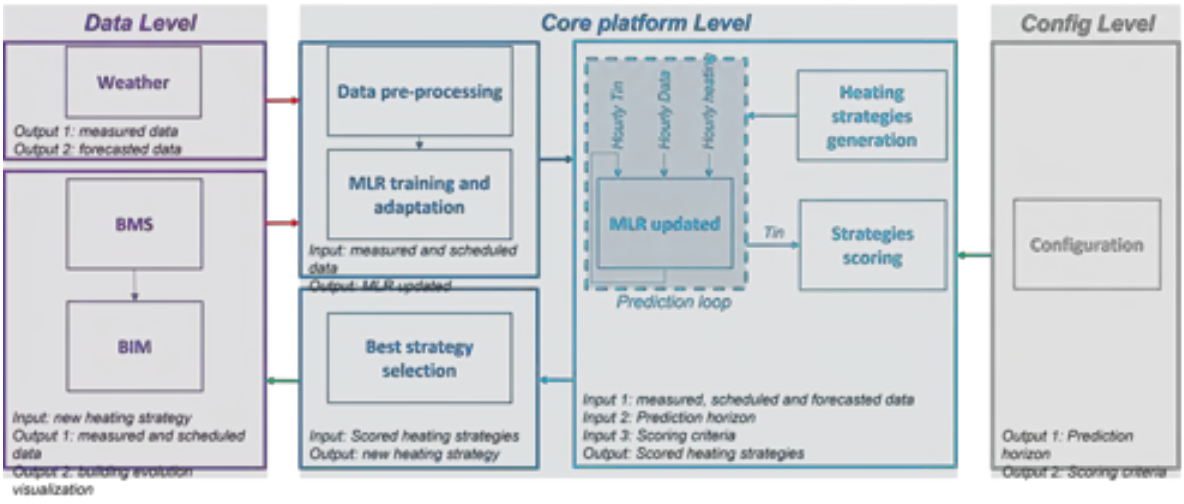

Figure 4: Control the heating systems of modern buildings.

transition, the building industry presents a strong potential for energy savings. The various thermal regulations and standards have set very high objectives in terms of energy performance for new or renovated buildings. Regarding existing buildings, the optimization of the control of their systems presents an important saving energy leverage. The goal of this work is to develop a data-driven, anticipatory approach to control the heating systems of modern buildings. This approach includes two aspects. The first aspect proposes an automated process for developing a forecasting model able to forecast the behavior of the building over a 24-hour horizon, using two types of models: a linear model (multiple linear regression) and a non-linear model (neural network). The second aspect concerns the use of a genetic algorithm for the identification of the optimal heating strategy to optimize the thermal comfort and the energy consumption of the building. Based on these two aspects, the Smart Building control Platform (SBcP) was set up. To validate this platform, we have tested it on an experimental building located in Béthune (Pas de Calais). The experimental results obtained showed that the considered multiple linear regression model is able to predict the indoor temperature with a root-mean-square error (RMSE) around 1.6°C over a 24-hour horizon. These results were collected over a 21-day period from May 3 to May 24, 2021. During this period, the heating of the studied building was controlled in an anticipatory way using the SBcP. In spite of the originality of the studied building (very fast dynamics because of its low inertia) and the variation of the weather (inter-season), the SBcP made it possible to guarantee the thermal comfort during 67% of the hours of occupations concerned while consuming the minimum possible energy.

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7.2 Low-carbon building materials and circular economy

In order to respond to current energy, environmental and societal challenges, it is essential to rethink the use of materials (origin, life cycle analysis, embodied energy, etc.).
The production of eco-friendly materials typically increases cost which can be a barrier to their widespread adoption. Research with an industrial partner allows a full integration of issues related to future applications into the research process. The use of alternative materials (sediments, demolition waste, non-dangerous incineration slag, etc.) as a substitute for natural granular resources or quarries appears as a sustainable solution.
Furthermore, incorporating additions functionality (i.e. standard materials with phase change materials) allows to bring added value to alternative materials. Phase change materials can add or boost characteristics and offer higher value in terms of use and carbon footprint.
Environmental aspects also need to be intergrated in the design from the start of the project. It is necessary to work towards labels/regulations/certification for the integration of alternative materials and investigate approaches to implement circular economy in the materials sector at a large scale.

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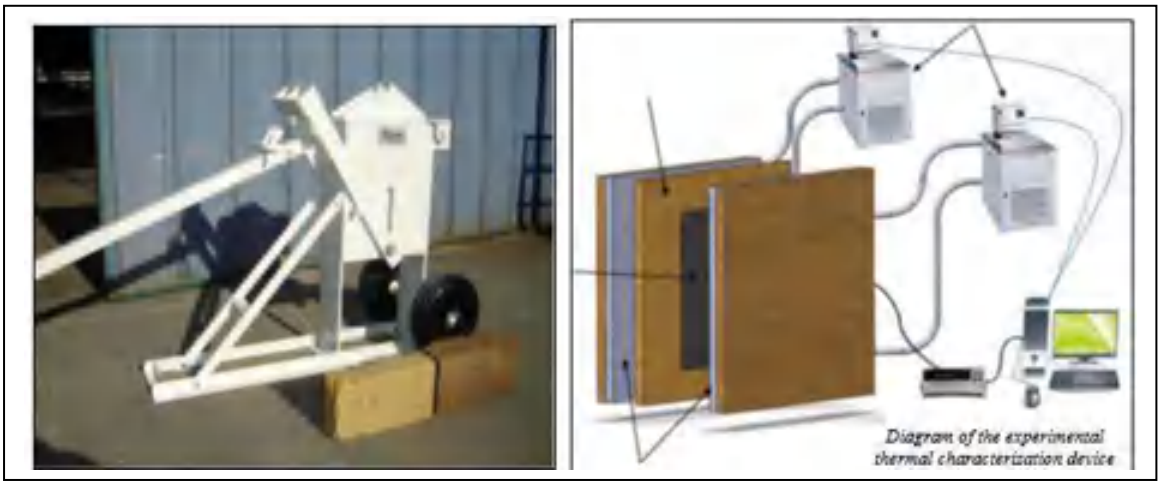
EcoBrique

Climate change has made energy management one of France's priorities. The "Grenelle de l'environnement" has set very ambitious progress targets for positive-energy buildings, particularly in terms of reducing energy consumption and integrating renewable energies. One of the levers for designing a positive energy building is to work on its envelope to make the most of solar gains in winter and improve comfort in summer. In France, brick is the most widely used construction material for the construction of the building envelope. In this context, the interest in mud brick as a sustainable material has grown considerably, presenting a solution to economic and ecological challenges.
The "ECO-BRIQUE" project led by JUNIA and in partnership with Vinci Construction and Briqueterie du Nord (BdN) for a period of 3 years, aims to develop, using a dual digital and experimental approach, an innovative raw brick that stores energy (solar) within a structure integrating phase change materials (PCM). This project is part of the theme of carbon-free energy efficiency and has significant potential for valuation in the form of a patent or technology transfer to building envelope designers.

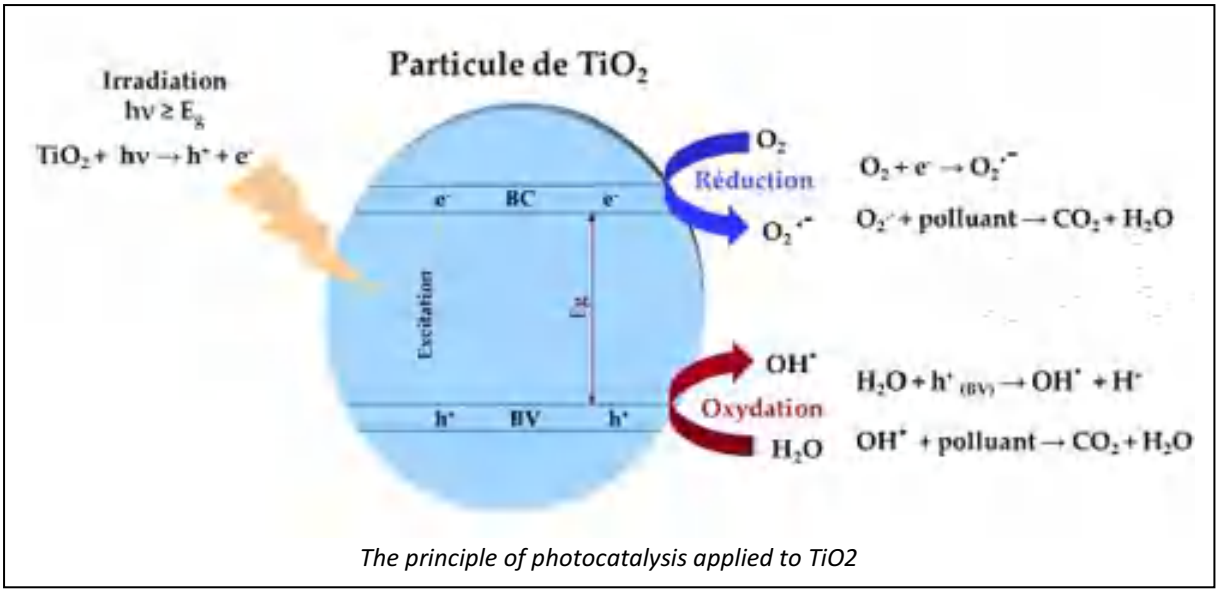
The results of the work carried out within the framework of the project will make it possible to build interdisciplinary research expertise, which of course will be put at the service of the regional economic fabric, as well as the academic training of the institutions involved.



Development of microencapsulated phase change materials for low temperature energy storage

In a world increasingly polluted by the consumption of fossil fuels, the use of solar energy is becoming essential to limit global warming. One of the main obstacles to the development of this intermittent energy source is the lack of a storage solution, making it possible to compensate for the phase shift between production and consumption. This research work is part of a context of energy efficiency and reduction of the ecological footprint through the design of a thermal energy storage system (TES) by latent heat provided by biobased (fatty acids) Phase Change Materials (MCPs). The latter have the advantage of storing and releasing latent heat during their solid-liquid phase transition. To limit any interaction with the external environment as well as the problems of leaks, the MCPs must be conditioned before their integration. Microencapsulation technologies are selected.

This research focuses on the selection of materials used to prepare the microcapsules, their implementation, the understanding of the mechanisms of synthesis, and the characterization of the particles allowing the optimization of the synthesis parameters. The first part of this work is devoted to the synthesis of graphene oxide (GO) and the study of its physico-chemical properties, in particular its behavior at the oil/water interface. Graphene oxide is used as an emulsion stabilizer to improve the mechanical properties and heat transfer of the microcapsules. The second part concerns the study of the influence of formulation and synthesis parameters on the characteristics of microcapsules based on titanium and silica and the optimization of encapsulation by the sol-gel process. Finally the concept of double membrane microencapsulation, comprising an intermediate membrane of graphene oxide and a second in silica, is studied. The fatty acids are successfully encapsulated, the microcapsules obtained have an encapsulation rate which can go up to 80%.

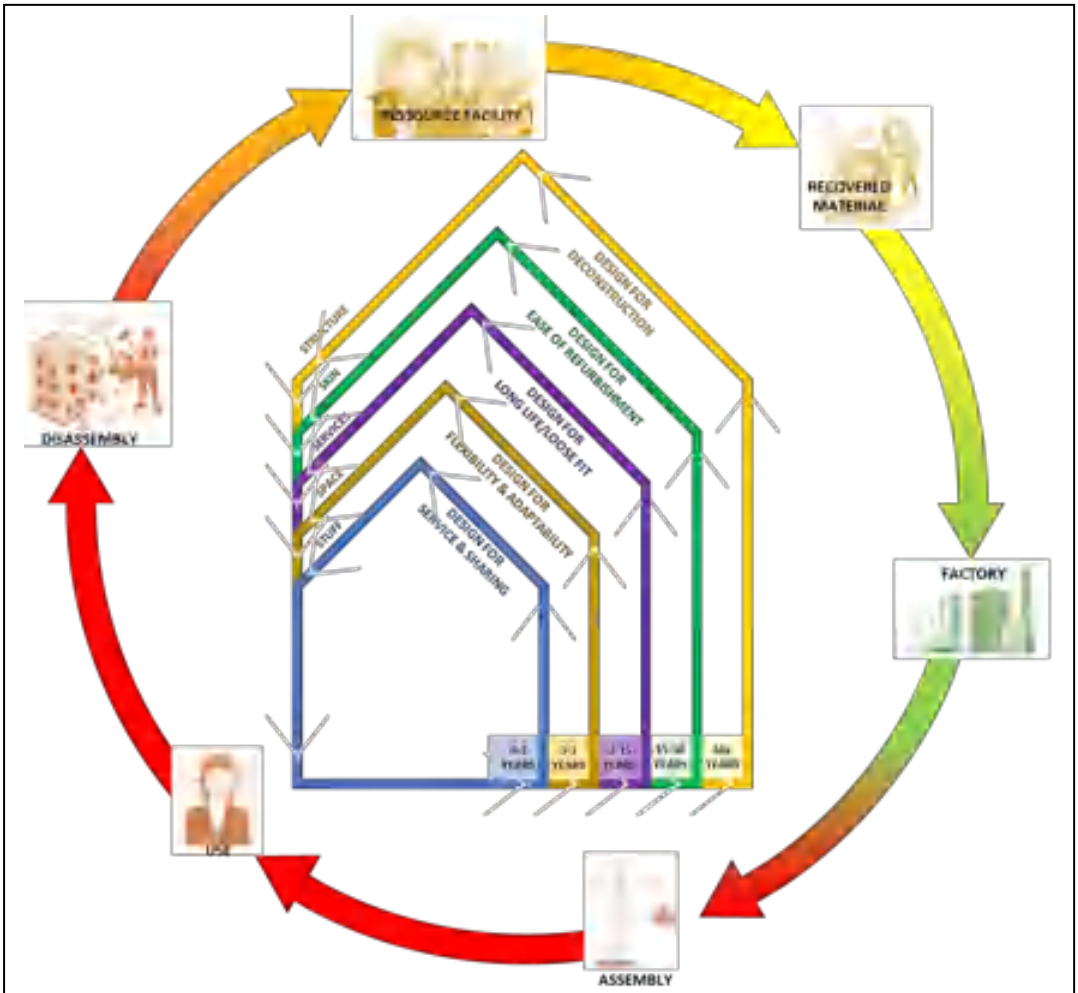


The principle of photocatalysis applied to TiO2

Development of an eco-design method for tertiary buildings

The concept of circular economy promises an alternative to the current linear economy of "take-make-use-dispose". The circular economy is a restorative and regenerative system in which resource use, waste and emissions are minimized by reducing, slowing down (extended use over time) and recycling material loops. The circular economy is operationalized through strategies such as reuse, repair, refurbish, recycle and recovery. In addition, many circularity indicators have been developed, but inconsistently in terms of their scope and purpose. However, the lack of academic and scientific knowledge on circular economy indicators constitutes an obstacle to the development of the circular economy in the building sector.

