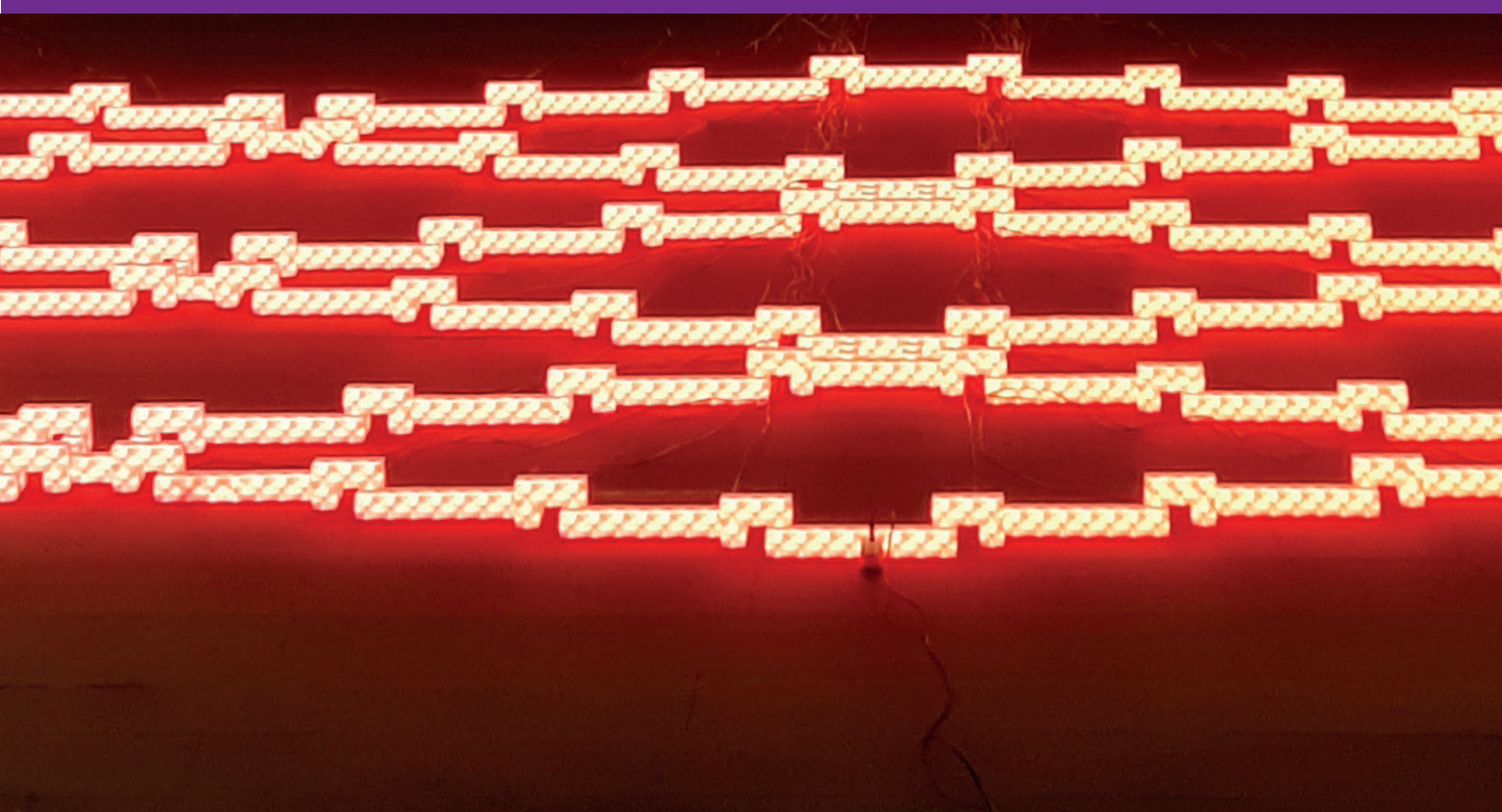
femto-st
SCIENCES &
TECHNOLOGIES

# 2021
# Annual report



# FOREWORD

Exploring Science and Innovation, from basic research to industries and spin-offs, from theory to experiments through high technology facilities, developing micro and nanotechnologies, increasing the density of functions and integrating intelligence for the engineering of components and systems with optimized performances, contributing to the future of a knowledge-based improved society.

The year 2021 was still deeply perturbed by the Covid pandemic started end of 2019 beginning of 2020. Worldwide actions, and particularly the efforts of many scientists worldwide, fortunately allowed for a large availability of different vaccines, with successful impacts in terms of a slow but safe recovery of quasi-normal life during 2021. In-person conferences restarted, with the pleasure and better efficiency of meeting and discussing with colleagues, a key ingredient for the progress of global science and knowledge. The Covid-19 crisis, together with the dramatically increasing critical effects of climate change, will however definitely change the way scientists will work and interact in the future. This framework should accelerate also the role of Science in the Society, and its even more intricated operation with social challenges. It has revealed more and more the importance and the related responsability of public research in the nowadays worldwide networked society. As you should discover in this annual report, FEMTO-ST institute has tried to strongly deepen its role in the Society. Our research directions is more and more intricated with social challenges (health, climate change, renewable energy, pollution detection, social impact of technologies), keeping also a maintained activity in upstream research which place is intrinsically indispensable next to the downstream one: research constitutes a continuum in time over short time scales, as well as over much longer ones.

The FEMTO-ST institute is the largest public research laboratory in the Bourgogne-Franche-Comté region, located in eastern France, next to Switzerland and Germany. It comprises 7 scientific departments with approxomately 750 staff members (PhD students, postdoctoral fellows, technicians, engineers, administrative staff, researchers and professors).

FEMTO-ST members are essentially employed by five different French public research organisation and higher education and research (HER) institutions: The National Centre for Scientific Research (CNRS) and the University Bourgogne-Franche-Comté (UBFC), the latter federal and regional HER entity being composed of seven HERa mong which three (the University of Franche-Comté, the National Engineering Institute of Mechanics and Microtechnology and the University of Technology Belfort-Montbéliard) have staff deploying their research activities at FEMTO-ST.

I wish you to enjoy reading this 2021 Annual Report, whether keeping up to date with our latest results and achievements, or discovering the wide range of our activities. You are welcome to join us in building fruitful future collaborative projects from fundamental research to industrial and social breakthroughs.

Laurent Larger
Head of FEMTO-ST Institute

Cover

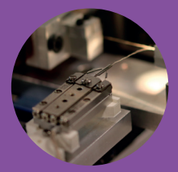
Blinky Blocks / Programmable Matter
Larger autonomous Blocks Structure
GuInness World Record

# A BROAD RANGE OF MASTERED SCIENTIFIC EXPERTISE

FEMTO-ST INSTITUTE constists of 7 research departments and two transverse axes RECITS and BIOM'@X, which make collaborative efforts to organise multidisciplinary research activities. We also encourage multidisciplinary research activities in collaboration between departments.

### APPLIED MECHANICS

- Materials, surfaces, processes, structures
- Micromechanics, microfabrication
- Fonctionalisation, smart structures
- Sustainability, reliability, bio-compatibility



### ROBOTICS & AUTOMATION (AS2M)

- Microrobotics, mechatronics
- Automation
- Prognostic & Health Management (PHM)

### TIME & FREQUENCY (TF)

- Oscillators/ resonators
- Time & Frequency metrology
- Microwave systems and sensors

### COMPUTER SCIENCE (DISC)

- Parallel and distributed computing
- Formal methods for software engineering
- High performance computing
- Distributed smart microsystemsrs

### ENERGY

- Hydrogen-energy
- Electromagnetic converters
- Thermal machines
- Metrology and energy management

### OPTICS

- Nonlinear photonics
- Complex optoelectronic systems
- Nano-photonics

### MICRO-NANOSCIENCES & SYSTEMS (MN2S)

- Parallel and distributed computing
- Formal methods for software engineering
- High performance computing
- Distributed smart microsystems
- Thermal machines
- Metrology and energy management

### RECITS

- Research and Study on Industrial, Technological and Societal evolutions

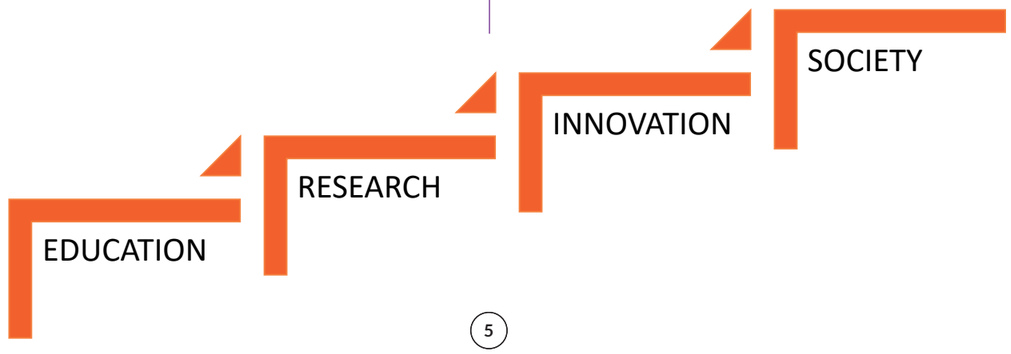
### BIOM'@X

- Towards a technological translational medicine



# CONTENTS





# FEMTO-ST

## IN FIGURE

760

MEMBERS

INCLUDING
- 225 Professors & Associate Professors
- 35 CNRS Researchers
- 252 PhD Students
- 41 Postdocs
- 82 Engineers/technicians