The circular economy must evolve towards a general reflection on the scale of the building from its design phase (eco-design) and thus enhance the studies carried out on the scale of the materials. The emergence of labels goes in this direction but there are no studies or scientific analyzes to classify the design of a building and thus guide the construction industry on several relevant indicators. With this in mind, this solution requires the enhancement and optimization of the end of life of a building from the design stage by integrating dismantling and deconstructability, as well as the scalability of the building to facilitate changes in use or assignment of spaces for example.



Credit UsefulProjects – circular Economy - Study prior to development of an eco-design method for tertiary buildings

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Health & well-being engineering

Microsystems and IA for medical diagnosis

Smart textiles

Multiscale robotics for biomedical application

Disability and dependency care

Developments focused on societal concerns related to health and well-being are organized around the continuum of available and controlled technologies. Reasearch in this area at JUNIA leverages a multi-scale and multi-disciplinary approach.

The research in Microsystems is built from an international collaboration seed with the University of Tokyo (LIMMS CNRS Laboratory). A complete approach for microsensors, micro actuators and microfluidic integration aims the development of a lab-on-chip to perform cells analysis and drug candidates assessment in the fields of cancer and parasitology. Artificial intelligence allows to treat the large amount of collected data to ease the (cancer) cell identification and the evaluation of molecule candidates on invitro cell cultures.

At a larger scale, research is being conducted on the development of functional textiles and e-textiles. The activities cover textile production and its "functionalization" with intelligent instrumentation. Domains of expertise are heat and mass transfers in a global approach on one hand and the development and characterization of textile sensors (heat flow meter, bioimpedance sensor, gas sensor, etc.) on the other hand.

In a coherent engineering approach, activities are developing towards robotics combining microtechnology, sensors, actuators with mechatronic simulation qnd realization of experimental platform with control and supervision. A first activity is targeted at advanced magnetic probe guidance for drug delivery in the inner ear and magnetic catheter optimization for navigation in a complex vascular network. The second activity aims at better inclusion of the elderly and/or disabled in society by improving their mobility. This research encompasses the development of a lower limb exoskeleton for children and an intelligent electric wheelchair capable of moving in any environment through an advanced navigation system.

Associated research units : gemtex iemn PRISME

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8.1 Microsystems and AI for medical diagnosis

Microsystems technologies (MEMS) and AI algorithms have become precious tools for biomedical applications. Our research with a transdisciplinary approach is aimed at acceleration and ease of the diagnostic process as well as the drug discovery in the fields of cancer and pathogenic agents.

Regarding cancer diagnosis, the research is focused on microsystems able to detect and classify circulating tumor cells. Indeed, no commercially available tools exist to identify and quantify these potentially metastatic cells. Our original approach is a hybrid MEMS/microfluidics system performing high-throughput biophysical characterization of single cells. Biophysical analysis, indicating whether a cell is cancerous, shows a high potential for cancer diagnosis and disease monitoring. The follow up of our technological approach led to the development of another BioMEMS device to analyze the activities of immune cells when in contact with leukemic cells. This tool exhibits excellent performance as a drug-testing platform and is under further development towards an industrial prototype.

In the area of drug screening we also designed and built MEMS systems to assess molecule efficiency against parasites. The challenge was essentially to develop automatized tools exhibiting sensitivity and efficiency equivalent to standard methods with a faster and simpler analytical process. Furthermore, AI image analysis algorithms are under development to ease pathogen detection and cancer diagnosis. Indeed, the acquisition of data via the MEMS-platforms, their display with noise suppression, the extraction of characteristics as well as the deployment of decision-making processes (based on sophisticated learning paradigms) will allow practitioners to have a quick and easy to use quantitative interpretation.

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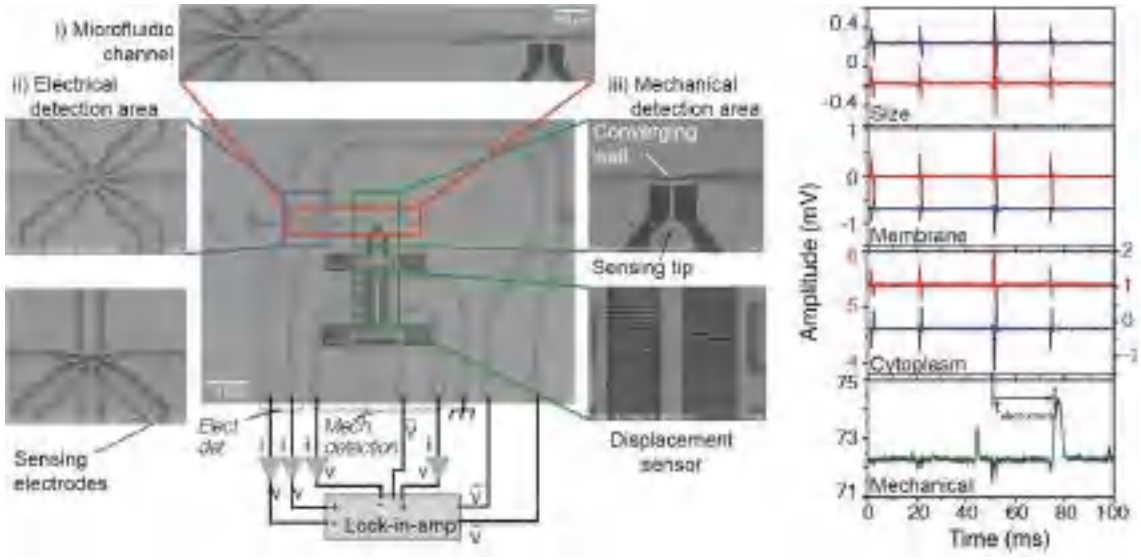
Microsystems for cancer studies

Liquid biopsy has been introduced as a new diagnostic concept predicated on circulating tumor cells (CTCs) or circulating tumor-derived factors. CTCs reflect disease progression and treatment responses, having considerable promise as a "liquid biopsy" for monitoring active tumor biology. Single-cell characterization is essential for cancer studies due to the high heterogeneity, especially for CTCs which require a reliable and high-throughput method due to their extremely low concentration in the blood to include cancer cell analysis in routine medical tests.

As an alternative label- and marker-free method for routine use, we developed the first optics-free high-throughput multi-parameter single-cell analysis method. This biophysical cytometry could conduct electrical and mechanical measurements for different biophysical properties, i.e., size, membrane capacitance, cytoplasm resistivity, rigidity, and viscosity. The throughput reached 40 cells per second even without optimizing the cell handling protocol. Thousands of cells could be measured in a couple of minutes to analyze with statistical learning tools. A new fabrication method was developed (a patent filed) to provide cell trajectory-free measurements by 3D electrodes for higher reliability of the impedance spectroscopy measurements. In another collaborative project with The University of Tokyo and COL, we sort CTCs from patient blood for further analysis with the developed biophysical cytometry. In parallel, biophysical characterization has also been applied to leukemic patient samples to detect residual cells for

determining disease progression as a prognostic tool. Further development of the system integrates it with an FPGA board to build a smart MEMS device with cell-specific adaptive



The developed hybrid MEMS/microfluidics device has dedicated areas for electrical and mechanical measurements with integrated electrodes, sensors and actuators. We obtain nine different signals for each cell to collect information on their size, membrane, cytoplasm and mechanical properties.

measurements and sorting (ongoing ANR PCSE project).

Microsystem for Drug screening to tackle pathogenic agents.

For the last twenty years, publications including "mechanical biosensors" are exploding (+1700% according to an analysis made on web of science). But micro-electro-mechanical systems (MEMS) were mainly aimed at preparing samples or detecting the presence of pathogens. To date, very few of these miniaturized tools have been developed to understand the infectious power and the development of pathogens. However, this parameter is essential to characterize compounds exhibiting an inhibitory activity on pathogenic agents.

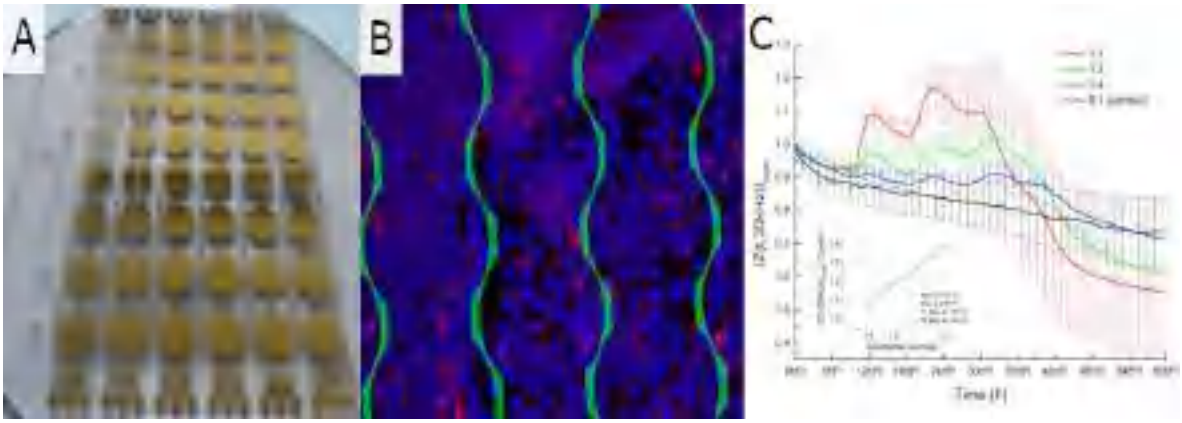
To overcome this methodological limit, we developed an automated platform integrating human cells grown on microelectrode arrays. This device (i) measured continuously the development of infectious agents by electrical approach (by impedance spectroscopy) and (ii) detected the inhibitory power of compounds identified as drug candidates.

The major challenge of these approaches, which were built at the interface between biology and microelectronics, was to make sense of the measured electrical signals. Thus, it was extremely challenging to correlate the impedance values with the phases of the pathogen development cycle.

The second challenge was to develop tools that are as sensitive and reliable as the methods routinely used by pharmaceutical companies for screening molecular banks while being faster and less expensive.

A first device has been used to study a parasite (belonging to the genus Cryptosporidium) and allowed to prove the concept. Through a European project, we have developed a prototype that designed to fit the needs of pharmaceutical companies.

Future applications of our devices will focus on the differentiation of the infectious power exhibited by different strains/variants of pathogenic agents (Parasite/Virus). It will open the way to an acceleration of the characterization of the risks represented by the variants of a targeted pathogen and will lead to discriminated variation in drug efficiency according to the considered strains/variants.



Prototype of a drug screening platform: A. Drug screening MEMS platform. B. Microelectrodes array (in black) with Human cell (nucleus in blue) infected by Cryptosporidium parasite (in red). C. Impedance measurement during 60h of infection with a range of parasite concentrations

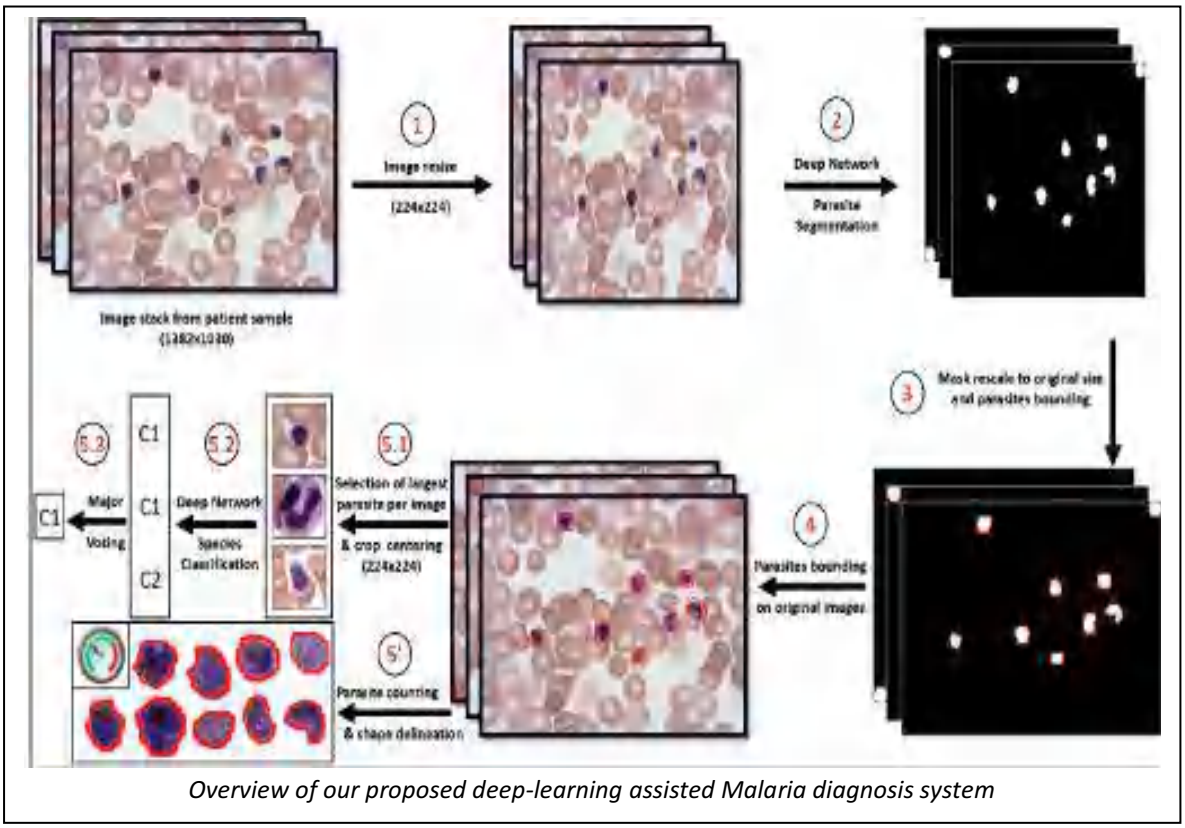
Development of deep learning-based precision tools for Malaria and Cryptosporidium parasites analysis from microscopic images

Parasitic infections represent a high risk of morbidity and death over the world. For instance, in 2018, the plasmodium parasite was responsible for more than 400 000 deaths worldwide. Among them, children under 5 years old are the most vulnerable group with approximately one death every two minutes. Another example of dangerous parasite is cryptosporidium which causes diarrhea and is considered as the second infectious agent responsible for children death under 5 years old in Africa and Asia. Within livestock, cattle (especially calves) are considered to be the main reservoir of this parasite. The World Health Organization (WHO) encourages the research of appropriate methods to treat this type of infections through rapid and economical diagnosis. Therefore, it is necessary to develop automated diagnosis and analysis systems, which could not only be reliable but also faster and more financially accessible. Microscopic image analysis by experts permits to analyze parasitic infections. In this context, Artificial Intelligence (AI) offers a real asset to automatize this task. In this sense, we have recently developed two powerful AI-based assisting tools for automatic analysis of plasmodium and cryptosporidium parasites from microscopic images. More specifically, we have proposed:

- A framework for diagnosing plasmodium infection in humans using microscopic images of thin blood smears. Compared to the state-of-the-art studies, our framework is rather based on a straightforward segmentation and classification approaches, permitting the analysis of the parasite itself instead of the cell. The framework permits to directly segment the parasite and to distinguish its species among four major classes: P. Falciparum, P. Ovale, P. Malaria and P. Vivax.