MORE THAN

100

WORLD WIDE INSTITUTIONAL ACADEMIC PARTNERS

7 RESEARCH DEPARTMENTS

12 START-UP IN 11 YEARS

463

SCIENTIFIC ARTICLES IN 2021

1 INNOVATION TRANSFER UNIT (FEMTO ENGINEERING)

1 MICRO-NANO TECHNOLOGY CENTRE (MIMENTO)

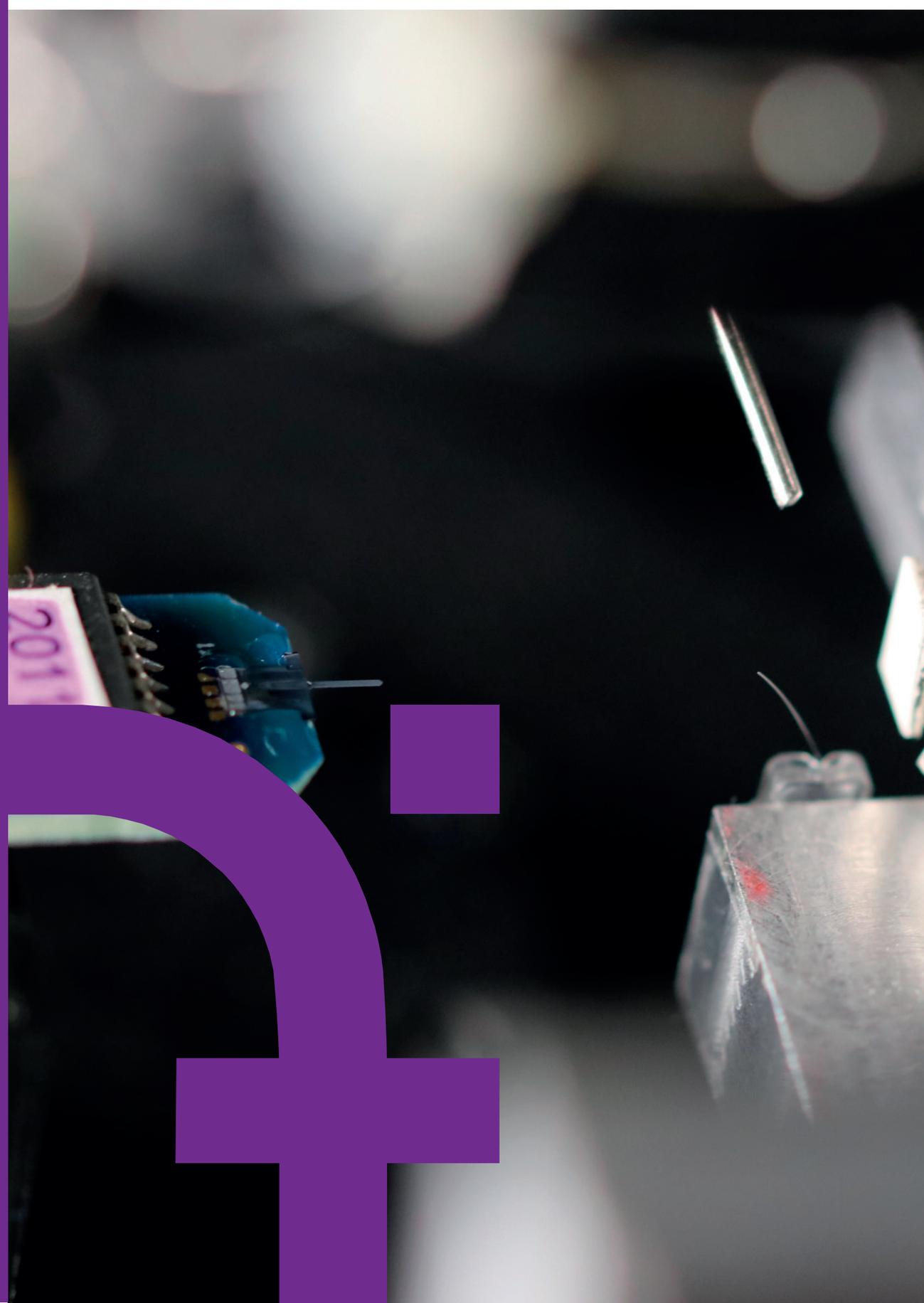
10 RESEARCH FACILITIES / INFRASTRUCTURES

37 M€

ANNUAL BUDGET

153

RESEARCH CONTRACTS IN 2021



# EDUCATION

## MASTER/PHD
## IN 5 RESEARCH AREAS

- PHYSICS, MATHEMATICS and APPLICATIONS
- ENERGY
- COMPUTER SCIENCE
- SMART SYSTEMS & STRUCTURES
- MATERIAL SCIENCE

# EIPHI

## ENGINEERING AND INNOVATION THROUGH PHYSICAL SCIENCES, HIGH-TECHNOLOGIES, AND CROSSDISCIPLINARY RESEARCH

Global Education-Research-Innovation strategy of EIPHI Graduate School has been boosted in 2021 by two key facts witnessing the role model of EIPHI for the international attractiveness and the fostering of the interdisciplinary research-training link of the Bourgogne-Franche-Comté (BFC) academic landscape. On the one hand the integration of 4 supplementary research institutes (ICMUB (molecular chemistry), ImViA (imaging, vision & robotics), UTINAM (physics, astrophysics & chemistry), LmB (mathematics) – 260 research staff) sustaining 5 additional international Master tracks, thus gathering within EIPHI 85% of the BFC permanent academic staff of the priority area "Advanced materials, waves & smart systems". On the other hand the launch of UBFC-InteGrate, a further PIA3 SFRI project gathering EIPHI with 2 new GS dedicated to the other UBFC priority areas (Environment & food; Medical care), thus building a unified Graduate Institute strongly structuring the regional academic space.

### KEY FACTS AND FIGURES IN 2021 ILLUSTRATING THE DYNAMICS OF EIPHI:

#### Research and research-training link

- In the frame of common annual call of EIPHI and BFC Regional Council for research projects (CFP), 22 new and most of the time multidisciplinary and collaborative projects (3.75 M€ total funding, including 14 PhD grants, 30 master internships and 14 postdoctoral positions) have been financed. The 17 projects involving funding for FEMTO-ST (2.1 M€, 9 PhDs, 4 postdocs) are dedicated to innovative processes and alloys for metallurgy, frictional properties of nanostructured films, microfluidic robotic actuators and nano-characterization tools for sorting and analysis of biological entities, soft robots actuated by electro-active polymers, artificial intelligence tools for protein nano-sequencing and for 3D SEM metrology, advanced prognostics & accelerated stress tests for resilience of fuel cells, phononic metamaterials for microthermal control, graphene integration on RF components, high-Q whispering-gallery mode resonators for 2-µm frequency combs, microfiber-based Brillouin laser sources, ultimate laser stabilization for time-frequency metrology…

- In 2021, 256 WoS-referenced publications have acknowledged EIPHI, of which 167 from FEMTO-ST including 2 highly cited papers and breakthrough results published in high impact factor journals (Adv. Mater., Sci. Robot., Nano Lett., Nat. Commun., Nat. Mach. Intell., Nat. Plants, Light-Sci. Appl., J. Power Sources…), e.g.: a critical review on hydrogen energy systems, nanorobotics structures with embedded actuation, recurrent neural network for prediction of optical fibre nonlinear dynamics, roton-like acoustical dispersion in 3D metamaterials, polarization conversion by a plasmonic helical nanoantenna, textile history and fiber durability from a 4000-year-old Egyptian flax yarn…

EIPHI-BFC
GRADUATE SCHOOL
CROSS DISCIPLINARY SCIENCE AND TECHNOLOGY

### EIPHI graduate school

University Bourgogne Franche-Comté - France
- 5 outstanding Research Areas
- Worldclass Research labs
- Close connection with industry
- Broad mobility opportunities
- Tutoring and mentoring
- Scholarships

Coordinated by:
Hervé Maillotte (FEMTO-ST) - Stéphane Guerin (ICB)

**frederic.peneau@ubfc.fr**
http://gradschool.eiphi.ubfc.fr/

#### Training and innovative pedagogy

As for 2020-21, EIPHI has hosted 261 master students (143 students in master programs related to FEMTO-ST), including 34 double-diploma with partner institutions, and 292 PhD students including 187 at FEMTO-ST(with 10% of international dual degree theses), with an overall selectivity around 20%. As a marker of the outreach quality of EIPHI training program, 70% of the internships are currently made outside our institutes (40% academic, 40% industrial, and 20% abroad – both academic & industry). Two important achievements have been made in 2021:

- The creation of an UBFC alumni platform for EIPHI members including industrial partners, recruiters and academics, to increase the students networking possibilities, career opportunities and their sense of belonging.

- The development of a dedicated open badges system credibly recognizing on an international standardized basis all extra-scientific skills and achievements earned during student curriculum.

As examples of such skill development incentivized by EIPHI, pedagogical demonstrators have been setup and presented by Master & PhD students at the most important French Optics Conference held in July 2021 in Dijon (with Nobel Prize G. Mourou). EIPHI is also organizing an annual contest for awarding the best presentations of the 1st year PhD students. Also, a larger scale initiative "French+Science" for foreign bachelors (1-month stay for learning French and getting a generalized overview of the scientific & training domains of EIPHI), co-organized with the "Centre de Linguistique Appliquée de Besançon" and Campus France) has involved 5 1st year PhD students at FEMTO-ST in the preparation and delivery of a popularization course with hands-on and lab visits to present their own research domain.

FEMTO-ST Ambassadors 2021" - winners of the 1st year PhD student poster competition

#### International activities

Globally 57% of the EIPHI Master and PhD students came in 2020-21 from 49 foreign countries (mostly Middle East, South Asia, Far East, Maghreb, Sub-Saharan Africa, Latin America, Europe). Joint programs between UFC/FEMTO-ST have been finalized with 2 universities in Indonesia (U. ITS & U. Indonesia) and North Macedonia (South East European University (SEEU)) in addition to about 20 cooperation programs activities of UBFC (ULB Brussels, EPFL Lausanne, ITMO Saint-Petersburg, CIO Mexico, DLUT China, …).

12 novel dual degree thesis with renowned foreign partners were started in autumn 2021 (4 for FEMTO-ST: U. Sherbrooke, U. Québec Trois-Rivières (CAN), U. Valparaiso (Chile)). EIPHI supports financially event organization, invitations of foreign researchers/professors within EIPHI laboratories, and international incoming/outgoing doctoral mobilities. Despite the pandemic, these CFPs led in 2021 to 93 incoming/outgoing international mobilities of master students and 8 PhD mobilities (1 to 6 months) to/from Norway, Germany, Italy, Brazil, Tunisia, Kenya, Canada, 1 professor from U. Kentucky, USA was invited for 2 months, a cycle of "Webinars on Metamaterials" and 3 international summer schools (Quantum technologies, Energy micro-harvesting, Bio-based composites).

It is worth noticing that 24 EU H2020 projects were currently running in 2021 within EIPHI institutes (17 at FEMTO-ST), including 9 MSCA ITN, RISE, COFUND (5 at FEMTO-ST), of which 3 are coordinated by FEMTO-ST members. To amplify this dynamism, a novel CFP, "EU Support", has been launched in 2021 aimed at helping EIPHI colleagues who intend to coordinate an EU Horizon Europe research-training project (MSCA, Erasmus Mundus…) in its setup phase (support to meetings and travels for constituting a consortium, assistance for preparing the application).

## DEEP DIVE IN TIME AND SCIENCE !

### OPTICS

Three days, 8 students, an artist photographer (Sarah Ritter), a researcher (Luc Froehly) and some scientific objects dating from the end of the 18th century to the beginning of the 19th century...this is the cocktail that gave rise to an "entrepreneurship" project for our MASTER PICS students. During this experience, which was part of their training, our students had to demonstrate their curiosity, their observation skills, their documenting ability and their team work spirit. Thanks to them, a Silbermann heliostat (1960), a planimeter (1854), and a Mader-Ott harmonic analyser (1909) were brought back to life for a few days.

In a very concrete way, our students were able to discover that the inventiveness of our predecessors of the past centuries had conditioned our research from today. This is for example the case of the Mader-Ott harmonic analyser, which was made available to the students, and which historically allowed Pierre Michel Duffieux (at the origin of one of the departments of FEMTO-ST ! ) to introduce the Fourier transform to the international optical community and to revolutionize the mathematical treatment of coherent optics. The thorough analysis of the documentation and archives as well as the mechanical principles involved in this complex system allowed this MASTER promotion to better understand the principles of harmonic analysis, a tool that they are confronted with in a concrete way in many fields of physics today as part of their studies. An educational video was also produced as a result of this immersion in the history of science.


References

Hawkes, Peter, and Noël Bonnet. "A symposium in honour of Pierre-Michel Duffieux." Microscopy Microanalysis Microstructures 8.1 (1997): IX-XIV.

Durand-Richard, Marie-José. "Historiographie du calcul graphique." (2016).

http://www.lecompendium.com/dossier_math_06_planimetre_amsler_morin/planimetre_amsler.htm

Gazanhes, Claude. "L'analyse harmonique des procédés mécaniques aux procédés électroniques." 19° Colloque sur le traitement du signal et des images, FRA, 2003. GRETSI, Groupe d'Etudes du Traitement du Signal et des Images, 2003.



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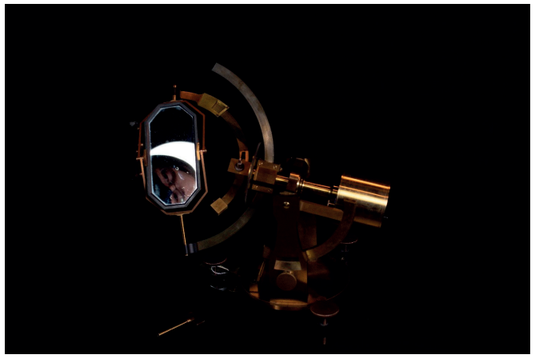
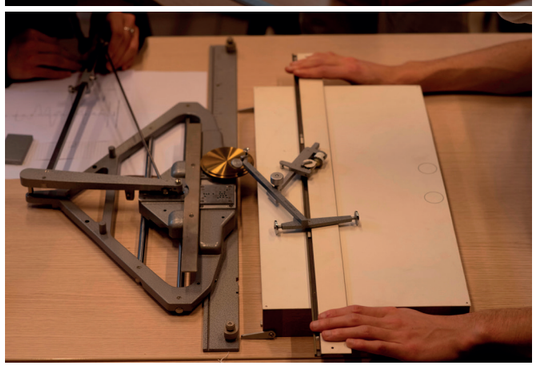






# RESEARCH TRAINING NETWORKS

## SUPUVIR: SUPERCONTINUUM BROADBAND LIGHT SOURCES COVERING UV TO IR APPLICATIONS

### OPTICS


Thibaut Sylvestre, John Dudley

ESRs : Amar Nath Ghosh, Solveig Perret, Etienne Genier


The scientific challenges addressed in the SUPUVIR European project was to overcome current shortcomings of broadband supercontinuum (SC) light sources in terms of wavelength coverage, noise, power density and robustness to offer a truly unique and groundbreaking technology for societal and industrial challenges, such as pollution, food quality monitoring, bio-imaging, molecular spectroscopy, detection and monitoring of key diseases, such as cancer and glaucoma. 15 Ph. D students were trained and involved in different work packages ranging from glass chemistry, fibre design and drawing, to the development of next generation SC light sources and their applications. Significant scientific progress was made in emerging UV and mid-IR wavelength ranges, evidenced by 65 scientific papers, and 3 SC light-based demonstrators were developed in the project. As a result, supercontinuum technology and its industrial applications have matured considerably.

The SUPUVIR project has organized several training events:

- Summer school "Supercontinuum Broadband Light Sources for UV and IR applications" (Besançon, 2017)
- Microscopy and Sensing Workshop (Cambridge, 2018)
- First Workshop on Photonic Crystal Fiber Technology for Ultrafast Optics Applications (Warsaw, 2018)
- "Entrepreneurship in Technical Science" (Helsingor, 2019)

**Partners:**

DTU Fotonik (coordinator,DK), Institut FEMTO-ST (FR), Ł-IMIF (PL), RECENDT (AT), Univ. Rennes (FR), Tampere Univ. (FI), Univ.Cambridge (UK), NKT Photonics (DK), LEUKOS Optical Systems (FR), VALMET Technologies (FI)


H2020-MSCA-ITN-2016 (Project number: 722380)

Funding for FEMTO-ST: 525 k€ (Total funding:4.4 M€)


https://www.supuvir-itn.eu/

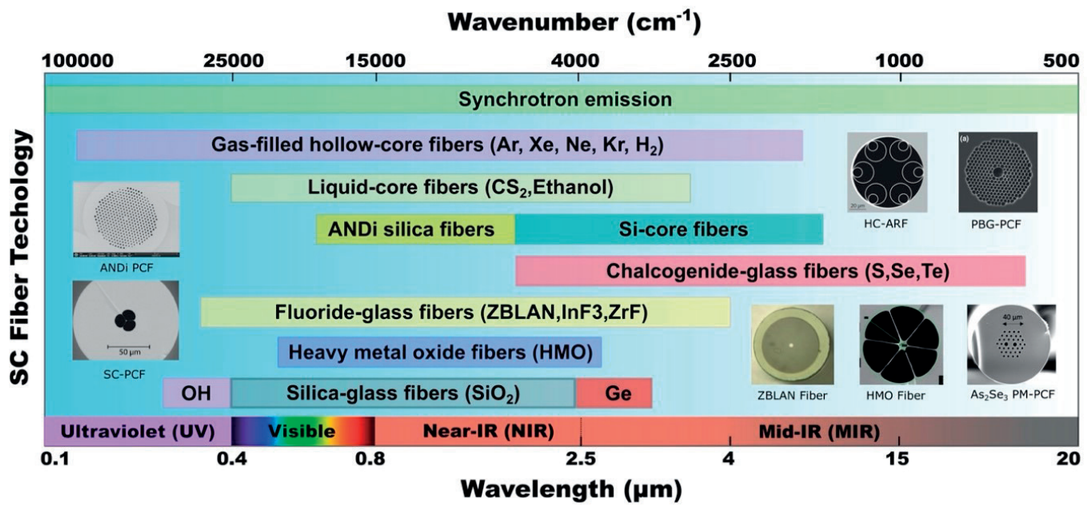

thibaut.sylvestre@univ-fcomte.fr



References

[Invited Review Paper] T. Sylvestre et al., J. Opt. Soc. Am. B 38, F90-F103 (2021).

https://www.osapublishing.org/JOSAB/abstract.cfm?uri=JOSAB-38-12-F90


Survey of supercontinuum light bandwidths in various specialty optical fibers covering the UV and the mid-IR ranges

# RESEARCH TRAINING NETWORKS

## SSUCHY -THE DEVELOPMENT OF SUSTAINABLE AND HIGH-PERFORMANCE BIO-BASED COMPOSITES

### APPLIED MECHANICS

Vincent Placet

Made with vegetable and animal-based biomass materials, bio-based composite materials today offer many advantages in ecological terms (renewable, recyclable and biodegradable resources), economic and social (availability, production cost, development of agricultural jobs) but also from a technical point of view (lightness, increased mechanical and damping properties). They can thus be an advantageous alternative for metallic or petroleum-based materials. In this context, "SSUCHY" was a R&D project which brought together 17 European partners, coordinated by the FEMTO-ST Institute which aims to build a complete value chain of bio-based composites, especially from hemp and wood. It starts from the biomass supply (selection of hemp varieties, optimization of cultivation practices) to focus on transformation processes related to the reinforcement of plant fibers on the one hand, and bio-based polymers on the other hand, up to the design and manufacture of composites and sandwich materials before proposing the realization of specific prototypes and demonstrators:

- High-end bio-based audio loudspeaker combined with recycled PET foam;
- Cockpit panel for electrical aircraft which has reached performance levels compatible with the requirements of the EASA (European Union Aviation Safety Agency) regulations;
- Bio-based monocoque scooter frame. The objective is to replace a steel frame in order to allow a drastic reduction of manufacturing costs while improving safety and durability.
- Hemp-based automotive floorpans, compatible with existing production lines. It not only reduces weight and noise in cars, but also provides better resistance to high temperatures and increased damping capacity.

The project has organized, together with other EU projects, the first summer school to train master and doctoral students on the basis of recent discoveries on natural fibres.

**Project partners:**

FEMTO-ST Institute (FR, coordinator), Chimie Paris Tech (FR), Ecole Nationale d'Ingénieurs de Tarbes (FR), Ecole Nationale Supérieure Arts et Industries Textiles (FR), ICMUB (FR), Catholic University of the Sacred Heart (IT), University of Bristol (UK), University of Derby (UK), University of Leuven (BE), University of Stockholm (SE) 3 SMEs: Wilson Benesch (UK), Eadco (DE) and NPSP BV (ND)

3 manufacturers: Akzo Nobel (ND), Linificio e Canapificio Nazionale (IT) and Trier (FR)

**Funding:**

Bio-Based Industries - H2020 (Project number: 744349)

Total funding:4.5 M€

vincent.placet@femto-st.fr




## ENHANCE - PIEZOELECTRIC ENERGY HARVESTERS FOR SELF-POWERED AUTOMOTIVE SENSORS: FROM ADVANCED LEAD-FREE MATERIALS TO SMART SYSTEMS

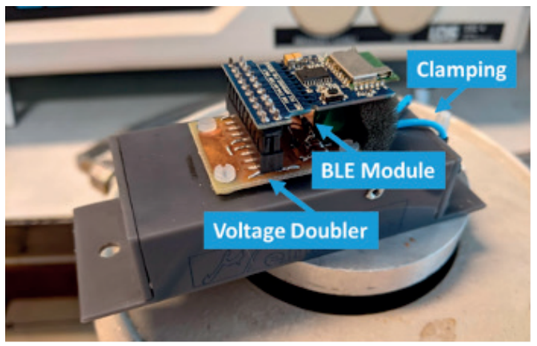
### TIME & FREQUENCY, AS2M, FEMTO ENGINEERING

Ausrine Bartasyte, Samuel Margueron, Bernard Dulmet,

Micky Rakotondrabe, Florent Bassignot, Djaffar Belharet

ESRs : Giacomo Clementi, Neetu Kumari, Merieme Ouhabaz

Energy harvesting and ultra-low power electronics are urgently needed for the implementation of self-powered, battery- and maintenance-free sensors. The integrated solutions with an energy harvester are much sought after in the market of the Internet of Things, health monitoring, and more generally for 4.0 industry. Vibrational energy harvesting is frequently considered as an alternative solution to photovoltaics for this purpose. So far $PbZr_{1-x}Ti_xO_3$ (PZT, lead-based material, banned by REACH and RoHS regulations in EU) ceramics were usually considered as the best performing electro-mechanical transducers. The main goal of the the ITN project ENHANCE, coordinated by FEMTO-ST, was to create a multidisciplinary research activity and teaching environment for the 13 Early Stage Researchers focused on the development of lead-free energy harvesters compatible with MEMS technology and able to power wireless sensors. Piezoelectric transducers based on thick monocrystalline LiNbO3 films integrated on a Si or flexible substrate as a metal or polymer (manufactured by bonding-polishing, patent EP20 203952) capable of generating the power density equivalent to that reported for PZT from vibrations with low frequency and low accelerations, available in the environment, have been demonstrated. This offers a low-cost solution of lead-free materials (LN crystals are available at the industrial level at a price of $ 25 / wafer 6 '') for micro-energy harvesting and micro-actuators.




Vibrational energy harvester based on $LiNbO_3$ transducer and including related electronics and communication BLE module.

The ENHANCE project offered European mobility for ESRS and multidisciplinary doctoral training (organisation of 6 European schools) ranging from molecular engineering, advanced materials, microtechnology, physics -electronics and system integration:

- "Knowledge Transfer, Patenting, Commercialization" (2020, London)
- "Mechatronics and Electronics for Energy Harvesting" (2020, Grenoble)
- "Piezoelectric MEMs & Energy Harvesters" during "International Workshop on Piezoelectric Materials and Applications in Actuators" (2019, Lyon)
- From Molecular Engineering to Advanced Materials", (2019, Cologne)
- "Career Opportunities: Education/Research/Industry" (2018, Lausanne)
- "Introductory school on Energy harvesting" (2018, Besançon)

**Project partners:**

Univ. Franche-Comté (FR), Imperial College London (GB), INSA Lyon (FR), Univ. Catania (IT), Grenoble INP (FR), Univ. Cologne (DE), AIXTRON (DE), Cedrat Technologies (FR), STMicroelectronics (IT)

Partner Organisations: EPFL (CH), EpiValence (UK), PSA Peugeot–Citroen (FR), frecInIsys (FR), KTN (GB).