- A framework for diagnosing Cryptosporidium infection in dairy cows using fluorescence microscopic images. To this end, we have proposed an original parasite segmentation methodology based on a coarse-to-fine approach. We have also proposed a classifier with a

high discriminatory power that is used to efficiently distinguish the life stages of the parasites among 4 asexual stages: oocyst, trophozoite, meront, and free form.



Overview of our proposed deep-learning assisted Malaria diagnosis system

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8.2 Smart textiles

This research topic contributes to the development of functional and e-textiles for medical and well-being applications within two major focus points:

• Heat and mass transfers (comfort):

Heat transfer, mass transfer and their coupling are characterized and analyzed with different existing methods (Skin Model, Moisture Management Tester, Dish Method, etc.). In order to approach the real conditions of use and analyze the coupling between heat and mass transfers, innovative caracterization methods are developed . The scientific challenge is the analysis of the coupling of the two transfers which impact each other. The originality of our approach is to analyze the coupling dynamically allowing to approach the behaviour in real conditions of use.

• Development and characterization of textile sensors (heat fluxmeter, bioimpedance sensor, gas sensor, etc.) for health and well-being applications.

E-textiles combine different expertises: textile, electronic and data processing. Thus, it exists several constraints of development and use like:

*integration of sensors into textile substrates,

*integration of rigid electronics and connectics into flexible textile substrates (miniaturization of electronics, …),

*the mechanical stresses of everyday use including washing, sweat and external conditions like temperature, pressure,

*collaboration and application of multidiciplines in one final product,

*ensure the sustainability and fiabilitiy.

These scientific and technological challenges which prevent the access of advanced textiles in the market are taken into account during our research and development studies.

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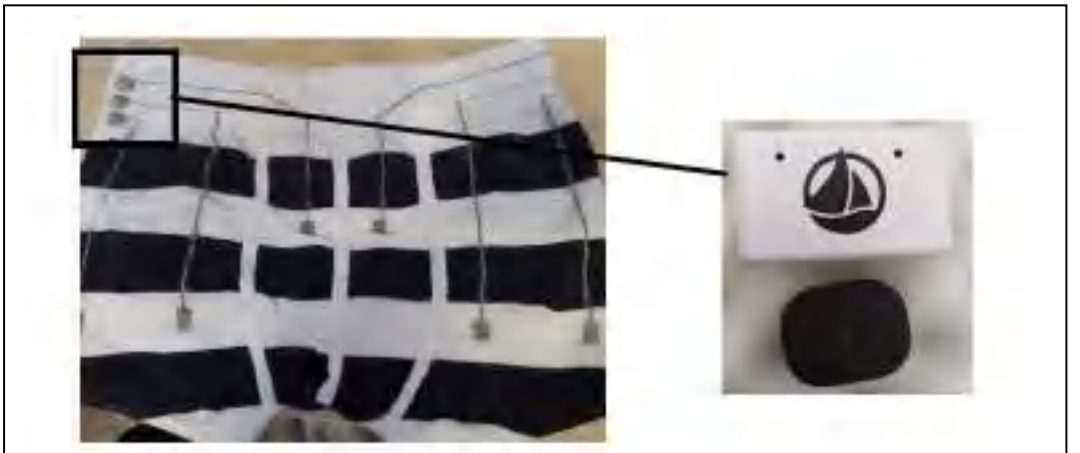
Smart Underwear for Enuresis

Enuresis is the involuntary voiding of urine during sleep in a child older than five years old. This urinary trouble affects almost 10% of children. To improve their life, a smart underwear, integrating textile electrodes, has been designed and fabricated. This underwear is able to monitor continuously and unobtrusively the child's bladder fullness in order to wake him up before the incontinence. To achieve this monitoring, a textile moisture sensor and textile electrodes (also referred to as textrodes) that enable bioimpedance measurements have been seamlessly embedded into the underwear. Those textrodes have been extensively characterized, in particular their withstanding to domestic washing. To prove the concept of evaluating the urinary bladder volume with textrodes, a pelvic phantom incorporating ex vivo pig's skin and bladder has been designed and fabricated. Also, a numerical simulation, based on a 3D reconstruction of the abdomen has been realized. The best electrodes' locations on the abdomen have been discussed regarding the obtained results. At the end, bladder volume variations were recorded on individuals that were urinating. Also, the underwear has been worn by individuals to evaluate potential noises on the signal, coming from other physiological process like respiration. The device's acceptability has been evaluated by doctors and enuretic children. As every child is unique, a learning algorithm is needed to learn the voiding patterns of everyone. Consequently, incontinence can be personally anticipated. A dedicated smartphone application, enabling both parents and children to follow the children's progress, has been designed. To our knowledge, this is the first study (collaboration with company Petit Bateau and GEMTEX laboratory) which integrates bioimpadance textrodes in an underwear to measure the bladder volume.



Smart underwear with bioimpedance sensors was knitted by using an industrial seamless machine (company Petit Bateau) for enuresis application. An electronic board was developed and it was connected to sensors by using pushbuttons.

Stress Detection by Using Textile Heat Fluxmeter

This work is part of the European project MOTION (Interreg 2 Seas Mers Zeeën), which aims to develop an exoskeleton for children with cerebral palsy. The developed exoskeleton was equipped with a smart garment to detect physical or physiological stress during rehabilitation. Previous studies on the stress have used different techniques like audio signals, cameras. These methods may have worked well, however, many children with motor problems also have cognitive problems. For them, it may be difficult to answer questions and express their feelings, and these methods do not measure the level of discomfort in real time.
Therefore, measuring discomfort continuously and objectively can be useful while using technological devices during rehabilitation. Thus, a textile-based electrocardiogram (ECG), a

textile-based respiration rate (RR) sensor, a galvanic skin response (GSR) sensor, and a textile heat fluxmeter (THF) were integrated into a smart garment to get physiological data for stress detection. This study focuses on the development and characterization of THF. Heat flux sensors currently available in the market are impermeable that is why they give incomplete results for the energy balance in a humid environment (sweating). Moreover, due to their semi-rigidity, they can only be used on flat or semi-flat surfaces. A THF can consider the humidity and it can be used for complex surfaces thanks to its permeability and flexibility. To evaluate the performance of the THF and determine its sensitivity, an experimental setup was developed. THF follows the evolution of a commercial heat fluxmeter output and gives a similar sensitivity as a commercial one. Human tests are realized on 20 healthy adults by simulating physical and physiologic stress (mental calculation, virtual reality tests, and sport session). The results show the influence of stress on the heat exchanges between the human body and the environment.

Smart garment containing three different sensors (ECG, RR and THF) developed for stress detection. ECG and RR sensors were developed by Centexbel and THF was developed at JUNIA. These sensors were integrated into a garment and an electronic board was developed to collect all signals coming from sensors.

Photonic Textiles

In France, the building sector is the most energy-consuming of all economic sectors (43% of total final energy consumed annually). Among this part, 65% is directly connected to Heating, Ventilation and Air-Conditioning systems. Developing technologies to reduce this energy consumption has become a societal challenge and has stimulated researches in the scientific community. One of the solutions is based on 'personal thermal management' in order to locally provide heating or cooling in the human body close environment rather than in the entire residential space.

This strategy consists of controlling the temperature of the space between the human skin and the textile, called microclimate, thanks to cooling and heating textiles. Within this context, at rest, 50% of the total heat loss of the human body is the radiative one in the Mid-IR (5 - 20 µm). Thus, designing textiles able to modulate these radiations, is of real interest. In this context, our objective is to develop original passive solutions, based on polymer membranes, complexed with textiles, in order to improve the feeling of thermal comfort for the people who wear them. With respect to the state of art, the interest is here to understand and control the role of the optical radiations (absorption, reflection, scattering) in order to manage the thermal comfort.

This research subject was already studied within an European Project (Photonitex, Interreg FWV) and a national project (POCOMA, ANR) is in progress to move to a higher Technology Readiness Level by relying on the involvement of company Damart. In these projects, our team is especially involved in development of photonic membranes by electrospinning process (for more information, you can consult "electrospinning of fibrous materials" section) and the optical and thermal characterization at the laboratory scale (thermal resistance; transmittance, reflection and absorption properties in the Mid-IR range, …).

A honeycomb structured electrospun membrane was developed by using electrospinning technology for photonic applications.

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8.3 Multiscale Robotics for Biomedical Application

The objective of this topic is to contribute to the development of tools for the design of interactive and multi-scale robotic systems in the context of medical applications. From an application point of view, autonomous or semi-autonomous robotic systems will ultimately improve the treatment techniques currently proposed to patients. From a scientific point of view, the research includes the mechanical design, the integration of components (sensors and actuators), or even the development of dedicated components, the design of control architectures, the synthesis of control laws and the experiments. A global mechatronic approach is developed to model, simulate and optimize complex devices by dealing with the following challenges: challenges related to modeling, challenges related to optimization and challenges related to the control of these systems. The demand for cost-effective devices that can quickly meet needs requires that these products are designed with minimal prototyping, relying on simulation to verify design requirements. Therefore, the use of a multidisciplinary (multi-physics) simulation environment plays a key role in the optimal design of mechatronic systems. The development of these mechatronic devices is accompanied by the creation of experimental platforms. The use of experiments remains an essential step for the validation of the considered approaches, their integration into the clinical environment and the sustainability of the themes studied.

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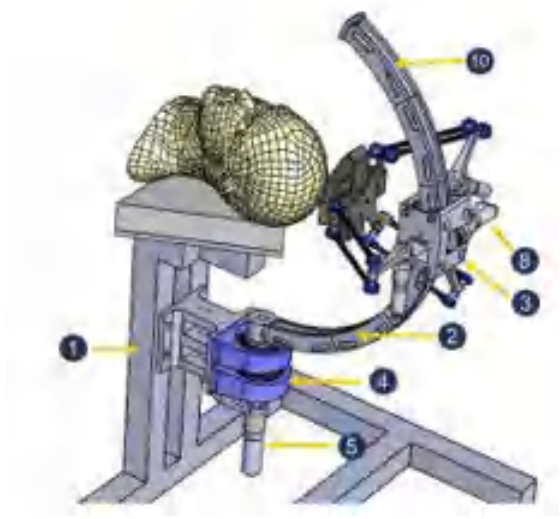
Design and realization of a robotic manipulator for magnetic probe guidance dedicated to inner ear drug delivery

Inner ear disorders treatment remains challenging due to anatomical barriers. Robotic assistance seems to be a promising approach. The use of magnetic nanoparticles, able to access the inner ear without damaging it, leads to an efficient targeted drug delivery into the cochlea. Several investigations have been carried out on the theme of nanoparticles control in the human body via the use of magnetic sources. We present a combination of a micro-macro system based on 4 permanent magnets that has been designed and prototyped [1,2,3]. The system allows to effectively control the navigation of magnetic particles remotely throughout the cochlea. The particularity of the developed effector is its ability to create a convergence zone of magnetic forces where the nanoparticles can be pushed/pulled. Two manipulator robots have been developed and prototyped, having respectively a serial architecture based on an RCM mechanism (3DOF) and a hybrid architecture, serial carrier, and Delta

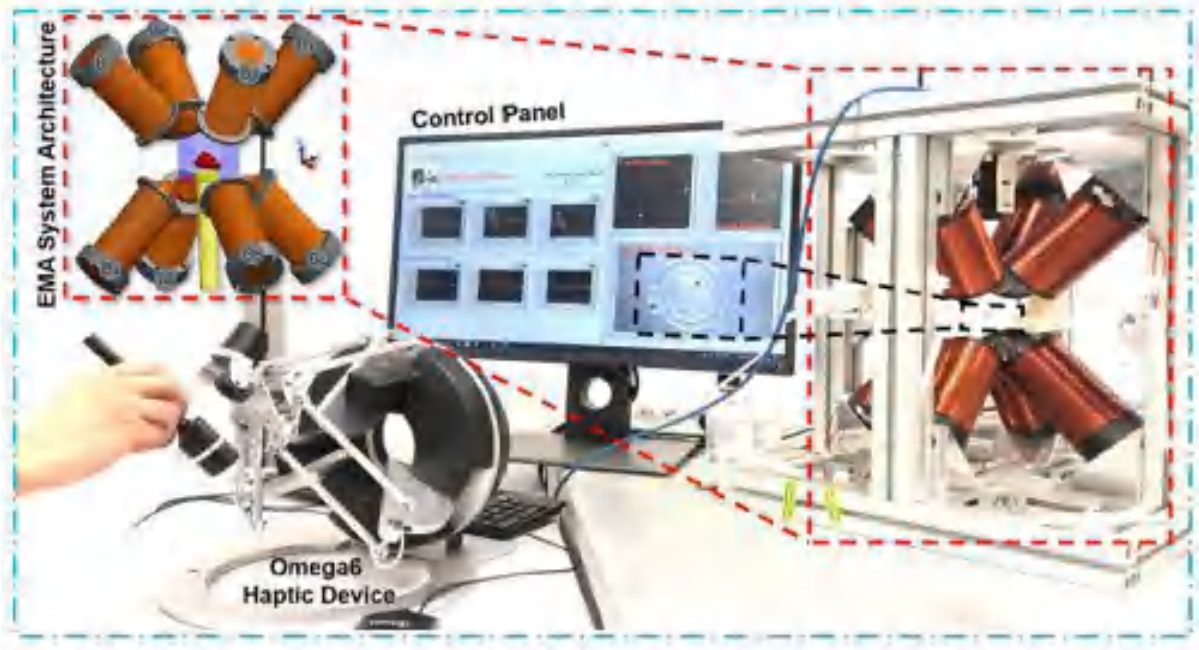


Mechanical design of the CochleRob manipulator

type positioner (5DOF), allowing the positioning and orientation of the latter in the 3D space around a patient's head. This robot has been controlled using Labview software. Finally, after various tests and results, the concept of cochlea processing robot has been validated [7].

Strategy for haptic-based guidance of soft magnetic particles in the cochlea

The delivery of drugs (therapeutic agents) into the inner ear using magnetic particles driven by magnetic fields is a very innovative and promising solution [5]. However, despite several studies on this subject, no solution has been adopted in the operating room. This is due to several factors such as the use of hard microrobots which threatens patient safety, the method of injection of the microrobots used which risks damaging the RWM round window membrane, as well as the difficulty of guiding of particles inside the cochlear canal. Our objective is to set up a drug delivery procedure in the cochlea based on the technique of magnetic guidance to respects the specific requirements of the application to simplify its integration in the medical field. For this we have proposed in this work a navigation strategy of soft microparticles to ensure biocompatibility. This strategy makes it possible to control the particles as soon as they are injected into the middle ear by ensuring their diffusion through the RWM using a chain method to minimize the risk of perforation and decrease the diffusion time. Thanks to a haptic device and after the diffusion of the particles, we form a bolus of particles inside the cochlea and then transport it to the target area. The particle diffusion method through the RWM is tested in an Insilico model followed by experimental in-vitro tests in an artificial cochlea [4,8]

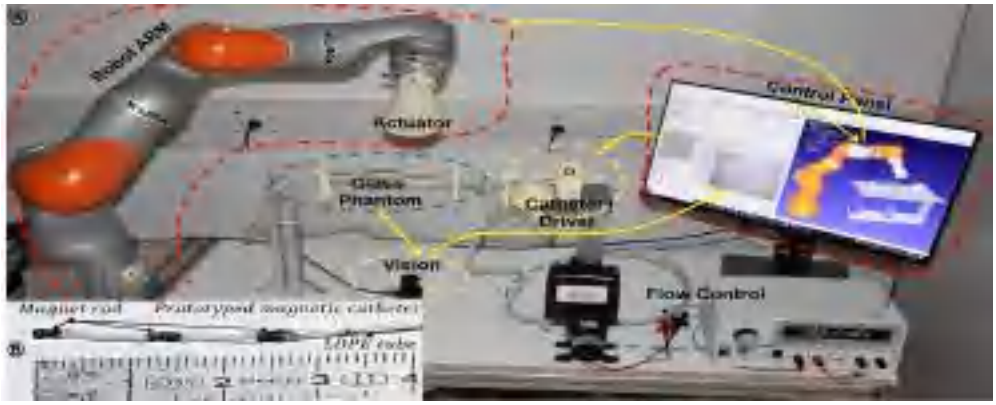


Conceptional view of teleoperated electromagnetic platform for microrobots navigation

Magnetic catheter optimized for navigation in a complex vascular network

The magnetic catheter is one of the most used tools in medical robotics. However, cardiac ablation is the medical application that mostly benefits from the strength of catheters. The size

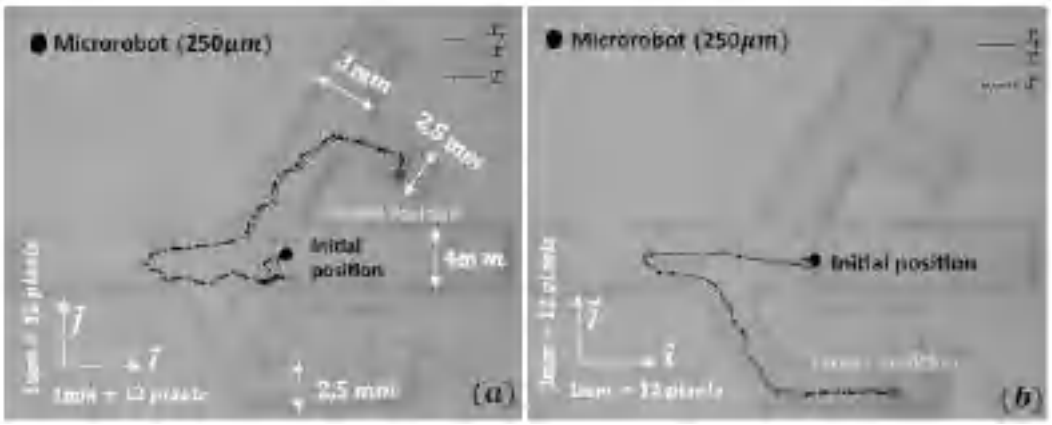
of these commercialized magnetic catheters is greater than 2.33mm which makes navigation in small arteries impossible. The objective is to develop a catheter capable of navigating in several organs in the human body to facilitate the treatment of various pathologies. An optimal catheter of 1mm in diameter composed of three cylindrical permanent magnets has been designed from modeling result based on the Euler-Bernoulli beam model and optimization of the catheter parameters using genetic algorithm. This catheter can navigate through complex trajectories with significant deflection angles. This allows several medical applications to benefit from the advantages of magnetic catheters such as interventional neuroradiology. This novel catheter has been prototyped and allowed testing its performance in vacuum space and in a vascular network with a complex trajectory [6].



Robotic manipulation platform for the navigation of an ulta-thin (1mm) magnetic catheter in a replica of a cerebrovascular network

Extended state observer based-model predictive control of a microrobot navigation following a trajectory generated by a joystick device

An extended state observer based-model predictive control (MPC) for trajectory tracking of a microrobot in a 2D fluidic environment has been implemented. The reference trajectory is generated using a joystick device and is estimated using an extended state observer (ESO). Assuming that the position of the microrobot is known, the aim is to design an observer based MPC control capable to track the reference trajectory delivered by a joystick device. Besides, the ESO observer is designed to estimate the unmodeled dynamics and unknown perturbations while further conserving state space. To optimize the MPC control, we have introduced a quadratic criterion where its' parameters are determined to have a specific behavior of the closed loop system [9].



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8.4 Disability and dependency care

Our objective is to increase the inclusion of ageing and/or disabled people in society by improving their mobility in a context where equipment is increasingly connected and autonomous in order to carry out a given mission; this is referred to as systems of systems. To this end, several avenues will be investigated to limit the degradation of the person's state of mobility, to work on the person's environment to make it more favourable to mobility and to improve and/or repair the person's state of mobility. Through a system of systems approach, we will propose the integrated design of modules and applications around chairs and orthoses to improve the autonomy of people with reduced mobility. This will also involve the analysis of driving data to propose an adapted aid. Signal and image processing augmented with artificial intelligence methods that ensure an improvement in the precocity or precision of diagnosis.

For motor disabilities, robotic systems must sufficiently counterbalance the disability (provide a benefit) by adapting to the person's morphology, while respecting the constraints induced by the disability(ies). These aids must be simple and acceptable in their daily use. The possibility of moving around in public and private spaces, which is the basis of any inclusion, requires sensors to reconstruct the environment and intelligent systems capable of improving navigation and/or movement capacities, as well as medical monitoring through data collection. The design is based on the 'patient-doctor-engineer' triptych, combined with validation through comparisons with the ground truth. The applications developed within JUNIA concern mobility : we are developing a lower limb exoskeleton for children and an intelligent electric wheelchair capable of moving around in any environment thanks to an advanced navigation system

Furthermore, precoce diagnosis of multiple sclerosis (MS) would help to slow down its evolution. Techniques for automated analysis of Cerospinal Fluid for rapid and secure detection of MS have been developed and tested in the perspective of simplified MS diagnosis

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Exoskeleton for children

Lower limb exoskeletons have been proven very useful for patients who suffer from motor function disability, in both clinical rehabilitation and daily activities. However, exoskeletons for the pediatricfield are still very limited.We defined, a novel lower-limb exoskeleton design for children . Based on the anthropometric data of the target group, the size of the exoskeleton is designed adjustable to suit children from 8 to 12 years old and it contains six active joints on the knee and hip actuated by Brushless DC motors with Harmonic Drive gears. The controller is based on a finite state machine model and the weight shift between two feet to generate the gait trajectory. An automatic step triggering mechanism is also included based on the feedback from the ground reaction force sensor on the foot. Two user interfaces on the exoskeleton and the host PC are designed for easily operating the exoskeleton by clinicians and engineers. Experiments have been conducted with three healthy volunteers following the predesigned rehabilitation session protocol. Results show that the exoskeleton can well follow the gait

trajectory generated by the control algorithm. All volunteers can fulfill all tasks in the test protocol wearing the exoskeleton with less

Exoskeleton structure

effort and the steps are automatically triggered by the presented controller.

Automated diagnosis in SEP

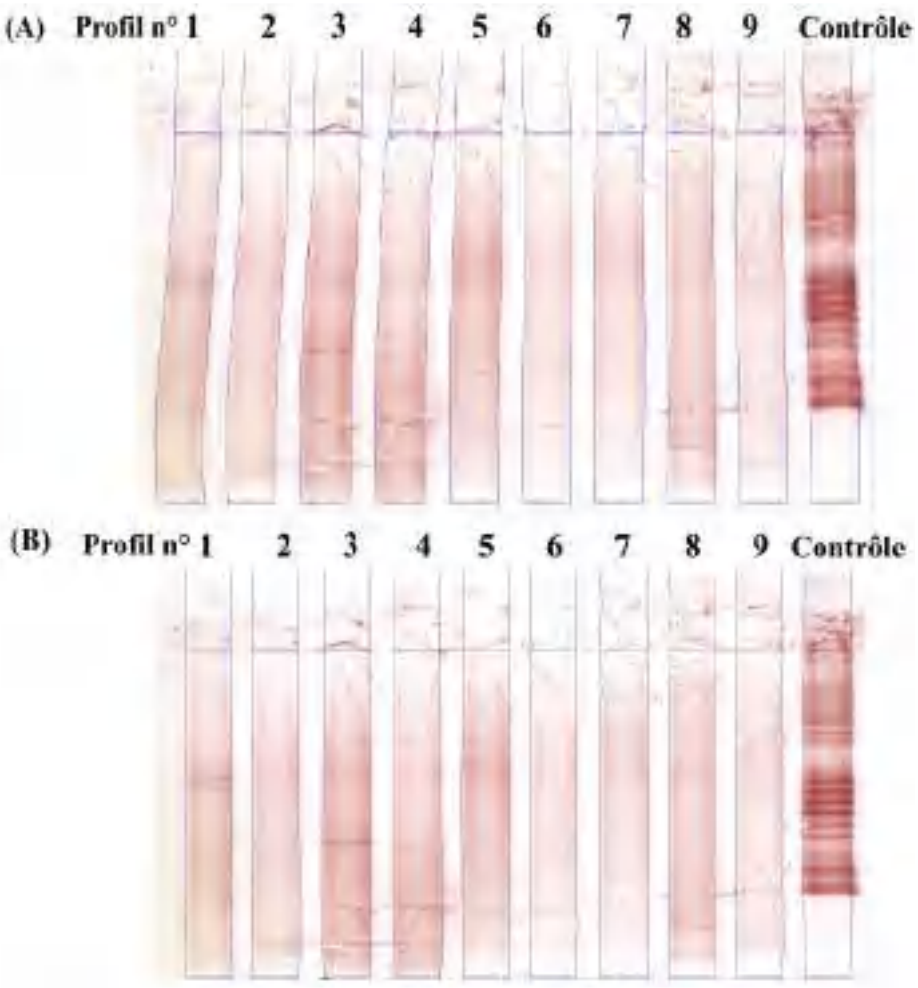
2.8 million people worldwide live with multiple sclerosis (MS), 30,000 of them are under 18 years of age. There is no cure for MS, and current treatment strategies aim to slow the progression of MS in order to delay severe long-term disability as long as possible. Therefore, it is important to make the diagnosis early. This encourages the development of automatic analysis of isoelectric focusing (IEF) images of cerebrospinal fluid that would speed up and increase the accuracy of the analysis. Analysis of cerebrospinal fluid (CSF) shows an abnormally high level of one class of antibodies: immunoglobulin G (IgG). IgG migration images by electrofocusing are analysed visually by experts; the presence of three or more OligoClonal Stripes in the IEF result of a CSF sample (called a profile) that are absent from the IEF result of the serum of the same patient indicates intrathecal synthesis and the CSF profile is then said to be oligoclonal. There was no image processing method developed for the automatic analysis of IgG IEF profiles in the diagnosis of MS. Our work is based on the following methodological contributions:

-Automatic segmentation of the different profiles (sample migration results) on the IEF image thanks to an approach based on an original formulation of active open contours

-Correction of geometric distortions using a hierarchy of image deformations

deformations

-Classification of bands using Deep Learning (DL) techniques



Realignment and correction of distorsions in IEF images of cerospinal fluid

Autonomous mobility

How to develop an optimal architecture of robotization, safe operation improving the autonomy of the PRM starting from electric wheelchairs

The autonomous wheelchair developed in the EDUCAT project (*https://www.educat2seas.eu/*) led by JUNIA allows for data collection and analysis. Navigation and driving assistance applications have been developed to improve the autonomy of people with reduced mobility. Through this project, which aimed to develop technological building blocks to improve the autonomy of people with disabilities, we developed applications to robotize a motorized wheelchair. More specifically, we developed a system for collecting and recording heterogeneous data, which allows data to be saved in the cloud and visualised in real time]. After installing some sensors (infrared, ultrasound), we set up an obstacle warning system. The installation of sensors such as lidars and 3D cameras allowed us to develop autonomous navigation applications. The modules developed can be adapted to existing electric wheelchairs on the market and have a maturity level of TRL6 or higher

Autonomous electric wheelchair developed in EDUCAT project

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Responsible chemistry

Synthesis of biosourced molecules

The responsible chemistry aims at the replacement of petrochemicals and other rare ressources by natural, renewable and abundant ressources. Futhermore, environmental impact of the process itself needs to be improved by reducing or eliminating energy consumption, emission of greenhouse gas and toxic residues.

The topic developped at JUNIA targets high value molecules for applications to human health (active ingredients for therapeutic and cosmetic purposes) and to plants (plant defense stimulators, biosourced fungicides). It is based on the 12 principles of green chemistry and takes into account several factors: consumer demand, environmental constraints, economic efficiency and scientific innovations.

Associated Research Unit: RID-AGE - U1167

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9.1 Synthesis of biosourced molecules

The responsible chemistry developped at JUNIA is applied to human health (active ingredients for therapeutic and cosmetic purposes) and to plants (plant defense stimulators, biosourced fungicides). It is based on the 12 principles of green chemistry and takes into account several factors: consumer demand, environmental constraints, economic efficiency and scientific innovations. This research activity aims to design chemical products and processes to reduce or eliminate the use or synthesis of hazardous or threatened substances with a risk of future supply.

Objectives:
- Design of new molecules, mostly biosourced;
- Organic sustainable synthesis applied to health and well-being;
- Physico-chemical characterization of organic compounds;
- Study of reaction mechanisms;
- Green processes;
-Study of the mechanism of action, bioavailability, metabolites;
-Structure-activity relationships.

The Sustainable Chemistry team has a very strong expertise built over 40 years on the valorization of pyroglutamic acid (also called pidolic acid in cosmetics) in molecules with high added value. Pyroglumatic acid is a waste molecule resulting from the sugar industry, more precisely from sugar beet molasses, and is also a constituent of many plant and animal tissues. This biosourced molecule has a number of important properties:
-Cell penetrating agent;
-Cell protection agent: salifies the protective amines of the hepatocyte and preserves the most important cells of the body (neurons, hepatic cells) from the action of toxic agents;
-Improves the assimilation and fixation of mineral ions;
-Decreases neuromuscular excitability (spasmophilia, anxiety);
-Increases the activity of local antiseptics and anesthetics, etc.