Funding: H2020-MSCA-ITN (Project number: 722496)

FEMTO-ST: 1.02 M€ (Total funding: 3.5 M€)

**Facility:** MIMENTO

https://www.itn-enhance.com

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# TRAINING ACTIVITIES

## A TEACHING VIDEO CHANNEL ON THEORETICAL ASPECTS OF COMPUTER SCIENCE

**DISC**

Pierre-Cyrille HEAM

The 2022 lockdown sent students home for several weeks, sometimes to areas where the network is incompatible with taking online courses. In the absence of any available offer, the channel «Informatique Théorique» was created with the aim of offering short videos on many technical points for a language theory course. The algorithmic aspects benefit greatly from the dynamism possible with this type of medium. The process of an algorithm and the underlying ideas can thus be better explained than with a paper medium.

After almost two years, the channel is now rich with more than a hundred videos dealing with logic for computer science, language theory, graph and automata algorithms,... The topics covered are dedicated to both undergraduate and Master students, in connection with some themes developed in the DISC department of FEMTO-ST.

Since its launch, the channel has had more than 8200 hours of viewing, of which about 60% from abroad; with around 700 views per day during the university period. Many new video projects are in preparation to enrich the library.

https://www.youtube.com/channel/UC4m4TCpEwpHSxmwr3zdkGXQ

pheam@femto-st.fr

**JUNE 28-JULY 2, 2021**

The 9th European Frequency and Time Seminar (EFTS)

Organizers: E. Rubiola et al. (TF)
20 participants (Besançon)
http://efts.eu

**JULY 6-8, 2021**

European summer school on bio-based composites

Organizers: V. Guicheret-Retel, A. Sabanovic, V. Placet (Applied Mechanics)
Partners: European projects SSUCHY, FLOWER, NETFIB, FiberNet
175 participants (online)
https://events.femto-st.fr/ESBBC/

**SEPTEMBER 15-17, 2021**

International school

Novel Nonlinear Substrates for neural Networks

Organizers: D. Brunner, A. Grabulosa, R. Talukder, A. Skalli (Optics)
Partners: European Training Networks POST DIGITAL
60 participants (hybrid)
https://postdigital.astonphotonics.uk/summer-school-novel-nonlinear-substrates-for-neural-networks/

**NOVEMBER 17, 2021**

1st European PhD Days in miniaturized robotics / European platform euRobotic

Organizers: M. Gauthier et al. (AS2M)
Partners: euRobotics platform
60 participants (online)
https://events.femto-st.fr/PhDDay-Mini-Robotics/

**NOVEMBER 24-26, 2021**

GDR RO school 2021

«Scheduling, Planning and Applications»

Co-organizer: J.M. Nicod (DISC)
Partners: LIP6, Sorbonne Université Paris
30 PhD students (Paris)
http://gdrro.lip6.fr/?q=node/257

**DECEMBER 6-18, 2021**

International Research School in Number theory and Applications 2021

Co-organizer: C. Maire (Optics)
Partners: IMSP, ICTP, CIMPA, CNRS, ANR.
25 participants (Dangbo, Bénin)

# RESEARCH

# THE SCIENTIFIC AXES OF FEMTO-ST INSTITUTE

**• Waves, complex matter and media of propagation**

microacoustics, phononics and integrated photonics, nonlinear photonics and dynamics of optical pulses, laser beam shaping and fs laser-matter interactions, spatial or temporal manipulation of quantum states, atomic spectroscopy, vibro-acoustics

**• Microsystems, micromechatronics**

microrobotics, miniature microwave and optical atomic clocks, biochips, microfluidic circuits for health applications, integrated sensors, energy transducers, MEMS

**• Complex systems and information**

fuel cell systems, thermal systems, systems and time-frequency metrology, health management prognosis, programmable matter, security and software testing, neuromorphic optical computing, embedded systems, distributed systems, artificial intelligence

**• Advanced materials and processes**

micro-/nano-fabrication, heterogeneous integration, metamaterials, electroactive materials ($LiNbO_3$), thin film growth, tribology, surfaces, molecular grafting on the surface, 3D-4D structuring, fs laser machining, composites and architectural materials, bio- and eco-materials, precision machining, micromechanics

## Web of Science: 463 scientific articles in 2021

# AWARDS

## 2021 EMERGING LEADER AWARD IN JOURNAL OF PHYSICS: PHOTONICS

### OPTICS

Daniel Brunner

Journal of Physics: Photonics brings together the best early-career researchers in materials science and publishes their exceptional work in an annual collection dedicated to 'Emerging leaders'. An emerging leader as defined by the IOP Journal of Physics: Photonics is a top researcher in their field who completed their PhD in 2010 or later. A limited number of early career researchers will be nominated by the journal's Editorial Boards, and the author of the best paper from each year's intake will be presented with the JPhys Photonics Early Career Award in recognition of their outstanding contribution.
On behalf of Editor-in-Chief Hugo Thienpont, JPhys Photonics was delighted to announce Daniel Brunner as the winner of the 2021 JPhys Photonics Early Career Award, in recognition of his outstanding article 'A complete, parallel and autonomous photonic neural network in a semiconductor multimode laser'.

Daniel Brunner is a CNRS researcher with a research focus on scalable and parallel photonic neural networks including novel photonic architectures and 3D photonic integration as well as fundamental theoretical aspects. He has received several University and the IOP's 2010 Roys prize, was a Marie Skłodowska-Curie individual fellow, edited one Book and two special issues and is a managing editor at Nanophotonics. He has been invited more than 45 times to present his results and has published over 50 scientific articles.

Neural networks are one of the groundbreaking computing concepts of our time. They lead a drive for parallelism across the entire processor and for a co-location of memory and arithmetic processing. Parallelism in particular made photonics a highly promising platform. We demonstrate for the first time how a fully parallel and fully implemented photonic neural net-work can be realized by spatially multiplexing neurons across the complex optical near-field of a semiconductor multimode laser. Importantly, all neural network connections are realized in hardware, and our processor produces results without pre- or post-processing. We train the readout weights to perform 2-bit header recognition, a 2-bit XOR logical function and 2-bit digital to analog conversion. Crucially, our proof-of-concept system is scalable to much larger sizes and to bandwidths in excess of 20 GHz.

**Facilities:** MIMENTO, SMARTLIGHT

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**References :**

X. Porte et al. 2021 J. Phys. Photonics 3, 024017 (2021). https://doi.org/10.1088/2515-7647/abf6bd

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## EFTF YOUNG SCIENTIST AWARD 2020

### TIME & FREQUENCY

Rodolphe Boudot

The EFTF Young Scientist Award is conferred in recognition of a personal contribution that demonstrated a high degree of initiative and creativity and led to already established or easily foreseeable outstanding advances in the field of time and frequency metrology. The award honours a person under the age of 40 at the date of the opening session of the EFTF conference.

R. Boudot is a CNRS researcher at FEMTO-ST. His research is focused on the development of compact and miniaturized cell-based atomic clocks. He has been the project coordinator, work package leader or scientific contributor in numerous research projects. From 04/2018 to 07/2019, R. Boudot has worked as a NIST Guest Researcher, in Atomic Devices and Instrumentation (ADI) Group, on laser cooling experiments in micro-fabricated cells. R. Boudot has co-authored 70 papers in international journals, has (co)-supervised 11 PhD students, holds 5 patents and has significantly contributed to the industrialisation of miniature atomic clocks in France.

R. Boudot has worked on the development of low SWaP (size-weight-power) and high-stability vapor cell atomic clocks based on coherent population trapping (CPT). R. Boudot has contributed to the development and metrological characterization of a Cs vapor microcell technology, in close collaboration with the MOSAIC team (MN2S, N. Passilly). R. Boudot and his colleagues have also developed advanced interrogation protocols that mitigate light-shift effects in vapor cell CPT clocks, greatly improving their previously limited frequency stability for integration times > 100 s.

**Facilities:** MIMENTO, Oscillator-IMP

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**References:**

M. Abdel Hafiz et al., Appl. Phys. Lett. 112, 244102 (2018). https://doi.org/10.1063/1.5030009

R. Vicarini et al., Sensors Actuators: Physical A 280, 99-106 (2018). https://doi.org/10.1016/j.sna.2018.07.032

## GRAND PRIX I-PHD 2021 BY BPIFRANCE & BEST PAPER AT JNRSE 2021

### TIME & FREQUENCY

Giacomo Clementi

To meet the great challenge of doubling the number of Deeptech startups in France, the government in partnership with Bpifrance launched the i-PhD competition, as part of the Deeptech Plan. It aims to reward young researchers with entrepreneurial projects mobilizing groundbreaking technologies.

G. Clementi did his undergraduate studies at University of Perugia (Italy). During his PhD at Institute FEMTO-ST/ University of Franche-Comté (2017-2020), he specialized in micro-energy harvesting working within the frame of the European MSCA project ENHANCE. His PhD topic concerned design and implementation of piezoelectric micro-energy transducers based on eco-friendly materials. In 2021, he continued as a post-doc "Entrepreneur Researcher Itinerary" of Bourgogne-Franche-Comté region and in December 2021 he started his tenure-track associate professor position at University of Perugia.

European REACH and RoHS regulations ban using lead-based materials. The key achievement of the G. Clementi work is the demonstration of very high performance of vibrational energy harvesters based on the lead-free material-$LiNbO_3$ (LN) integrated on flexibles substrates, capable of generating the power density equivalent to that reported for standard lead-based PZT piezoelectric ceramics from vibrations with low frequency (105 Hz) and low accelerations (0.1g) (such vibrations can be found easily in transport). It is important to note that LN, well-known in acoustics and photonics, were not considered in the state-of-the-art for vibrational energy harvesting before although, it offers a low-cost solution of lead-free materials. The vibrational energy harvesting systems were developed in close collabora-tion with EPFL, INSA Lyon and ST-Microelectronics (IT). This opens new opportunities for sustainable micro-energy sources needed for autonomous & wireless sensors in applications of IoTs and automotive industry.

Fundings: MSCA ITN ENHANCE & RISE Reactive Too, ICE/ BFC region, Bpifrance, SATT/Sayens, Graduate school EIPHI

**Facilities:** MIMENTO, MIFHYSTO
https://www.itn-enhance.com/

**References:**

G. Clementi et al., Appl. Phys. Lett. 119, 013904 (2021).
A. Bartasyte et al., Patent EP20203952 (2020)

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# AWARDS

## PRIX “PÉPITE” IN THE REGIONAL «FEMALE INITIATIVE « COMPETITION

**AS2M**

Safa Meraghni

For the 16th consecutive year, Initiative France, a network of associations supporting entrepreneurship throughout France, has organized a regional competition to promote female entrepreneurship in Region Bourgogne-Franche-Comté. FEMTO-ST’s freshly-minted PhD (2021) Dr Safa Meraghni was one of the 5 award recipients, out of 103 applicants, for a “pepite” award recognizing her entrepreneurial project "Smart Medical Assistant". The award ceremony took place on December 6th, 2021 in Dijon in the presence of representatives from the State, the Bourgogne-Franche-Comté Region and Bpifrance.

Dr Safa Meraghni obtained her PhD in Computer Science in FEMTO-ST’s AS2M Department (PHM team) in 2021, in collaboration with the University of Biskra (Algeria). During her PhD, Dr Meraghini also validated a Master in Management and Administration of Companies, innovation and entrepreneurship course.