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Drug candidates obtained from biosourced feedstock: case of anticancer molecule HEI 3090

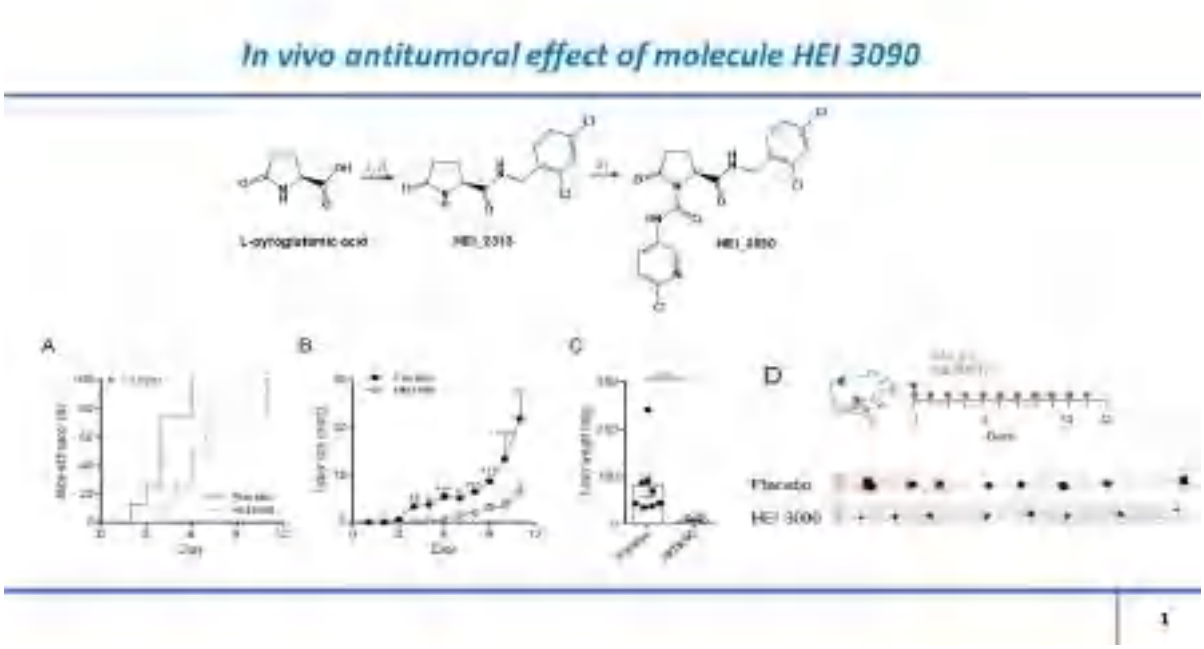
Lung cancer is the leading cause of cancer death. Despite the implementation of targeted treatments, the overall 5-year survival of patients with advanced non-small cell lung cancer (NSCLC) is less than 20%, which underlines the urgent need to develop new approaches to effectively treat the lung tumors. The goal of our consortium has been to design a new immunotherapy to strike the NSCLC, promising for patients with tumors resistant to current therapies.

In this context, we have synthesized at JUNIA a new antitumor chemical compound (HEI3090). Its antitumor activity depends on the activation of the ATP/P2RX7/NLRP3 pathway on tumor-associated dendritic immune cells, representing a new immunotherapeutic strategy that could be combined with other treatments to fight against NSCLC.

The HEI 3090 molecule displayed robust results (world patent, proof of concept already

published, 3 PhD theses, several grants), has reached the level of maturity necessary to provide new fundamental knowledge on the use of this compound to inhibit lung tumors. By increasing lung tumor immunogenicity, HEI3090 opens new clinical perspectives in pulmonary immuno-oncology. Indeed, HEI3090 may increase the percentage of patients who could benefit from immunotherapy. Phase I clinical trial is expected to start in due course.

The synthesis of the title compound was accomplished starting from L-pyroglutamic acid also known as the "forgotten amino acid", biosourced affordable raw material, present in high concentration in sugar beet molasses. Furthermore, molecule HEI 3090 has also an anti-fibrotic effect in vivo and could be used to treat idiopathic pulmonary fibrosis (IPF).



HEI 3090 inhibits tumor growth and ameliorates mice survival (LLC: Lewis Lung Carcinoma)

Ecocatalysis applied to the synthesis of molecules of interest

The ecocatalysis aims to find new biosourced catalysts to replace catalysts from petrochemistry (for example, classic Lewis acids). To obtain ecocatalysts, plants were grown on soils with high metal contamination (industrial wastelands of Hauts-de-France, Belgium or UK) to capture in their aerial parts certain metals useful in chemical catalysis such as zinc or iron while decontaminating the soil. Zinc is a chemical element represented in red in the new periodic table of the elements published by the European Society of Chemistry (EuChemS) in 2019 (https://www.euchems.eu/euchems-periodic-table/). The red color indicates that the dispersion will make these elements much less readily available in 100 years or less. This phytoextraction of metals from the soil using plants can be applied to small areas (a few tens of m2) as well as to large areas (a few hectares). The resulting ecocatalysts have been used and tested by our team in chemical reactions, previously chosen for their importance in the synthesis of compounds of biological interest, natural products, adjuvants for cosmetics or even indicators of the content of certain metals in the soil. The families of reactions considered to date, non-limiting, are in close relation with the biological targets on which our team is working and are:

• *Amidation (or aminolysis) reactions of esters*
• *Sulfonamidation*
• *Aza-Michael reactions*
• *Condensations via the formation of N-acyliminium salts for access to natural products of interest*

Four PhD theses have been realized so far on this topic. The project received several grants and is currently part of the Interreg North-West Europe REGENERATIS project and also AMI CVIB EXTRACUIVRE project. The PhD students had several distinctions for their work (DOC'Force award, prix de thèse, Ma thèse en 180 secondes, etc). Several communications for the general audience have been assured by the members of our consortium.

The concept of ecocatalysis : from contaminated soil to the synthesis of molecules of interest

Carbon dioxide transformation in high-value added molecules

Carbon dioxide is a highly critical greenhouse gas. In the frame of the project Interreg North-West Europe RIVER lead by JUNIA the idea proposed was to convert carbon dioxide recovered in fumes from vessels into high-added value molecules used in cosmetics (nontoxic gels) and in therapeutics (synthesis intermediates of drugs). In order to provide the proof of concept for the transformation of CO2, a laboratory scale demonstrator was designed and implemented. Our demonstrator of CO2 transformation has successfully been explored at the laboratory scale (ambient temperature, atm. pressure, low cost and non-toxic catalysts).The pure or recovered gross CO2 from boat or vehicle fumes have been successfully transformed using the RIVER technology into a broad portfolio of useful fine chemicals such as cosmetic ingredients, main ingredients of drugs and synthetic intermediates.

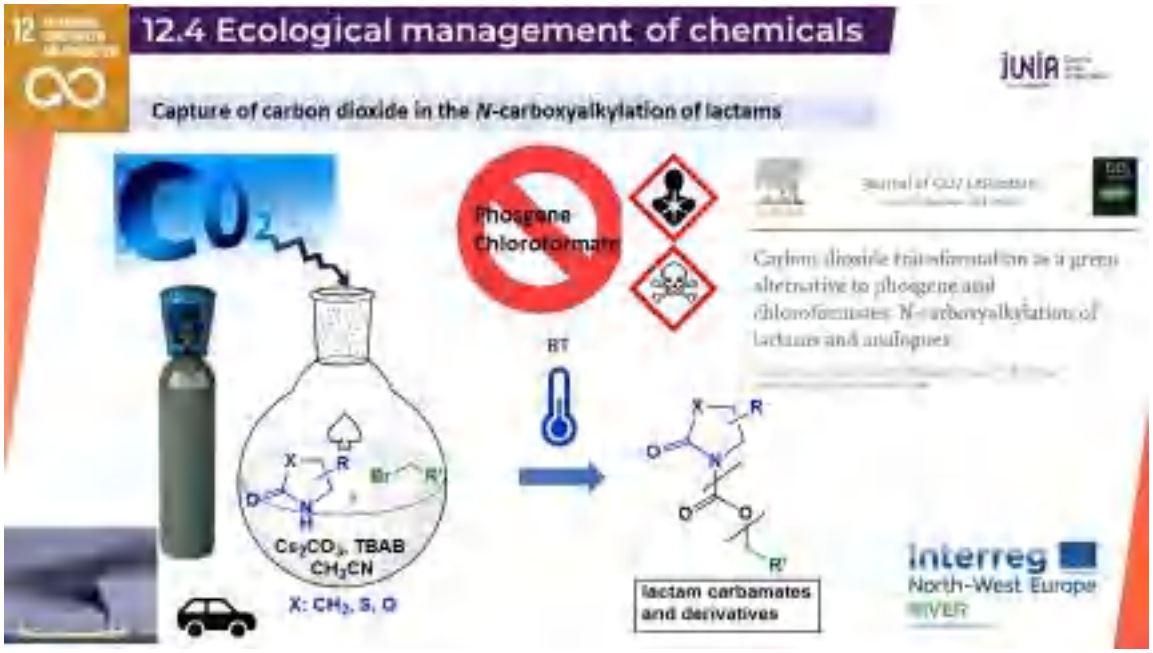
All these products constitute the "CO2 tree". To the best of our knowledge, this is the first chemical collection made from the unwanted gas. It is worth mentioning that the RIVER CO2 tree has now reached 63 molecules and we continue to seek additional profitable pathways of CO2 transformation to enrich the portfolio of products.

Results:

- Effective CO2 transformation (CCU in addition to CCS);
- Validated proof of concept;
- 63 molecules synthesized;
- Respect of green chemistry principles; unprecedented CO2 transformations;
- Interest of the technology in the petroleum, cosmetic and pharma industries;
- Technology validated with raw CO2 from car diesel engine;

Perspectives:

- Enrich the CO2 tree in order to constitute the most important chemical collection from the unwanted gas.
- Contribute to the decarbonation of industry by proposing carbon capture and use effective processes.



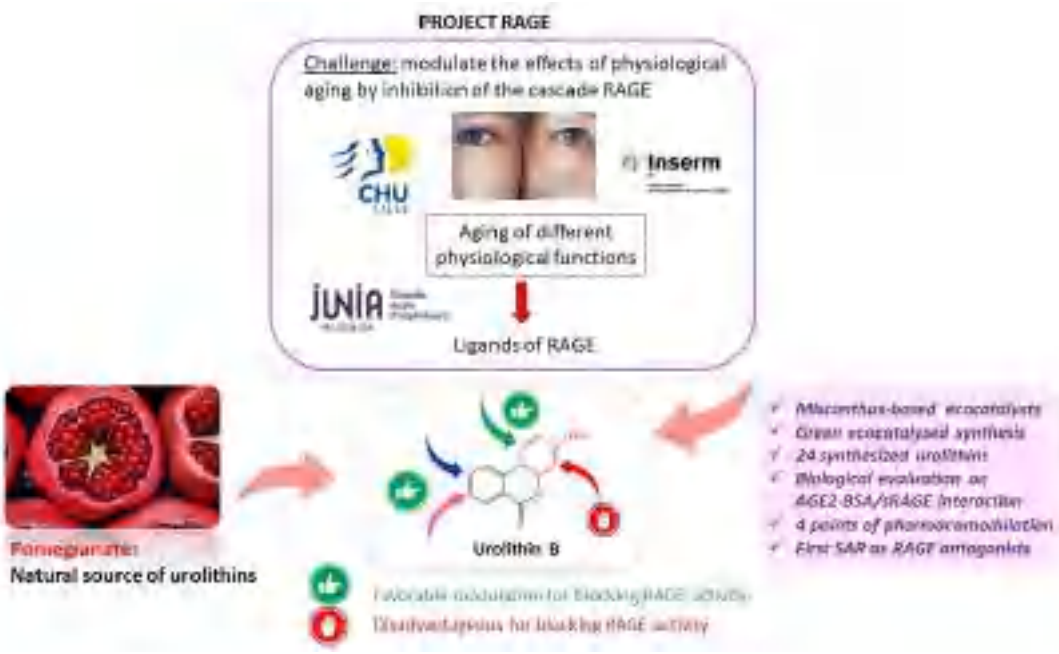
Example of pure or carbon dioxide from fumes chemical transformation into useful molecules as a green alternative to the use of toxic phosgene and chloroformates.

Anti-aging molecules

RAGE (advanced glycation end product receptor) is a multi-ligand receptor involved in the mechanisms of physiological or accelerated aging following an acute inflammatory episode. 28 ligands (pro-inflammatory, -fibrotic, -aging, neoangiogenic, etc.) have been identified to date, making RAGE a receptor involved in inflammation related to aging called inflammaging. The first clinical trials using Azeliragon, the reference inhibitor of RAGE to date, have not yet concluded positively in the control of cognitive decline. Among the consequences of aging are neurological but also muscular damage, which is often neglected. This not only points to RAGE as a pharmacological target of interest but also underlines the need to develop other more specific and affine molecules preventing the deleterious effects of this receptor.

In this context our team has identified new promising molecules targeting RAGE. The synthesis of these molecules is environmentally friendly. However, before being able to patent these molecules and their potential uses, a step of validation of the functional effects in vitro is essential. We chose the muscle cell as a study model given its contribution to age-related physical disability. Futher research is ongoing with the objective to identify new specific molecules inhibiting the RAGE receptor in order to control accelerated aging after an acute

inflammatory episode. In the long-term this could be applied to humans to slow down the accelerated physical aging that may contribute to the onset of addictions.



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Degraded soil management and valorization

Managing degraded soils and population exposure

Biomass production and valorization on degraded soils

Soils degraded by human activities, in particular industrial activities, represent major challenge in terms of human exposure to contaminants and in terms of remediation and valorization of the contaminated areas. Givent the industrial history of the Hauts-de-France region, large areas have been contaminated by Metallic Trace Eelements (MTE) by the past mining activities as well as the activities of two lead and zinc smelters. Because of the high contamination level of cadmium, lead and zinc in soils located in urban contexts in the surroundings of these smelters, the local production of herbs, fruits and vegetables is problematic due to the highconcentration of these metals in crops. In addition, the contamination can present health hazards, particularly related to the ingestion of soil particles. Therefore, the great challenge for policy makers, site managers, planners and municipal officials is the assessment of human exposure in order to ensure a safe crop production on these contaminated urban areas and to preserve the human health.

Given this general context, the main research interest is on soils contaminated by metallic trace elements (MTE) with a focus on two topics:

Managing degraded soils and population exposure

Biomass production and valorization of degraded soils

The challenge of the first topic is to find the best amendment/mixture of amendments that allows the safe crop production on the contaminated aera and to develop a simple and economical test to assess the human exposure.

Sub-urban and agricultural areas were also effected by the past emissions of the two lead and zinc smelters. Although the MTE concentrations are lower than those of urban soils, the MTE concentrations in some crops are higher than the permissible values making them impossible to sell for human or animal consumption. For this reason, the objective of the second topic is to propose alternative approches to use of these soils. In particular, the production of non-food biomass on these contaminated soils appears as a good option and various pathways for valorization (bioenergy, biochars, biosourced catalysts) are explored.

Associated research unit :

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10.1 Managing degraded soils and population exposure

The past emissions of two Pb and Zn smelters (Metaleurop Nord and Nystar) have largely contributed to the contamination of the surrounding soils: Cd, Pb and Zn being the main metals found in agricultural soils, while other metals and metalloids, i.e. As, Sb, Hg, were found in urban and peri-urbans soils. In fact, the concentration of these pollutants in these soils is often greater than in agricultural soils due to the dust emissions from traffic, heating and the addition of contaminated materials used as backfill. Because the behavior of metals and metalloids is different, studies are necessary to explore the key factors influencing the pollutant uptake by food crops. Moreover, the accumulation of these pollutants in leafy vegetables, root vegetables, fruits and aromatic plants is not the same.

In situ and ex-situ experiments must be carried out before giving advice to gardeners who consume their self-produced food. Some of these recommendations are based on the evolution of cultural practices (e.g.. addition of mineral and/or organic amendments, selection of vegetable varieties). For food crops produced on agricultural soils, effects of phytoparmaceuticals currently used in conventional agriculture are being studied. The contamination of urban and peri-urban areas is a real problem that must be considered on a global scale. Because the total concentration of metals/metalloids is not representative of their bioavailability, a more realistic concept was developped based on the assessment of bioaccessibility of metals/metalloids using the standardized UBM test. For several reasons, a simplified method was recently developped by our team and our partner, and it is currently being standardized by ISO

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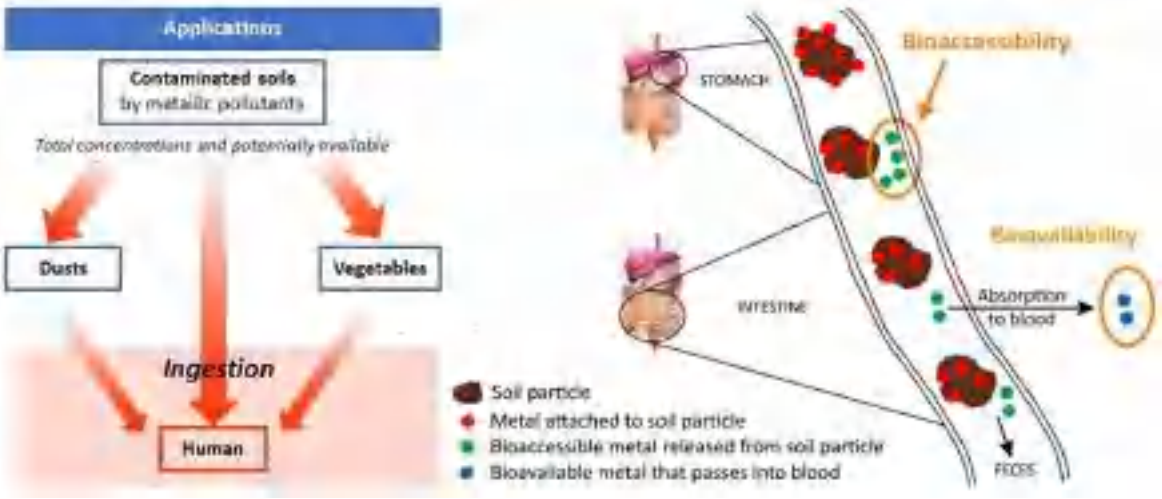
Exposure of populations to metallic pollutants via the ingestion of soil particles: towards a new ISO standard

Soils enriched with metal(loid)s pose a potential threat to human health if they are directly ingested or transferred through food. Incidental ingestion of soil particles is considered an important exposure pathway, particularly for children through outdoor hand-to-mouth activities. In the current context of management of polluted sites, human risk assessment through the ingestion of contaminated soil particles remains an area that is subject to uncertainties in the approaches to protecting the health of populations. Current protocols are based on total concentrations. However, only a fraction of them, i.e. the bioavailable fraction, is assimilated by the body and is likely to induce a toxic effect. Bioavailability is in practice estimated by the measurement of bioaccessibility, i.e. the soluble fraction that can be released into the gastrointestinal tract and reach the bloodstream. Oral bioaccessibility is based on the standardized UBM (ISO 17924) test, which is considered the reference method for assessing the bioaccessibility of As, Cd and Pb. Several projects funded by the Region, the Ademe and ARS have been conducted to assess the oral bioaccessibility of metals in different matrices using this test (BIOMIS, BIOAC, BioacLeg, POUSSEXPO) and they have shown the interest of

taking into account this parameter to better assess the exposure. Predictive models were also established. However, this method is not generally used by managers of contaminated sites for time, cost and complexity reasons. Thus, a simplified method to measure bioaccessibility could be of great interest and it was the subject of the ODESSA project (supported by Ademe). Digestion with hydrochloric acid solution meets the criteria as extractant for routine analyses. It is intended to help users to select few samples in a second-tier study and a complementary



Integration of bioaccessibility/bioavailability for a better assessment of human exposure

validation approach to use the UBM for better assessment of human exposure. This simplified test is currently being standardized by IS0.

Immobilization of metal(loid)s in kitchen gardens located in urban and peri-urban area

The need for nature in the city, the craze for "healthy eating" and difficult socio-economic backgrounds contribute to the development of gardening in (peri-)urban areas. Due to their environmental and historical context, the soils of vegetable gardens are mainly contaminated with metal(loids). This contamination can present health hazards, particularly related to the ingestion of soil particles or vegetables. Thus, according to their mobility and their speciation within the soil, metal(loids) could be taken up by vegetables and enter into the food chain, as demonstrated by different research programs (REPJAR, JASSUR). Nowadays, the great challenge for policy makers, site managers, planners and municipal officials is to ensure a safe crop production and human health while allowing the use of contaminated urban spaces for vegetable growth. The immobilization of metal(loids) through the incorporation of amendments into the soil appears to be an efficient solution due to its cost-effectiveness and its sustainability, and their lower life cycle environmental footprints. The aim is to allow safe crop production on urban garden soils moderately contaminated (300 mg kg-1 Pb) by reducing human exposure associated with urban gardening and crop consumption. This approach was assessed in the POTAGER project where 14 amendments were tested in private and community gardens moderately contaminated with Cd, Pb, and As located in Nantes and Lille. Based on the contamination (source, nature, extent), the soil physicochemical parameters and the input rate, the most efficient amendments to reduce the metal(loids) mobility and oral bioaccessibility in soils and their uptake by crops (i.e. lettuce) were compost used alone or in combination with zeolite, hydrated lime, potting soil and bone meal. More specifically, these amendments might limit the risk of food chain contamination as well as human exposure.

Management of urban kitchen garden soils moderately contaminated by metallic elements using natural mineral and organic amendments

Pesticides and soil characteristics: what are the relations likely to explain the consequences on potato production and consumption risks?

Plant protection products constitute a central tool in modern agriculture in the fight against crop pests. A better understanding of their environmental impact and their fate in our ecosystem is a major challenge for scientific research associated with the agricultural world. The research focuses on

(1) the correlations existing between the physico-chemical properties in the studied conventional plots and the persistence/retention of several targeted phytosanitary products (in connection with the cropping patterns).

(2) the potential effets of phytosanitary cocktails on the soil microbiological parameters in these plots.

Together with the Regional Chamber of Agriculture of Hauts de France and the Pôle Légumes Région North the effects of phytopharmaceuticals on potato, a symbolic regional crop, has been studied. The multidisciplinary research is adapted to three scales: field, experimental plots and controlled conditions in laboratory.

Linear regressions applied to 10 pesticides (7 fungicides and 3 herbicides) have shown a positive correlation between the sequestration of Prosulfocarb and the organic carbon content, as well as a complex role of clays showing positive correlation coefficients for Cyazofamid and Mandipropamide and negative ones for Zoxamide, Prosulfocarb and Propamocarb. These results have promoted a better understanding of the links between the physico-chemical properties of regional soils and the residues of phytosanitary products found in potatoes grown on these soils. Prospects related to tillage and in particular the addition of organic matter are being studied to limit the dispersion of phytosanitary products in the environment.

Study of the ecotoxicological effects of plant protection products on the quality of soils, their functioning and the quality of harvests using a multiscale approach (fields, experimental plots and controlled *conditions in the laboratory*

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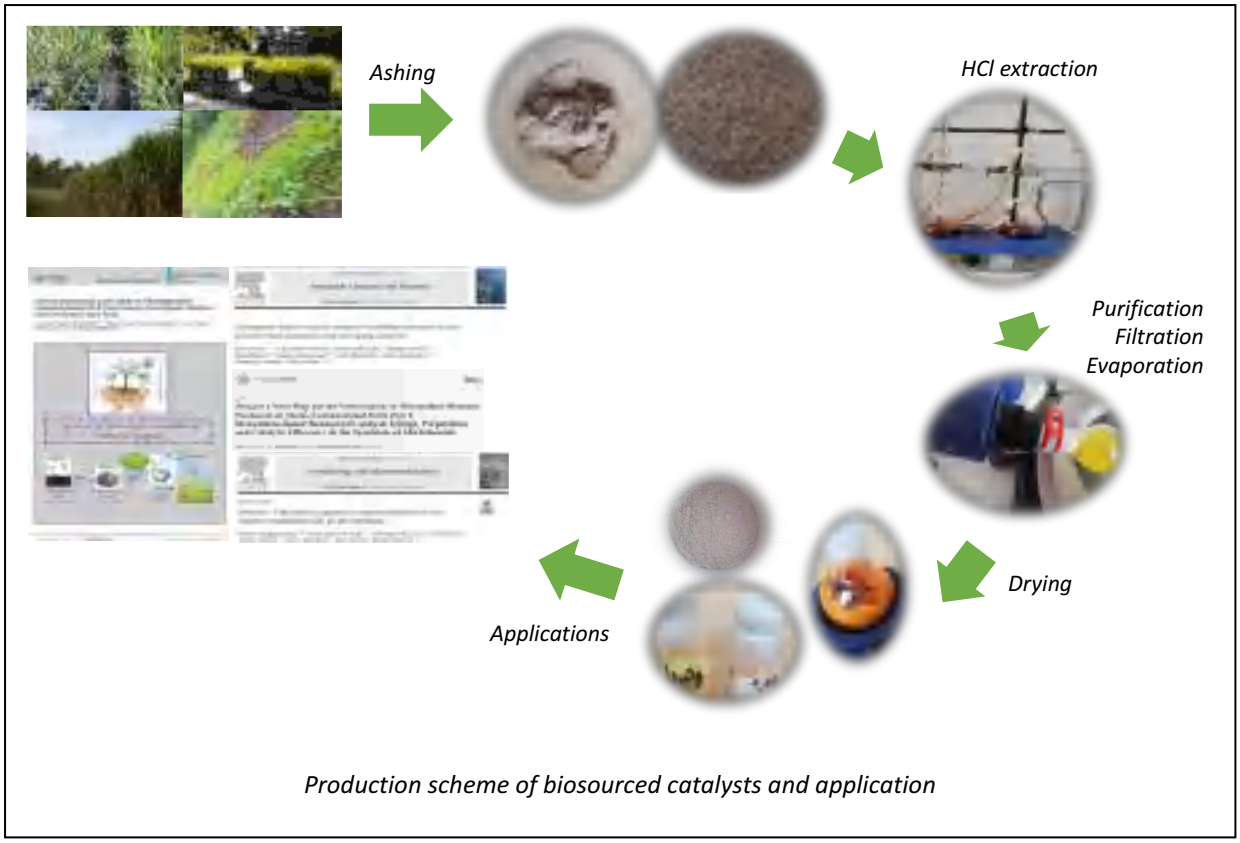
10.2 Biomass production and valorization on degraded soils

Due to the past emission of two metallurgical plants in the North of France (Metaleurop Nord at Noyelles Godault and Nystar at Auby) a very large area (120 km2) was contaminated with metallic trace elements, particularly cadmium (Cd), lead (Pb) and zinc (Zn). In this former mining region, agriculture is still a major activity and a large part of agricultural soils were affected by the contaminated dust emissions. Consequently, the production of food crops was problematic due to the concentration of these trace elements in the plant biomass. Some studies were conducted and a prefectural decree was established defining non-cultivable and cultivable areas , as well as the area to be monitored. It was also recommended to employ non-cultivable soils for non-food crops. Beyond early approches using various species of trees to produce wood, the potential of Miscanthus × giganteus for immobilizing metallic trace elements, as well as the potential of this perennial plant for bioenergy production has been explored in the last decade. Heat treatments on miscanthus under an inert atmosphere were applied to produce biochars as a basis for further valorisation of the metallic elements. Various amendments were tested on contaminated areas to assess their effect on the metalic trace elements immobilization and soil fertility. More recently, other non-food biomass have been grown on contaminated agricultural soils and various valorization methods are being developped or are still in progress.

Contact : Christophe WATERLOT, christophe.waterlot@junia.com

Production of biosourced catalysts from non-food biomass grown on contaminated soils

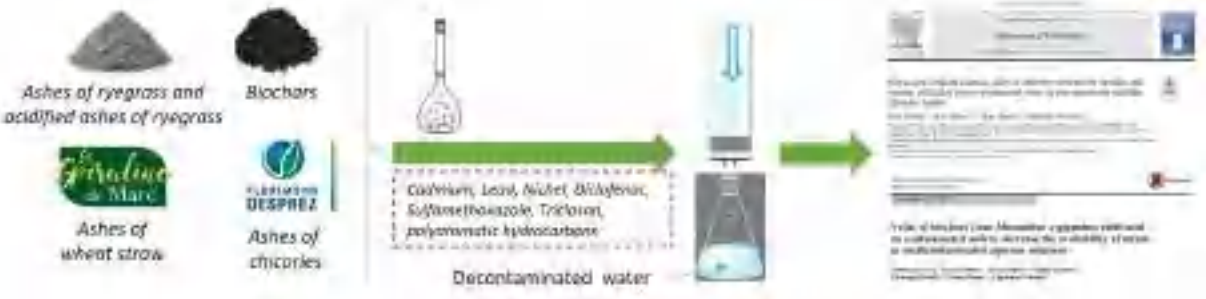
Valorisation of degraded soils that are not suitable for food and feed production is essential to maintain agricultural and economical activities of farmers. In some cases, non-food biomass is produced on degraded and contaminated agricultural soils and new applications are being developed using biosourced by-produtcs instead of petroleum-based products. In this context, producing non-food biomass on degraded and contaminated soils by metallic trace elements makes a lot of sense particularly if the transformation of the biomass results in products of significant economic value. In this way, ryegrass (Lolium Perenne L.) and miscanthus (Miscanthus × giganteus) have been produced in France and Belgium on contaminated agricultural soils and mining sites. The first objective was to manage these contaminated soils and the second one was to explore the potential conversion of this biomass into biosourced catalysts. Regardless of the trace element, they can be used alone or combined in organic chemistry to produce molecules of interest (pharmaceuticals, cosmetics….). With this objective, regional, national and international projects are still ongoing. The concentration of metallic trace elements in biomass was determined and then transformed into homogeneous and heterogeneous biosourced-catalysts after a few steps (ashing, extraction, condensation, filtration, purification) and used in organic synthesis to produce pharmaceuticals and cosmetics (idrocilamide, moclobémide, urolithin derivatives, piroxicam, meloxicam…)



Production scheme of biosourced catalysts and application

Slightly contaminated biomass as potential sorbents of pollutants in water

The choice and the production approach of non-food biomasses on contaminated agricultural soils depend on their valorisation. Thus, one of the historical choices fell on micanthus giganteus, a perennial grass and a sterile hybrid of Miscanthus sinensis and Miscanthus sacchariflorus due to its its ability to grow on marginal land, its tolerance to metallic trace elements, water efficiency, non-invasiveness, low fertilizer needs, significant carbon sequestration and high yield, and high nutrient efficiency. Its physical and chemical properties to produce bioenergy and biochars have garnered significant interest among researchers. Despite high concentration levels of metallic trace elements near the former smelter Metaleurop Nord, Miscanthis has demonstrated to be a suitable candidate for the production of bioenergy and biochar due to its ability to exclude trace elements. We demonstrated the efficiency of biochars in the adsorption of metallic trace elements (Cd, Pb and Zn) and polycyclic hydrocarbons in water. However, we unsuccessfully attempted to use the ashes of miscanthus as potential adsorbents. In contrast, ryegrass ash waste from the production of biosourced catalysts (previous section) has been shown to be effective in retaining organic pollutants (anti-inflammatory drug (diclofenac), an antibiotic (sulfamethoxazole) and an endocrine disruptor (triclosan)). Based on these results, ash wastes from wheat and chicories were evaluated. Results showed that both supports were effective in retaining metallic pollutants, chicory being the best support, better than activated charcoal.