It was during her PhD project, which concerned both scheduling algorithms and the design of a portable medical device "SBra" to detect early breast cancer (Interreg France-Switzerland project with AS2M department), that Safa identified innovation opportunities to help physicians with the administrative burden of recording patient data. This Award recognizes the potential of Dr Meraghini’s Smart Medical Assistant (SMA) project. This smartphone application allows medical professionals to record exchanges with their patients, transcribe them and then, thanks to intelligent processing, extract the relevant information to help with medical diagnosis, thus saving practitioners precious time.

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## BEST STUDENT AWARD AT IEEE IUS 2021

**MN2S**

Julio Iglesias

Our PhD student Julio Andrés Iglesias Martínez has received the Best Student Paper Award of the category “Physical Acoustics” at the IEEE International Ultrasonic Symposium, which was held virtually in September 2021. His work consists in achieving three-dimensional phononic crystals at the micro-scale with record band-gap width.

Julio Andrés Iglesias Martínez is a second year PhD student of the MN2S department, working in the Phononics and Microscopy team. His thesis work is devoted to ultrasonic crystals and acoustic metamaterials. He has published eight papers in international peer-reviewed journals.

The study of periodic artificial structures such as phononic crystals opens up the possibility for engineering effective mechanical and acoustical properties, as well as introducing bandgaps. Ultrasonics offers a wide range of potential applications, such as imaging techniques at frequencies from 1 to 15 MHz, typically. Thanks to additive manufacturing, the fabrication of complex structures such as 3D phononic crystals are now made possible. However, the limited resolution of conventional 3D printers, of the order of a few tens of micrometers, limits their working frequencies well below 1 MHz. That is a reason why three-dimensional phononic crystals operating at frequencies above 1 MHz remain elusive. In this work, we designed, fabricated, and characterized a 3D phononic crystal that has a wide band gap for frequencies extending from 0.6 MHz to 7.5 MHz, which sets a record in the field. The crystal samples are fabricated at the microscale using two-photon lithography, thanks to the facilities of the MIMENTO nanofabrication center of FEMTO-ST Institute.

Facility: MIMENTO

https://teams.femto-st.fr/phononics-microscopy/en

**References:**

I. Martínez et al., Appl. Phys. Lett. 118 (6) 063507 (2021). https://doi.org/10.1063/5.0033615

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## BEST STUDENT PRESENTATION AWARD AT ESBBC

**APPLIED MECHANICS & AS2M**

Jason Govilas

This award was attributed to the best presentation given by a PhD student during the first European Summer school on Bio-Based Composites (ESBBC). The event aimed at gathering the main academic and technical players in the field of bio-based composites and highlighting the work of young researchers.

Jason Govilas holds a Master’s Degree in mechanical engineering from the Université de Franche-Comté. He is currently in the third year of his PHD on the material characterization of plant fibres using micro-mechatronics. This research project involves the Applied Mechanics and AS2M departments of the FEMTO-ST institute in collaboration with the French agronomical institute in Nantes (INRAE). This work is also part of the European union’s NETFIB project and supported by the EIPHI graduate school of the University de Bourgogne-Franche-Comté.

The extraction and separation of plant fibres from annual plants is a key step in the production of bio-based composites. An innovative micro-mechatronic setup was developed to study the interface between fibres during separation. Inter-fibre adhesion and separation was characterised for the first time. The role of cellulose microfibrils in this process along with their toughness was also revealed.

**References:**

https://events.femto-st.fr/ESBBC/

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## THESIS PRIZE/ CONFERENCE GRANT AT MIM2021

**APPLIED MECHANICS**

Fangnao Xiao

This award was received for work “Liquid - liquid doping mechanism, fabrication, numerical simulation of W-Zr(Y)$O_2$ alloys with excellent properties” at International Conference on Injection Molding of Metals, Ceramics and Carbides, 22 – 25 Feb., 2021 (online).

An innovative liquid-liquid method involving doping at molecular level is retained to prepare a W alloy with excellent physical properties with uniformly distributed and ultrafine oxide particles. $ZrO_2$ is distinguished as an excellent reinforced particle due to its high hardness, wear resistance, thermochemical stability, and corrosion resistance. There has been little research on precursor morphology, synthesis mechanism, phase composition and physical characteristics of $ZrO_2$ reinforced W powder by the liquid-liquid method. The deeper investigations on $ZrO_2$ dispersion-strengthening of W and heavy alloys in terms of $ZrO_2$ doping level, sintering process, strengthening mechanism and mechanical properties are still lacking.

This research work focuses on the study of the preparation of nanosized oxide particles dispersion-strengthened tungsten alloys by the liquid-liquid doping technique. The powder preparation process was optimized to reduce doping phase size and to homogenize the phase distribution by using a molecular-level doping. An innovative method was developed to avoid the detrimental contaminants during the mixing process of the doping phase and tungsten powder. The numerical simulation in 2D and 3D was carried out to investigate the effects of reinforced particle size, number, distribution and mass fraction on the mechanical behaviour of tungsten alloys.

https://www.mpif.org/Events/MIM2021/MIM2021GeneralInformation.aspx

**References:**

F. Xiao et al., J. Alloys Comp. 855 (1), 157335 (2021). https://doi.org/10.1016/j.jallcom.2020.157335

F. Xiao et al., J. of Alloys Comp. 878, 160335 (2021). https://doi.org/10.1016/j.jallcom.2021.160335

F. Xiao et al., Int. J. Adv. Manuf. Technol. 116, 439 (2021). https://doi.org/10.1007/s00170-021-07293-y

F. Xiao et al., Materials Today Com. 27, 102223 (2021). https://doi.org/10.1016/j.mtcomm.2021.102223

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# AWARDS

## BEST PRESENTATIONS

### BEST POSTER AWARD AT ISOT 2021

**MN2S, AS2M**

Sylwester Bargiel, Fernando E. Garcia-Ramirez, Przemyslaw Struk, Jean-Loup Skora, Quentin A. A. Tanguy, Olivier Gaiffe, Philippe Lutz, Jean-Marc Cote, Huikai Xie, and Christophe Gorecki

The award was received for the work "3-D micro-assembly approach to fabrication of a scanning MOEMS-based endoscopic probe for Optical Coherence Tomography imaging" at International Symposium on Optomechatronic Technology 2-5 Nov 2021, Besançon, France.

The awarded paper concerns the fabrication of a MOEMS-based endoscopic probe enabling a real-time, non-invasive optical imaging of biological tissues using a Swept-Source Optical Coherence Tomography (SS-OCT) method. The fabrication process is based on a 3D micro-assembly and local adhesive bonding of four building blocks, i.e. a 2-D MEMS micromirror scanner, a Mirau micro-interferometer, a GRIN collimator and a flexible PCB. The assembly steps were performed in a MIMENTO cleanroom using semi-automatic chip-bonder equipment. This work is carried out within the framework of a PhD thesis of Fernando E. Garcia-Ramirez and supported by the INSERM Plan Cancer program (ROBOT project) and RENATECH network and in collaboration with CHU Besançon, Beijing Institute of Technology, Silesian University of Technology (Poland), and Polish Academy of Sciences.

**Facility:** MIMENTO

**References:**

P. Struk et al., Opt. Lett. 43 (19), 4847 (2018).
https://doi.org/10.1364/OL.43.004847

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### BEST PAPER AWARD AT ICEMS 2021

**ENERGY**

Antony Plait and Frédéric Dubas

The "Best Paper Award" at the IEEE International Conference on Electrical Machines and Systems (ICEMS, Gyeongju, Korea, 31 Oct.-03 Nov. 2021) was received for their work on "Electrical conductivity influence on eddy-current losses: analytical study and experimental validation"

The paper focuses on the validation of a 2-D analytical model for the eddy-current loss calculation in conductive massive parts (magnet, copper, aluminum...). The electrical conductivity influence associated with the segmentation is studied. The difference between the experimental results and the analytical predictions is less than 5 %.

It is demonstrated experimentally that the segmentation can decrease eddy-current losses in some materials, and increase them in others. It is also established experimentally that segmentation does not automatically reduce eddy-current losses (which has never been published before in the literature).

www.researchgate.net/profile/Frederic-Dubas
www.researchgate.net/profile/Antony-Plait

**References:**

A. Plait and F. Dubas, in Proc. IEEE ICEMS, 554 (2021).

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### BEST PAPER AWARD FINALIST AT DARS

**DISC**

Pierre Thalamy, Benoît Piranda, André Naz and Julien Bourgeois

The DARS (Distributed Autonomous Robot Systems) conference is a single track conference that gathers every two years all the major actors of the distributed robotics field. Two awards are delivered, one for the Best Student Paper Award and one for the Best Paper Award (from 3 finalists). The work on "Behavioral Simulations of Lattice Modular Robots with VisibleSim", presented by FEMTO-ST researchers was nominated as a Best Paper Finalist.

Robotics research needs complex hardware and software that is why simulation is often viewed as an alternative for testing. Large scale self-reconfiguring modular robotic systems needs a scalable simulation environment which cannot be physics-based.

VisibleSim is an open-source behavioral simulator for lattice-based modular robots that uses discrete-event simulation for ensembles of up to millions of modules. We describe VisibleSim basics and introduce features and usage from a user standpoint.

VisibleSim is built with extensibility, versatility, and flexibility in mind, can be used as a powerful visualization tool, and already has a proven track record with several modular robotic architectures.

https://www.programmable-matter.com/

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### BEST PAPER AWARD FROM THE INTERNATIONAL ACADEMY, RESEARCH, AND INDUSTRY ASSOCIATION

**TIME & FREQUENCY**

Meddy Vanotti, Sacha Poisson, Virginie Blondeau-Patissier, Laurie André, Stéphane Brandès, Nicolas Desbois, Claude P. Gros

The Best Paper Award at The Sixth International Conference on Advances in Sensors, Actuators, Metering and Sensing (ALLSENSORS 2021, Nice) was received for the work "SAW Based CO2 Sensor: Influence of Functionalizing MOF Crystal Size on the Sensor's Selectivity".

The awarded work shows the capability of a Surface Acoustic Wave (SAW) based sensor functionalized with ZnTACN Metal-Organic Framework (MOF) to detect carbon dioxide. This work emphasizes the influence of the MOF crystals size on the sensor's selectivity. The authors show infinite selectivity toward oxygen in the whole MOF crystal size range. More interestingly, the authors show the possibility of reaching virtually infinite selectivity to the major disruptive influences such as carbon monoxide by using submicronic MOF crystals. This work was carried out in collaboration with ICMUB laboratory (Dijon).

https://www.iaria.org/conferences2021/AwardsALLSENSORS21.html

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# NEW MEMBERS

## DISC

Joseph Azar

Associate Professor (UFC)

Joseph Azar is an associate professor at the University of Franche-Comté (UFC), France. He received his Ph.D. in computer science in 2020 from the "Université de Franche-Comté", France. In 2017, he received his Master's degree in Computer Science and Risks Management from the Lebanese University. His research interests include affective computing and multi-sensor data mining.

His research topics concern digital signal processing applied for IoT applications, deep learning for time series, energy efficiency through data reduction for IoT, and deep learning for healthcare and affective computing.

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## MN2S

Agathe Figarol

Associate Professor (ISIFC, UFC)

Agathe Figarol received her PhD in 2014 from the Ecole des Mines de St-Etienne for her work on the link between the toxicity and the physicochemical properties of carbon nanotubes. After a year as a regulatory toxicologist, she worked as a post-doctoral researcher first at the Paul Sabatier University in Toulouse on the transport of polymeric nanocarriers through the endothelium into tumours, then in Osaka University on a 3D in vitro blood-brain barrier model. In 2020, she was a temporary lecturer at the Jean Lamour Institute and the Nancy Faculty of Pharmacy. She has joined UFC as an associate professor.

Since 2021, Agathe has joined the BioMicroDevices group, in the MN2S department/FEMTO-ST Institute. She aims to develop instrumentalized “organ-on-chip” models to assess the biological response of healthy and tumoral vascularized tissues - with a focus on the brain microvasculature and glioblastoma - to innovative drugs such as nanocarriers.

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## AS2M

Ning Liu

Associate Professor (UFC)

Associate professor at Université de Franche-Comté Sciences et Techniques, Ning Liu received the Ph.D. degree in 2020 for her work on the infinite-dimensional modelling of electro-active polymer actuators and control of flexible structures from Université Bourgogne Franche-Comté. She then worked as postdoctoral research in LAI at École Polytechnique Fédérale de Lausanne where she focused on the modelling of soft actuators dedicated to cardiac assist device.

Her research activities are mainly focused on the modelling and control of soft actuators with the port-Hamiltonian approach. More theoretically, she is interested in the structure-preserving discretisation and passivity-based control of infinite dimensional port-Hamiltonian systems.

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## AS2M

Moncef Souahli

Associate Professor (UFC)

Moncef Souahli obtained his PhD degree at the National Polytechnic Institute of Toulouse (INPT) on system condition monitoring for industry 4.0. He was a Postdoctoral researcher at National Engineering School of Tarbes and worked on the development of innovative prognostics approaches for efficient predictive maintenance. He is currently an Assistant Professor at the University of Franche-Comté.

His research interests include data science for system health monitoring, prognostics and health management (PHM), predictive maintenance, system failure mechanisms analysis, data processing, signal processing, fault/failure detection and diagnostics/prognostics, machine learning, and deep learning for application domains such as energy, robotics, railways, medicine, and pulp mills.

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https://scholar.google.com/citations?user=eWkstPgAAAAJ&hl=fr&oi=ao

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# NEW MEMBERS

**ENERGY**

Issam Salhi

Associate Professor (UTBM)

Issam Salhi received the Master's degree in control system engineering and the PhD degree in Electrical engineering in 2006 and 2010 respectively, both from University Cadi Ayyad (Marrakesh, Morocco). In 2010, he became associate professor at University Cadi Ayyad and since September 2021 he is an associate professor at the University of Technology of Belfort-Montbeliard (UTBM).

Main research fields of Issam Salhi include fuel cells for transportation, green hydrogen production, modern control of nonlinear systems (mainly renewable energy systems) and converter design, analysis, and control.

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**MN2S**

Benjamin Brunel

Associate Professor (ISIFC/UFC)

Benjamin Brunel received his PhD in 2018 from the University of Grenoble Alpes (LIPhy laboratory), for his work on dynamic light scattering applied to the measurement of cell displacements in optically thick tissues. He then worked as a post-doctoral researcher at the University of Reims (BioSpecT unit), on Raman and infrared spectroscopy imaging of colon cancer histological sections to predict the effectiveness of a therapy using machine learning models.

His current work focuses on the development of a sensor for multiplexed measurement of blood analytes. This lab-on-a-chip would separate red blood cells by acoustophoresis to evaluate lower signal components, analyzed by surface-enhanced Raman spectroscopy and regression models, aiming at a faster and cheaper analysis of blood.

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**ENERGY**

Amel Benmouna

Associated Researcher at FEMTO-ST,
Associate Professor (ESTA)

Amel Benmouna received her PHD degree in electrical engineering from UTBM in 2019. Currently, she is Associate Professor at ESTA, school of Business and Engineering, at Belfort, France and she is doing her research at FEMTO-ST institute.

The topics of her research is focused on the fuel cell, hybrid system, energy management of hybrid system for electrical vehicle, passivity passed control applied for energy management of hybrid system, hydrogen storage. In particular it concerns the study of the energy management of hybrid systems based on fuel cell for vehicle applications. Non-linear control based on passivity is used which is a powerful nonlinear technique, it is considered as a general way to stabilize a large class of physical systems.

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**DISC**

Hassan Noura

Full Professor (UFC)

Hassan Noura received his Ph.D. Degree from Polytech Nantes in 2012, France. In 2013, he joined Paris-Sud XI University, as a postdoctoral researcher. In 2014, He joined CEA-LETI, Grenoble as a research engineer. Then, he joined QMIC, Qatar as a senior research engineer in 2015. In 2016, he got his HDR from Paris VI (UPMC) and joined Telecom ParisTech as a senior research engineer. After that, he joined AUB, Lebanon in 2017 as research associate. Afterwards, he joined AOU in 2019 as the coordinator of the "Information Security and Digital Forensics" master program. In 2021, he has joined UFC as a full professor.

His research is focused on applied cryptography, network and multimedia security, machine learning for cybersecurity, robust and optimization of machine learning solutions, and deep learning schemes for IoT systems.

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# RESEARCH HIGHLIGHTS

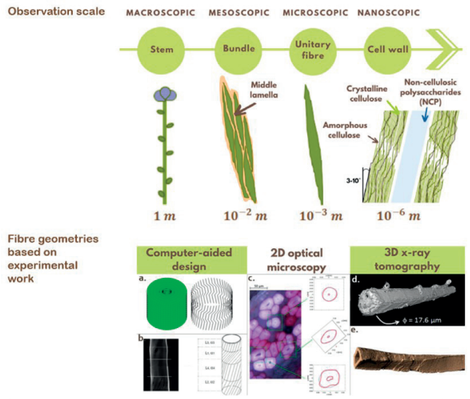
## A CRITICAL REVIEW OF THE ULTRASTRUCTURE, MECHANICS AND MODELLING OF FLAX FIBRES AND THEIR DEFECTS

### APPLIED MECHANICS

Vincent Placet

Driven by environmental legislation and public awareness related to climate change, the market for plant fibre composites has been growing steadily for the past 10 to 20 years. However, the growth rate of this sector is not yet up to the ecological transition to mass production which requires overcoming some barriers. Among them, structural defects within plant fibres are known to reduce the mechanical properties at the composite scale. It is therefore crucial to better understand the nature, origins, and consequences of these defects to increase the use of plant fibres as reinforcements in composites and thus to move towards a more carbon-neutral material industry, an objective of the European green deal.

The main objective of this review is to provide new insights




A top-down and multi-scale approach covering the nanometric to the millimetric structural organization of flax fibres

into the defects found in plant fibres and their influence on their mechanical properties. For this purpose, a critical analysis of the experimental and modelling work has been performed by a multidisciplinary consortium of French scientists from INRAe Nantes, IRDL and FEMTO-ST. Thanks to a top-down and multi-scale approach covering the nanometric to the millimetric structural organization, the ultrastructure of flax fibre is taken as an example and its defects are presented. In particular, advanced testing methods and innovative numerical approaches are discussed to better understand the very complex mechanical behaviour of plant fibres.

**References:**

E. Richely et al., Progress in Materials Science 124, 100851 (2022).
https://doi.org/10.1016/j.pmatsci.2021.100851

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## LESSONS ON TEXTILE HISTORY AND FIBRE DURABILITY FROM A 4000-YEAR-OLD EGYPTIAN FLAX YARN

### APPLIED MECHANICS

Vincent Placet, Gemala Haspari

Man has always used plant fibres, such as flax, for the manufacture of fabrics and clothing. Praised in ancient Egyptian times, linen is still used today by spinners and weavers who work to diversify its uses and properties. Linen-based technical fabrics are also the object of growing interest for composite applications in the transport, nautical, sports and leisure sectors. They offer a more environmentally friendly alternative due to the renewable and recyclable nature of this plant material. The question of durability and aging of these materials is at the heart of this most innovative research. For linen, its use dating back to the Neolithic period, it is possible to have access to ancient fabrics and thus to study the effects of a real and long-term aging on the properties of these fibres. This is the idea of Dr. Alain Bourmaud at the IRDL (Institut de Recherche Dupuy de Lôme). In collaboration with scientists from the Louvre Museum, the LMGC, the SOLEIL synchrotron, INRAE Nantes, the University of Cambridge and the FEMTO-ST institute, the properties of fibres extracted from 4000-year-old mortuary cloths found in Egyptian sarcophagi were characterized and compared to the properties of present-day flax textile fibres. The results showed that these ancient fibres still have excellent mechanical properties, testifying to the good preservation conditions due to the hygrothermal environment prevailing in the tombs. The characterization work was carried out using state-of-the-art techniques such as atomic force microscopy and biphoton microscopy. The FEMTO-ST researchers involved have carried out X-ray nanotomographic analyses in order to obtain 3D images of the flax yarns and fibre of the mortuary cloth.

**Facility:** MIFHySTO

References:

A. Melelli et al., Nature Plants 7, 1200 (2021).
https://doi.org/10.1038/s41477-021-00998-8

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## USER-CENTRED DESIGN APPROACH WITH MISIDENTIFIED END-USERS: CASE STUDY FOR SMART COMPOSITE STRUCTURES

### APPLIED MECHANICS & RECITS

Florence Bazzaro

This research was conducted in collaboration with University Savoie Mont Blanc, SYMME laboratory and, Université de Technologie de Compiègne, Roberval laboratory.
This research focuses on the identification of the uses of an emerging technology. Indeed, an innovation can be the result of the continuous improvement of an existing solution or a new and unique solution resulting from a discontinuous process. The use of a user-centred design approach is recognised as enabling innovative product design. However, this methodological framework is not suitable for the development phases of a technological module. A technological module is an invention at the laboratory stage where, by definition, future uses and/or users are not well identified. This study presents an approach to identify the possible future uses of technological modules whose users are misidentified. This approach is based on user-centred design processes. To demonstrate the potential of the proposed approach, a smart composite structure was studied. It is a structure made of a composite material into which smart materials are integrated to make it functional. The results obtained show that this approach makes it possible to identify new fields of application, which have not yet been considered by the smart composite community.

**References:**

F. Bazzaro and Y. Meyer. J. Eng. Design, 33 (1), 1 (2022).
https://doi.org/10.1080/09544828.2021.1951686

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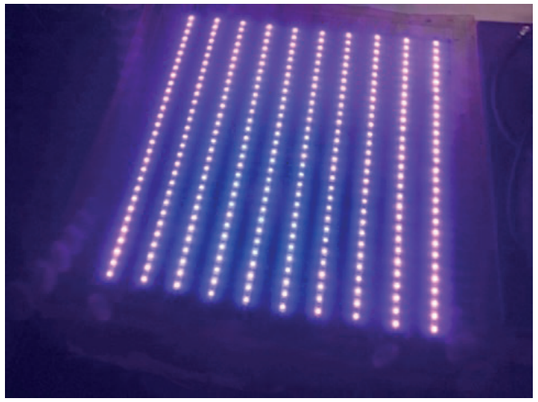

450x450 mm² translucent punch equipped with Led UV tapes, (b) Punch with the tapes activated (copyright USMB/SYMME laboratory)

## NANOROBOTIC STRUCTURES WITH EMBEDDED ACTUATION VIA ION INDUCED FOLDING

### AS2M

Amine Benouhiba, Léo Wurtz, Jean-Yves Rauch, Joël Agnus, Kanty Rabenorosoa, and Cédric Clévy

4D structures are tridimensional structures with time-varying abilities that provide high versatility, sophisticated designs, and a broad spectrum of actuation and sensing possibilities. The downsizing of these structures below 100 µm opens up exceptional opportunities for many disciplines, including photonics, acoustics, medicine, and nanorobotics. However, it requires a paradigm shift in manufacturing methods, especially for dynamic structures. A novel fabrication method based on ion-induced folding of planar multilayer structures embedding their actuation is proposed—the planar structures are fabricated in bulk through batch microfabrication techniques. Programmable and accurate bidirectional folding (-70°/+90°) of SiO2/Cr/Al multilayer structures are modelled, experimentally demonstrated and then applied to the embedded electrothermal actuation of controllable and dynamic 4D nanorobotic structures. The method is used to produce high-performance case-study grippers for nanorobotic applications in confined environments. Once folded, a gripping task at the nano-scale is demonstrated. The proposed fabrication method is suitable for creating small-scale 4D systems for nanorobotics, medical devices, and tunable metamaterials, where rapid folding and enhanced dynamic control are required.