Biomass as raw material for the purification of contaminated water

Production of non-food crops to be used as biofuel source in a contaminated area

The contaminated area of "Metaleurop Nord" in Noyelles-Godault, France covers 120 km2 affected by past metallurgical activities of a lead and zinc smelter. The research being conducted aims at studying the ability to grow non-food crops on those lands for biofuel production. The crops chosen, Miscanthus x giganteus, hemp, switchgrass, and sorghum, are known for their high biomass production. They are being tested to determine their ability to extract trace elements from the soil while also producing a sufficient amount of biomass to be used as a biofuel source. A sampling campaign was conducted to investigate the climate and soil conditions of the area and a 12-week pot experiment was carried out to study the effect of mycorrhizae fungi, protein hydrolysate, and humic/fulvic acids on Cd, Pb, and Zn phytoextraction and plant growth. While these initial steps have shown promising results, the next crucial phase is to conduct a field trial. In this field trial, the crops are planted at a larger scale and exposed to the uncontrolled environmental conditions. The goal of the field trial will be not only to understand the phytomanagement potential of the chosen plants and soil treatments but also to estimate the biomass yield, in order to valorise the biomass for biofuel production. This way, sustainable solutions for the clean-up of the contaminated soil will be found and the transition towards a greener energy source will be initiated. Results from the field trials are still pending.

Field trial of growing biomass for use as biofuel on contaminated area : Miscanthus x giganteus, hemp, switchgrass, and sorghum before harvesting, after 5 growth months (October 2022°

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Quantum technologies

Nanodevices for quantum technologies

Quantum algorithms

Quantum technologies" are based on the manipulation of the quantum states of systems to realize devices with capabilities unattainable with classical devices.

These quantum technologies are still in their infancy. They concern three sectors: sensors, computing, and communications. They offer the prospect of a new generation of disruptive applications that will give those who master them a definite advantage in the economic, financial, and military.

The design and development of devices using quantum systems faces many obstacles. Indeed, the complex and evanescent nature of quantum properties makes the development of technologies using them particularly difficult. In the same way, for the algorithmic on quantum computers, the change of paradigm obliges to discover new modes of calculation, of use of computers.

The objective of this theme is to contribute to the progress in the field

1) by developing elements used in devices for communications, sensors, and computers

2) by evolving and building algorithms usable by quantum computers with respect to the various physical implementations.

The topic "Nanodevices for quantum technologies" is concerned with the development of all nanosized devices that can be considered as individual quantum systems that can be used in the development of quantum technologies. The topic "Quantum Algorithms" deals with the exploitation of quantum properties to build "programs" capable of solving certain problems whose complexity is such that they cannot be solved by a classical computer. The latter activity started very recently.

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11.1 Nanodevices for quantum technologies

The complex and evanescent nature of quantum properties makes the development of technologies using quantum nanodevices particularly challenging. The control and the manipulation of these properties, which are extremely sensitive to external perturbations and very easily self-destructing, are fundamental for quantum technologies.

In the light of this, investigations of the electronic and optical properties down to the individual nanostructures or nanodevices scale are mandatory to allow correlation between the structure (size, shape, surface) and the quantum properties (density of states, coherence of the emission, entanglement degree..). This will allow developping theoretical models and rationalizing growth-by-design protocols of quantum devices.

The widespread of quantum devices for quantum light sources, photodetectors or sensors further require the development of mass production compatible growth protocols, thereby including low-cost and scaling up aspects. We are particularly interested in quantum devices allowing the emission /detection of single photons or pair of polarization-entangled photons for applications in quantum communications and quantum sensing.

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Van Hove Singularities and Trap States in Two-Dimensional CdSe Nanoplatelets

The holistic understanding of the fundamental electronic properties of nanomaterials is a prerequiste to any development or rationalization of new nanomaterials. Furthermore, establishing the correlations existing between the nanostructuration or the local environement and the quantum properties of nanomaterials is mandatory to develop theoretical models and growth-by-design protocols.

Because of their high brightness at room temperature, low fabrication cost and versatility, wet-chemistry-grown semiconducting nanoparticles (CdSe), often referred to as nanoplatelets (NPL), are appealing for a broad range of applications, such as photo-detection, lighting and lasing, single photon emission, quantum sensing. The quantum confinement in NPL is controlled at the atomic layer scale and the in-plane dimensions can be fine-tuned by controlling the growth reaction parameters.

Here, by scanning tunneling microscopy (STM), we unveiled the electronic properties of individual NPL (shape,size, orientation) in correlation with their environement (temperature, pressure,…). In condensed matter physics, a stepwise reduction of the dimensionality, i.e. the degree of freedom of the motion of electrons, from bulk to the nanoscale is known to lead to striking electronic and optical properties.

The observation of Van Hove singularities in the conduction band implies a paradigm shift on the electronic structure of typical CdSe NPLs considered in the literature. As the electron density of states exhibits a striking modulation that is directly related to the length of the NPLs, delineating the in-plane electron motion at low temperature has important consequences for a deeper understanding of the exciton dissociation, diffusive transport, and annihilation in NPLs.

Van Hove singularities and trap states in two-dimensional CdSe nanoplatelets

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Nemanja Peric, Yannick Lambert, Shalini Singh, Ali Hossain Khan, Nathali Alexandra Franchina Vergel, et al.. Van Hove singularities and trap states in two-dimensional CdSe nanoplatelets. Nano Letters, 2021, 21 (4), pp.1702-1708

11.2 Quantum algorithms

For many current challenges of our society and environment, we are faced with operations research and optimization problems whose size has become too large to be properly apprehended by classical machines, including supercomputers. It is necessary to have higher computing power and quantum computers are seen as the best candidates to answer a large part of these issues, provided that the algorithms are efficient on such computers. Computers using the properties of matter, in particular entanglement and state superposition, execute instructions of their own, and this is the object of quantum algorithmics. Among the many issues in this field, our work focuses on:

- Accelerate calculations to solve today's problems. While some calculations take thousands of years on a classical computer, quantum computers would complete them in seconds. It is therefore a question here of concentrating on the difficult problems where the calculations are today too heavy to obtain good results.

- Be at the forefront of quantum algorithms. Study quantum algorithms (software) alongside the evolution of quantum computers (hardware) to be ready when they outperform classical machines on a broad set of problems. The implementation of these algorithms on today's quantum machines should not cause serious difficulties in adapting to future machines. Thus, even if there are still many technological barriers for the hardware components, the research on quantum algorithms will allow faster adoption in the future.

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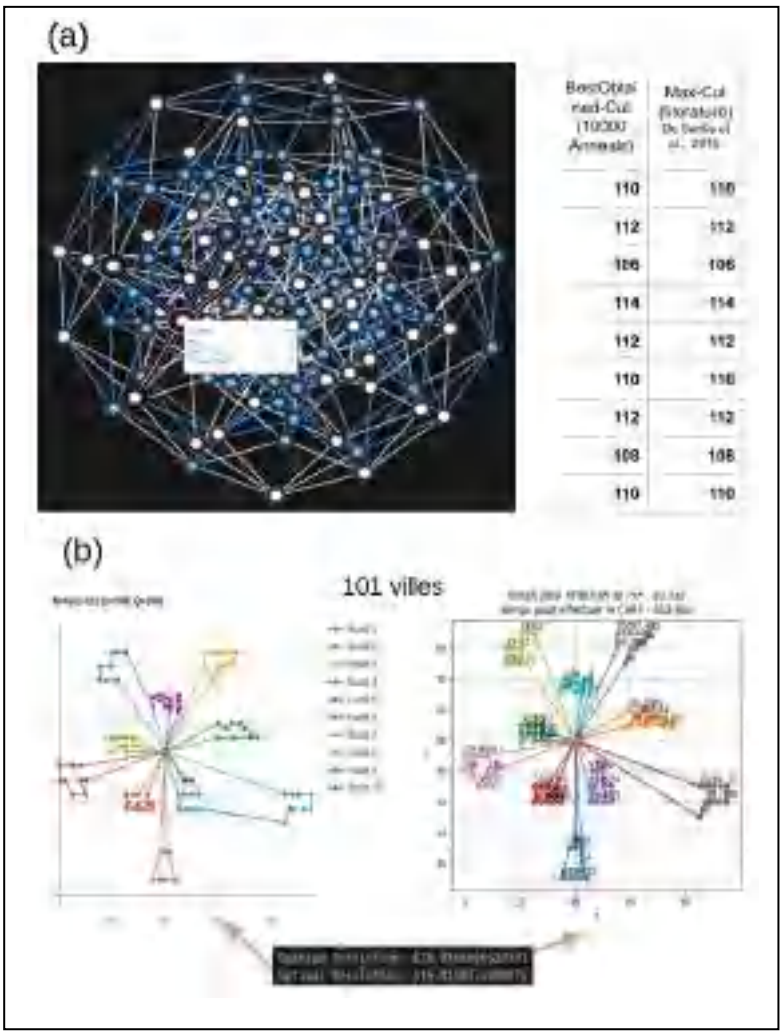
Combinatorial optimization with quantum annealing machines

Quantum annealing is a method based on simulated annealing where temperature variations are replaced by quantum fluctuations that cause qubit state transitions. ISING problems and Quadratic Unconstrained Binary Optimization problems (QUBO) can be tackled by quantum annealing-based machines. The interconnected qubits of the machine may be connected to the binaries of our model: qubits are binary variables and each pair of them linked by a coupler has a strong impact on the equality or the non-equality of the two binaries of the associated pair.

Quantum annealing is based on the fact that any system tends to seek its minimum energy state. Starting from qubits in a state of superposition where all the solutions to the problem are fairly represented, the machine will apply a magnetic field by targeting the qubits and couplers in such a way as to make their value energetically favorable in the direction of optimization (minimization). For the coupled qubits the quadratic products of the binary variables are considered here and the physical system will make it energetically favorable for them to take (or not) the same values. In order to solve optimization problems with constraints on quantum annealing based machines, these constraints must be relaxed thus penalizing the objective function.



The unconstrained Max-Cut problem (figure a) and the Capacited Vehicles Routing constrained Problem (figure b) have been both adressed by reformulating the classical models to fit for the D-Wave system. Initial results on instances from the literature are very encouraging: while we found optimal solutions solving the former problem, we obtained good solutions with the latter (with a gap < 1% from the best known solution).

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ANNEX

Annex 1. Societal impact assessment of research activity

An indicator of the societal impact of the research activity has been set up in order to express its effective and measurable contribution to society as a whole. This indicator is based on the Sustainable Development Goals (SDGs) defined by the UN as a benchmark for evaluation.

The SDGs were validated in 2015 by all UN member countries and are targets for 2030. Positioning research activities in relation to this reference framework makes it possible to ask new questions promoting the enhancement of research activities (projects, themes, valorization towards training), to show the contributions to the 4 transitions structuring JUNIA's strategy, and to inspire research activities towards new avenues of valorization. An original methodology in 4 steps has been developed, inspired by the THE Impact Ranking and the DD&RS reference system of the Conférence de Grandes Ecole and France Universités:

Step 1: Declaration, the theme is consistent with the SDG sub-goal.

Step 2: Evidence 2.a. The evidence shows that the theme contributes effectively and innovatively to the SDG sub-goal, through scientific publications, patents, licenses, demonstrators or prototypes,... 2.b. The evidence shows a secondary, potential and general contribution to the SDG sub-goal. C. The evidence does not show a significant contribution to the SDG sub-goal.

Step 3: the evidence is public, the results and innovations of the theme are accessible, appropriable and have concrete benefits for society (therefore a wide audience) through popularization actions (conferences, publications, general public media, social networks, etc.), training, dissemination of technical or software applications or services or new economic models (circular economies)...

Step 4: A committee of experts on the SDGs and Sustainable Development in general challenges and validates these contributions to the SDGs. Each of the themes of the JUNIA research roadmap will be progressively evaluated.

The first Societal Impact of Research Committee met and evaluated the contributions of 3 research themes to one or more SDG sub-goals, according to the following distribution:

- Agriculture: agroecology and resilience

Contribution to SDG 2.4 "Efficient and resilient agriculture" 100% validated

- Responsible chemistry

Contribution to SDG 12.4 "Environmentally sound management of chemicals" 100% validated

Contribution to SDG 12.5 "Waste reduction" 80% validated

- Degraded soil management and valorization

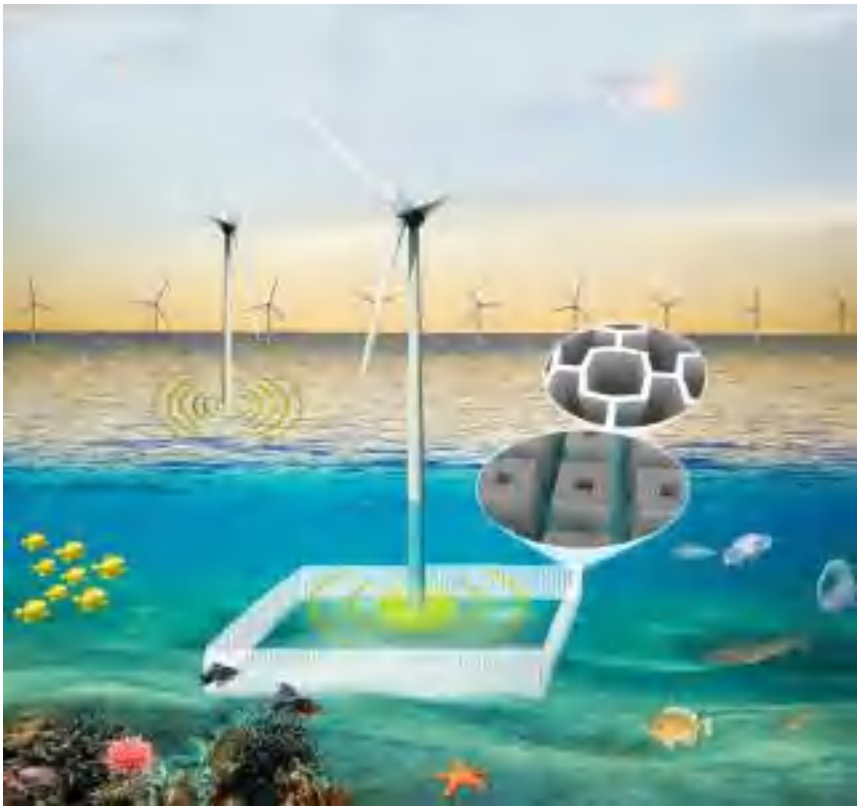
Contribution to SDG 3.9 "Health-Environment" 100% validated

Contribution to SDG 12.5 "Waste reduction" 80% validated

Contribution to SDG 15.3 "Land Degradation" 100% validated

The Societal Impact of the other themes will be gradually analyzed in 2023 and 2024.