Website: https://www.femto-st.fr/en/The-institute/news/nanorobotics-future-femto-st-enters-4th-dimension

**Facilities:** Micro-Nano Robotics Center, MIMENTO

**References:**

A.Benouhiba et al., NanoRobotic Advanced Materials33 (45), 2103371 (2021).
https://doi.org/10.1002/adma.202103371

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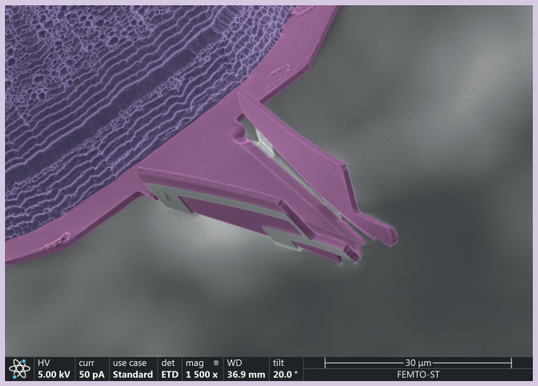


SEM coloured image of an ion-folded folded gripper with embedded actuation

# RESEARCH HIGHLIGHTS

## OBSERVATION OF ROTON-LIKE DISPERSION RELATIONSHIPS IN ELASTIC AND ACOUSTIC METAMATERIALS

**MN2S**

Julio A. Iglesias Martínez, Vincent Laude, and Muamer Kadic

Lev Landau pioneered theories describing superfluids, in particular liquid helium. One of his most important discoveries was the description of an unusual dispersion relationship for acoustic waves in superfluid Helium-4 at low temperature, commonly called a roton. Rotons have since then been observed in inelastic scattering experiments with neutrons, since 1961. In 2020 and 2021, two theoretical papers discussed the existence of roton-like dispersion relationships in periodic media and metamaterials. It was suggested that a periodic system of springs and masses including third-neighbour interactions produces a dispersion relationship similar to the one observed in superfluids.

This has now been demonstrated experimentally by a German-French collaboration (Karlsruhe Institute of Technologie and FEMTO-ST in Besançon). The researchers report on the experimental observation of the roton effect in both elastic and acoustic metamaterials. The figure shows the remarkable similarity between both observations, at audible frequencies for the acoustic metamaterial and at ultrasonic frequencies for the microfabricated elastic metamaterial. A remarkable aspect is the continuous transition, obtained by a simple adjustment of the wavelength, from the usual forward propagation of waves to their backward propagation, followed by a minimum of the dispersion relationship, characterizing the effective existence of the roton.

This study shows that taking advantage of interactions beyond nearest neighbours, which is fairly accessible with elastic and acoustic systems, opens up unprecedented experimental perspectives for controlling the dispersion of phonons and their interactions. Those experimental results can also be extended to other areas of wave physics, such as electromagnetism.

https://teams.femto-st.fr/phononics-microscopy/en

**References:**

J. A. Iglesias Martínez et al., Sci. Adv. 7, eabm2189 (2021). https://doi.org/10.1126/sciadv.abm2189

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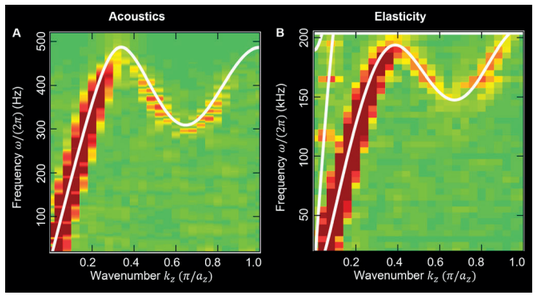


Measured dispersion relation A) with the acoustic metamaterial (@ FEMTO-ST) and B) with the elastic metamaterial (@KIT).

## DIRECT (3+1)D LASER WRITING OF GRADED-INDEX OPTICAL ELEMENTS

**OPTICS, MN2S**

Daniel Brunner, Xavier Porte, Johnny Moughames, Muamer Kadic

We propose and demonstrate the single-step additive fabrication of graded-index optical elements by introducing exposure to light as the additional dimension to three-dimensional (3D) laser writing, hence (3+1)D writing. We use a commercial printer and photoresist to realize the proposed single-step fabrication method that can be swiftly adopted for research and engineering. After presenting the characterization of the graded-index profiles via basic structures, we demonstrate two different optical devices: volume holograms that are superimposed using angular and peristrophic multiplexing, and optical waveguides with well-defined refractive index profiles. In the latter, we precisely control the propagating modes via tuning the (3+1)D-printed waveguide parameters and report step-index and graded-index core–cladding transitions.

https://www.osapublishing.org/optica/fulltext.cfm?uri=optica-8-10-1281&id=459999

**References:**

X. Porte et al., Optica 8, 1281 (2021). https://doi.org/10.1364/OPTICA.433475.

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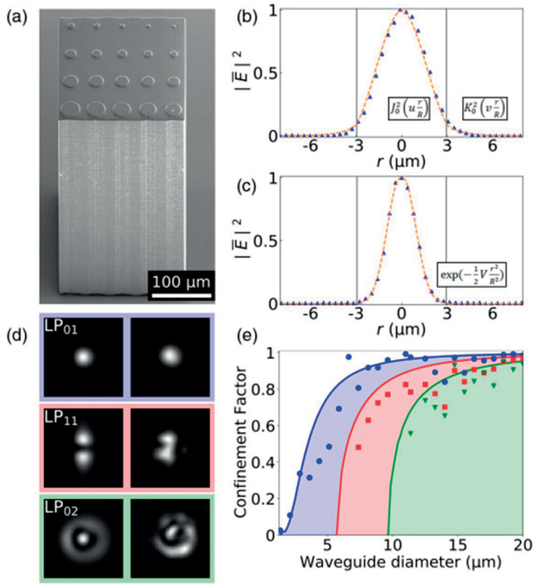


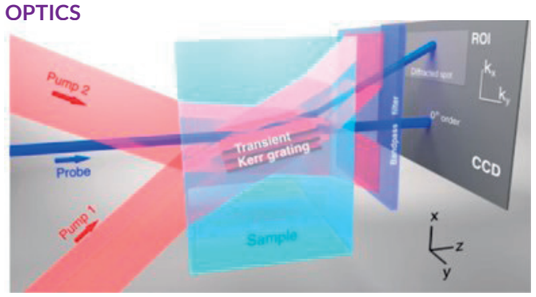

(a) (3+1)D printed STIN waveguides. (b,c) Output intensities and fits of a 6 µm diameter STIN and a GRIN waveguide, respectively. (d) Intensity profiles of injected LP modes (left) and their outputs (right). (e) Theoretical confinement factor for each mode LP01 (blue), LP11 (red), and LP02 (green).



## IN-SITU DIAGNOSTIC OF FEMTOSECOND LASER PROBE PULSES FOR HIGH RESOLUTION ULTRAFAST IMAGING

Chen Xie, Remi Meyer, Luc Froehly, Remo Giust, François Courvoisier

**OPTICS**




Principle of the transient grating induced by an infrared pump pulse in a transparent dielectric. The signal is generated by diffraction on the pump-induced transient grating and appears clearly in the far-field.

Ultrafast imaging is essential in physics and chemistry to investigate the femtosecond dynamics of nonuniform samples. It relies on pump probe experiments. Recent years have seen the emergence of very successful ultrafast imaging techniques. However, further progress in ultrafast imaging towards high spatial resolution is hampered by the lack of characterization of weak probe beams. For pump–probe experiments realized within solids or liquids, because of the difference in group velocities between pump and probe, the determination of the absolute pump–probe delay depends on the sample position. In addition, pulse-front tilt is a widespread issue, unacceptable for ultrafast imaging, but which is conventionally very difficult to evaluate for the low-intensity probe pulses. We have demonstrated that a femtosecond laser pump-induced micro-grating generated from the electronic Kerr effect provides a detailed in-situ characterization of a weak probe pulse. It allows one to solve the issues of absolute pump–probe delay determination and pulse-front tilt detection. Our approach is valid whatever the transparent medium with non-negligible Kerr index, whatever the probe pulse polarization and wavelength. Because it is nondestructive and fast to perform, it can be repeated to calibrate experimental conditions, particularly in the case where complex wavelength, spatial frequency or polarization encoding is used.

https://www.femto-st.fr/en/Research-departments/OPTICS/Research-groups/Optoelectronics

**References:**

Xie, Chen, et al., Light: Science & Applications 10 (1), 1 (2021). https://doi.org/10.1038/s41377-021-00562-1

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## CHAOS AND INSTABILITY IN A SUPERCONTINUUM LASER

John Dudley, Thibaut Sylvestre, Jean-Marc Merolla

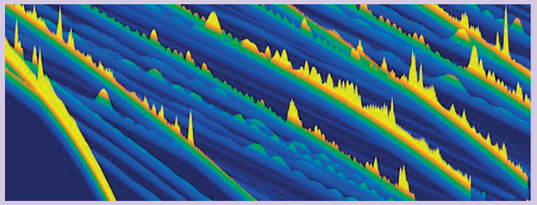
**OPTICS**

Lasers emitting stable ultrafast pulses of light are widely used in industry and have also been central to fundamental Nobel Prize-winning research. But in addition to such highly stable operation, such lasers can also produce highly irregular output, and in this case their study yields new insights into the nature of chaos and instability. However, although such instabilities have been known for decades, their experimental study is challenging, and their origins are poorly understood. In collaboration with the Universities of Tampere, Aston and ICB laboratory, FEMTO-ST researchers made significant progress during 2021 in the ongoing effort to understand the ultrafast chaotic nature of lasers, elucidating for the first time their noise-like pulse operation. In particular, they constructed a special class of optical fibre laser to operate only in a highly chaotic supercontinuum regime, and this allowed advanced real-time experimental techniques to comprehensively measure its instability characteristics. Numerical simulations of the laser agreed quantitatively with experiment over an optical bandwidth as broad as 1000 nm and a three-order of magnitude dynamic range, representing one of the most remarkable tests of nonlinear laser modelling ever reported.

**References:**

F. Meng et al., Nature Communications 12, 5567 (2021). https://doi.org/10.1038/s41467-021-25861-4

john.dudley@univ-fcomte.fr



Numerical simulations showing the evolution of chaotic ultrafast solitons in a supercontinuum laser.

# RESEARCH HIGHLIGHTS

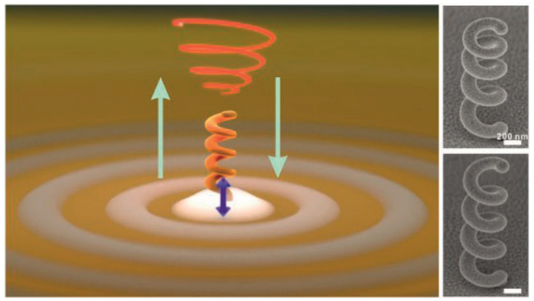
## POLARIZED NANOPHOTONICS

### OPTICS, MN2S

Philippe Boyer, Fadi Baida, Miguel Suarez, Roland Salut, Nicolas Martin, Thierry Grosjean

Controlling the polarization vector of light provides a key approach to manipulating light-matter interaction in subwavelength structures. In turn, tailoring the local optical response of subwavelength structures offers new possibilities to light polarization control. This duality in nanophotonics has been recently highlighted at FEMTO-ST.