POSEIDON : Unconventional principles for underwater wave control in the sub-wavelength regime / ERC Starting Grant



The growing interest in marine renewable energy and human activities related to the oceans are the main causes of a **an alarming increase in the noise level in the oceans and seas**. However, the performance of underwater noise mitigation systems has long been (and still is) limited by the fact that dissipation is inherently low at the sub-wavelength scale. Therefore, an effective solution to attenuate underwater waves in the low and broadband frequency ranges does not yet exist. POSEIDON aims to close this scientific and technological gap **developing a new class of metamaterials with unprecedented wave reflectivity and absorption over broad sub-wavelength frequency ranges**.

"The project will explore the intimate relationship between the microstructure and macroscopic vibrational properties of a multiscale metamaterial immersed in a heavy fluid, on the assumption that nature would offer already optimised solutions that we should be able to learn from" (Marco).

Smart electricity grids play a crucial role in the current **energy transition**, enabling **better integration of the renewable sources of energy** into the grid and a **more efficient use of energy** altogether.

The EU-funded project ebalance-plus will **develop smart-grid solutions to increase the energy flexibility and the electric grid observability**, providing new services for distribution grid operators, transmission system operators, aggregators, energy retailers, DER managers, building facility managers, prosumers, and consumers, empowering them with more functionalities to interact with the grid and manage the energy flows.

Aims of the project

The **aim** of the project is to **increase the use of flexibility** and **resilience** of energy networks, by means of an **energy balancing platform,** which will integrate smart production, storage and consumption technologies.

This energy balancing platform is based on a **fractal-like hierarchical architecture** that replicates the existing grid topology with a bidirectional communication framework, assuring the scalability of the solutions.

https://www.youtube.com/watch?v=0FAWoez5sqs

https://www.ebalanceplus.eu/

PPILOW : Poultry and Pig Low-input and Organic production systems' Welfare / H2020

The PPILOW project aims to co-construct through a multi-actor approach solutions to improve the welfare of poultry and pigs reared in organic and low-input outdoor production systems.

The project will target nonconventional and outdoor rearing systems with reduced (notably drug) inputs and organic systems (as defined by EU, so considering defined rearing conditions, organic and local feed use and preventative approaches to health management with limited use of chemical inputs).

Although these high-quality systems enable a high degree of expression of **natural behaviour** by the animals, there are still several welfare issues in organic and low-input outdoor systems that can be similar to conventional systems (e.g. beak trimming in laying hens, the killing of one-day old layer male chicks, and male piglet castration) or more specific to these systems (e.g. exposure to outdoor sanitary threats, piglet survival).

https://www.ppilow.eu/

GOLD : Growing energy crops on contaminated land for biofuels and soil remediation / H2020

Soil pollution is a global problem making vast areas of agricultural land unexploitable

In Europe it is estimated that 2.5 millions sites are potentially contaminated 650.000 hectares of land cannot be cultivated because of excessive concentrations of organic or inorganic pollutants.

Approach :

Grow energy crops on contaminated land

Optimization of high-yielding lignocellulosic crops for phytoremediation

Pilot field trials on polluted sites in EU, China and India

Optimization of phytoremediation for organic and inorganic soil pollutants

Produce low ILUC risk biofuels

Biomass pre-treatment, gasification and fermentation

Biomass pyrolysis and upgrading to refinery-compatible intermediates and fuels

Extraction of pollutants in concentrated forms

Optimize the value chain

Integrated environmental, economic, social assessment

Modelling of the selected value chains

Design of effective replication strategies

https://www.gold-h2020.eu

Common Challenge

According to data collected from 14 European centres in the *Surveillance of Cerebral Palsy common database* (*Cans 2000*), 30% of children with Cerebral Palsy is not able to walk at 5 years of age and 16% of the CP children need assistive devices to walk, while 54% can walk without aids (*Beckhung et al. 2008*). This means that 46% of the CP children might benefit from innovative technology like lower limb exoskeletons to promote walking. CP occurs at different prevalence rates, according to statistics, from 1.4 to 3.0 per 1000 live births (Johnson 2002). Within the 2 Seas region there are between 1.970 - 3.940 CP children younger than 10 years (32.643 – 65.285 CP children in Europe) that might be addressed by assistive technology developed in MOTION.

Overall objective

MOTION addresses two challenges :

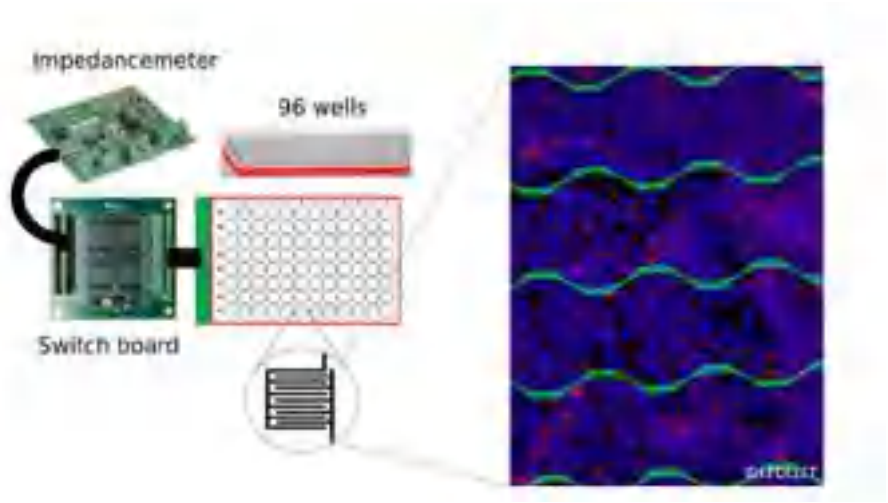
Improve the quality of life of children with neurological disorders through advancements in development, validation and adoption of bionic rehabilitation technology.

Facilitate knowledge and technology transfer from research to industry, healthcare professionals, end users and policy makers by setting up a transregional network

https://www.linkedin.com/posts/motion-interreg_motion-closure-conference-activity-7022190681813065728-MODo/?utm_source=share&utm_medium=member_desktop)%20

https://www.motion-interreg.eu/

H4DC : Health 4 Dairy Cows / Interreg 2Seas



Cryptosporidium is a major cause of waterborne disease outbreaks worldwide. The protozoan parasite is the aetiological agent of a disease called Cryptosporidiosis that affects animals and humans. In cattle farms, this common disease causes stunted growth, high mortality and increases the weakness of these animals which further threatens the economic viability of a sector which already faces frequent crises. In humans, this pathogenic agent is considered the second cause of fatal severe diarrhoea in children under 2 years old in Africa and Asia. In Europe, Cryptosporidiosis outbreaks are frequent, an outbreak which occurred in 2013 in Ireland had an estimated economic impact of 19 million.

Contaminated calves can excrete millions to billions of parasites per day, they are often considered as a source of contamination and consequently po se a threat to human health. Fighting Cryptosporidium excretion in farms will not only lead to reduced economic impact in calf production but also reduced risk to human health as stated by the One Health approach.

H4DC is an European project which consists in working on this disease by reducing the impact of cryptosporidiosis in farms. Indeed, the project aims to increase farm productivity in a number of different countries, making these businesses more efficient and successful, with a lower impact on human health. For this purpose, this project aims to provide pilot farms, detection tools and technological devices that can accelerate the discovery of new drugs at the lowest possible cost.

https://h4dc-interreg2seas.eu/

RIVER : Non-Carbon River Boat Powered by Combustion Engines/ Interreg NEW

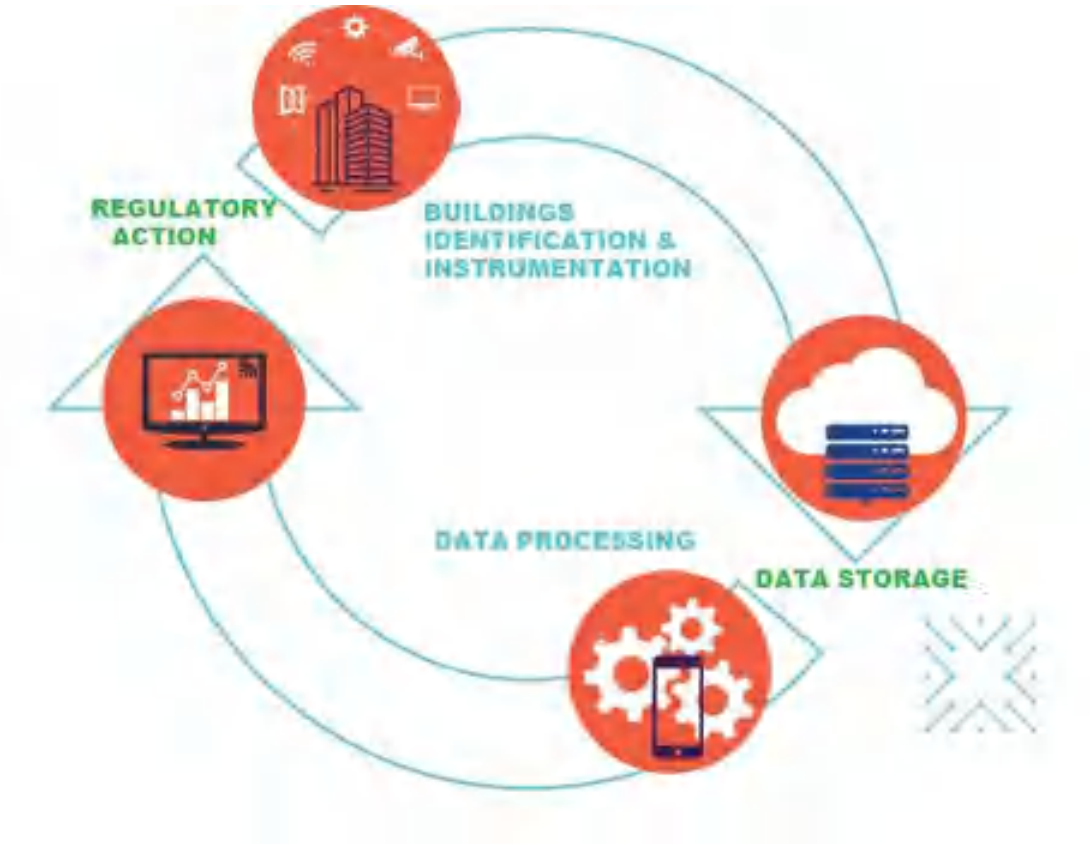
The EU recently adopted rules requiring limits to carbon emissions and type-approval of internal combustion engines for Non-Road Mobile Machinery (Directive 97/68/EC, 01/2017).

This set more stringent limits for emissions from inland waterway (IW) vessels. There is an urgent need for emission reduction due to stronger environmental standards aims. Replacing NWE's ageing fleet with RIVER technology offers the potential for emission reduction. The objective of RIVER is to reduce or eliminate the pollutants from the polluting engines. It is expected that 6600 engines on existing vessels will need to be replaced in 2018-50 and 2400 new vessels will come into operation.

RIVER aims to address these issues and to apply an Oxy-fuel combustion technology for Diesel engines that eliminates NOx (part of the GHG), and to capture, store all CO2 emissions and reduces fuel consumption by up to 15%. The project includes 9 partners from 5 MS and 5 associated.

https://www.youtube.com/watch?v=vJ0cn-aP460

https://www.nweurope.eu/projects/project-search/river-non-carbon-river-boat-powered-by-combustion-engines/



The project aims to explore the potential for intelligent buildings as Smart Nodes within intelligent energy networks or Smart Grids at the heart of Catholic University of Lille. The vocation of the SBnodesSG chair is to ameliorate user comfort and energy efficiencies by incorporating connected objects and big data in the intelligent management of buildings and energy networks.

Within the SBnodesSG chair, buildings will become intelligent and as such, ever active participants in the energy eco-system beyond simple service to the smart grid. In fact, they self-optimise both individually and collectively through real-time interaction.

Chaire SBnodesSG

Ma-Per-En Energy Performance Management driving a new governance / Life Programme EU commission

Project objectives:

The building sector is highly responsible for GHG emissions. In order to reduce energy consumptions and GHG emissions, various actions are implemented which significantly rely on technology: thermal renovation, development of Res, energy storage…

The impact of the behaviour of the users of the buildings is poorly investigated and generally underestimated. Yet, the technological solutions deployed do not provide the expected effects, either because of technical contingencies or because they are not adapted or not really appropriate. The impact of those solutions is impaired by an increase in the demand in energy and new consumption habits (rebound effect).

Ma Per-En

Annex 3. Publicly funded research projects

FUNDERS	PROJECTS ACRONYMS
ADEME	DEESSE - SO MEL SO CONNECTED – BasR – MisChar – DYSPAT – POTAGERS - Bioac'ERS - ODESSA Normalisation – MISTIIC – TRANSPAU – MISTIGATION – Bioaccessibilité / thèse de BILLMAN Madeleine - PlantEval2.0
Agence de l'Eau	OAD Azote - RES'EAU - Reliquat N (CAD) - AFRAME – RECHARGE - DRIPPERF
ANR	LEOPAR – exoAGEing – Staccato – JEDAI – Tropical – RAMSES – FORMOSA – MEANDRE - DIRAC III-V – CERES – MASCOFIL – EFFICACE – HANIBAL – STACCATO – SAFIRS – CYTOMEMS – POCOMA – NANODYN – HETEROCLIPS – COSMAC - ANR CHU ENGINEERING LILLE
CASDAR	CASDAR Epointage
ERDF	CPER ALIBIOTECH – HCS PHARMA – Nyrio Isite – CHASIMODO – FEDER CUTI- Catalyseurs biosourcés – FEDER MINAKEM – GENES DIFFUSION – INDI – ALLINPEP-
FAEDER	HOUBLON - PAYSAG'EA
H2020	EBALANCE+ - PPILOW- GOLD - SHIFT
Interreg	Bio4safe – EDUCAT – MOTION- RIVER – H4DC – PHOTONITEX – TEXACOV – REGENERATIS – NEW CLAND- SMART AQUAPONICS - BIOPROTECT- TOTEM – BIOSCREEN -
MEL	ANTROPOLAB – SBNodesSG-
Région Hauts de France	StorAir – BIFUN- BioMEMS -VENTURIA – MINIPEST - PHYTOIL – HYBRI DC- Thèse Niloufar Khomarloo – ALLIANANO – SARS FIGHT -SAFE – SAFARRI – ECOBRIQUE – EE 4.0 – Ferm'Endive – BiHauts Eco de France – Ritmea – VIAMEA – SMARTGRAZE – OSETTA

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