An original theoretical model based on a Jones formalism has been developed to reveal the underlying principle of polarization-induced Fano resonances [1]. This property has been validated in an experimental proof of concept using commercially available wire-grids and a terahertz time domain spectrometer. This alternative path to the realization of Fano resonances by using stacked metallic metasurfaces permits a control of resonances quality factors which theoretically tend to infinity by the variation of rotation angle between metasurfaces.




Artistic view of the polarization conversion from an individual plasmonic helical nanoantenna.

An individual plasmonic helical nanoantenna has been demonstrated to locally convert longitudinally-polarized confined near-fields into circularly polarized freely propagating waves, and vice versa [2]. To this end, the nanoantenna has been coupled to cylindrical surface plasmons bound to the top interface of a thin gold layer. Helices of varying pitch length were experimentally shown to broaden the operation bandwidth. Interconnecting circularly-polarized optical waves (carrying spin angular momentum) and longitudinal near-fields provides a new degree of freedom in light polarization control.

**Facility:** MIMENTO

**References:**

[1] X. Romain et al., Commun. Phys. 4, 115 (2021). https://doi.org/10.1038/s42005-021-00623-2

[2] M. Wang et al, Nano Lett. 21 (8), 3410 (2021). https://doi.org/10.1021/acs.nanolett.0c04948

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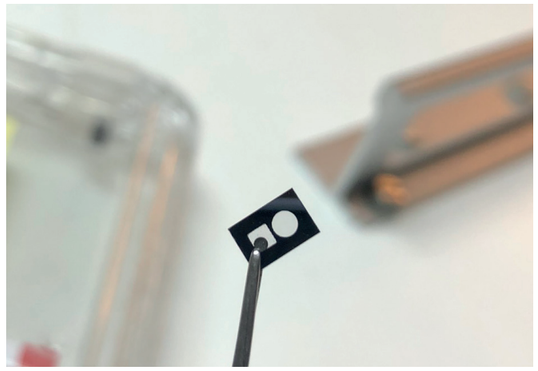
## TACKING LIGHT SHIFTS IN MICROCELL ATOMIC CLOCKS

### TIME & FREQUENCY, MN2S

Moustafa Abdel Hafiz, Nicolas Passilly, Rodolphe Boudot



Photograph of a Cs-Ne microfabricated vapor cell. CPT resonance

Chip-scale atomic clocks (CSACs) demonstrate an unrivaled size-power-stability budget and are now widely used in many applications with a significant economic impact. In traditional CSACs, alkali atoms interact continuously with the interrogating light field in a microfabricated cell. In this configuration, the clock frequency presents a significant sensitivity to variations of the light field. These light-shift effects are known to have a major effect on the clock's mid-term stability.

In order to tackle this issue, inspired from some of our previous studies, we have demonstrated the implementation of advanced pulsed interrogation protocols for light-shift mitigation. These methods actually permit the extraction of the light shift experienced by the atoms during light pulses and to make appropriate compensation in next clock cycles.

With these sophisticated techniques, we find that the dependence of the clock frequency to laser field parameters variations is reduced by more than two orders of magnitude, with respect to the standard method. We have also demonstrated a clear improvement of the clock Allan deviation of the microcell clock, between 102 and 105 s.

The benefit of these techniques could have a relevant impact by stimulating the development of new-generation CSACs adopting such pulsed probing methods.

**Facilities:** MIMENTO, OSC-IMP

**References:**

M. Abdel Hafiz et al., Applied Physics Letters 112, 244102 (2018). https://doi.org/10.1063/1.5030009

C. Carlé et al., IEEE Trans. Ultrason. Ferroelec. Freq. Contr. 68, 10, 3249-3256 (2021). 10.1109/TUFFC.2021.3085249

M. Abdel Hafiz et al., Appl. Phys. Lett. 120, 064101 (2022). https://doi.org/10.1063/5.0082156

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## THREE HIGH-IMPACT PUBLICATIONS ON THE APPLICATION OF CONTROL SYSTEMS TO NEUROSCIENCE

### AS2M

Jean-Julien Aucouturier

With the arrival of JJ Aucouturier (Directeur de recherche CNRS) in the AS2M department in Jan. 2021, a new line of research was launched in the PHM team on applications of system identification methods (namely, the technique of "reverse correlation") for the analysis and prediction of neuroscience data. This new activity is off to a good start, as it has produced three high-impact publications in 2021: an article published in Nature Communications applying reverse correlation to understand how listeners can infer whether

EEG experiments conducted in the AS2M Department's new neuroscience research group.

their interlocutor is honest or lying from the sound of their voice (Goupil et al.); an article published in Current Biology investigating emotional voice perception in congenitally blind patients (Arias, Bellmann & Aucouturier); and one article published in Clinical Neurophysiology applying similar technique to optimize the detection of consciousness from EEG recordings in coma patients (Pruvost-Robieux et al.). This work was notably conducted in collaboration with doctors in GHU Paris Psychiatrie et Neurosciences (Hôpital Sainte-Anne) in Paris, France.

**References:**

P. Arias et al., Current Biology 31(19), PR1112-R1114 (2021). https://doi.org/10.1016/j.cub.2021.08.059

L. Goupil et al., Nature Communications 12, 861 (2021). https://doi.org/10.1038/s41467-020-20649-4

E. Pruvost-Robieux et al. Clinical Neurophysiology, in press, 2021 https://doi.org/10.1016/j.clinph.2021.12.015

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## MICROFLUIDICS AT FIBER TIP FOR NANOLITER DELIVERY AND SAMPLING

### AS2M

Antoine Barbot

This article explores the potential of a hydrophobic microfluidic allowing the manipulation of a picolitre drop in a dry environment. This allows an extensive use of the capillary mechanism arising from the triple line interaction between the liquid, the gas and the surface. In particular capillary valves are demonstrated to create, deliver and sample picolitres of fluid by assembling a micrometre size microfluidic chip at the tip of a capillary bundle. Such a mechanism could allow precise local drug delivery as well as a minimally invasive biopsy with important spatio-temporal resolution. This technology was developed in collaboration with Imperial College London and is now part of FEMTO-ST expertise as well with the recruitment of Antoine Barbot as Chargé de recherche CNRS.

**References:**

A.Barbot et al., Adv. Science 2004643 (2021). https://doi.org/10.1002/advs.202004643

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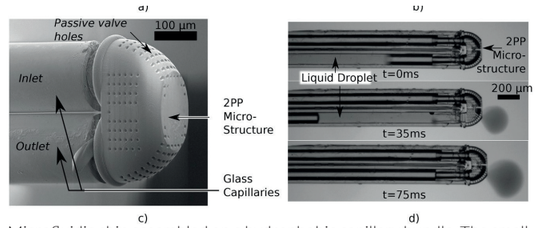


Microfluidic chip assembled on a hydrophobic capillary bundle. The small holes act as a capillary valve that let the fluid pass but not the gas.

# RESEARCH HIGHLIGHTS

## CONTRIBUTION TO THE DEVELOPMENT OF EXTRACELLULAR VESICLE-BASED MEDICINAL PRODUCTS

Céline Élie-Caille, Wilfrid Boireau

**MN2S**

This position paper reports on the growing use of extracellular vesicles (EVs) as a new medicinal procedure, and on the establishment of a French network, bringing together experts in extracellular vesicles and nanomedicine, named "EVOLVE". This network to which C. Elie-Caille & W. Boireau bring their expertise in EVs bioanalysis and nanocharacterization, aims at the perspective of a clinical application of these natural and possibly customized nanovesicles.

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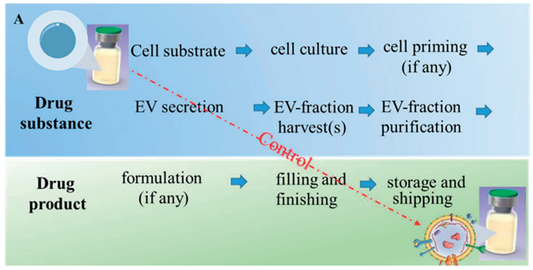
**References:**

Silva et al., Adv. Drug Delivery Rev., 179 114001 (2021) https://doi.org/10.1016/j.addr.2021.114001




Simplified workflow of the main steps related to EV-based product manufacturing.

## NOVEL POROUS CARBON MATERIAL FOR THE DETECTION OF TRACES OF VOLATILE ORGANIC COMPOUNDS IN INDOOR AIR

Achraf El Mohajir, Franck Berger, Jean-Baptiste Sanchez

**MN2S**

A highly sensitive and selective silicon-based micro-analytical prototype was used to identify a few ppb of volatile organic compounds (VOCs) in indoor air. Herein, a new non-activated tannin-derived carbon synthesized by an environmentally friendly method, DM2C, a MIL-101(Cr) MOF and a DaY zeolite were selected for the preconcentration of BTEX compounds (i.e. benzene, toluene, ethylbenzene and xylenes). Integrating a small amount of these nanoporous solids inside a miniaturized preconcentration unit led to excellent preconcentration performance. By taking advantage of the high adsorption-desorption capacities of the DM2C adsorbent, concentrations as low as 23.5, 30.8, 16.7, 25 and 28.8 ppb of benzene, toluene, ethylbenzene, ortho- and para-xylene, respectively, were detected in a short analysis time (~10 min) even in the presence of 60 % relative humidity at 25 °C. The DM2C showed excellent stability, over a period of 4 months and more than 500 tests, as well as repeatability, which makes it a very reliable adsorbent for the detection of trace VOCs in indoor air under realistic conditions in the presence of humidity.

https://www.femto-st.fr/fr/Departements-de-recherche/MN2S/Groupes-de-recherche/MINAMAS

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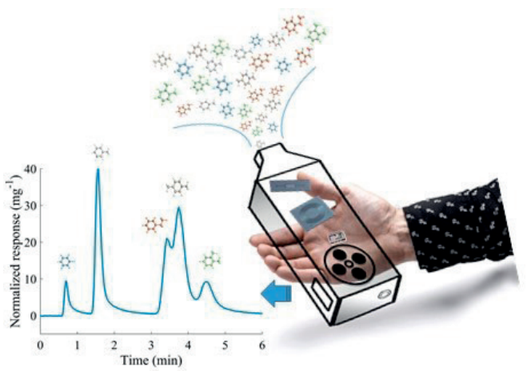
**References:**

A. El Mohajir et al., ACS Applied Materials & Interfaces 13 (33), 40088 (2021) www.doi.org/10.1021/acsami.1c10430




Dynamic normalized response, normalized per milligram of adsorbent, of the innovative micro-system for the detection of BTEX under realistic conditions

## MEDICAL ENGINEERING (AI, DATA)

Bruno Perez, Christophe Lang, Julien Henriet, Laurent Philippe

**DISC**

Managing risks related to the actions and conditions of the various elements that make up an operating room is a major concern during surgery. In these studies, we propose to focus on the causes that lead to incidents as well as their prediction, which are essential elements in the determination of alerts. For that purpose, we have designed an architecture that couples a Multi-Agent System (MAS) with Case-Based Reasoning (CBR). The ability to simulate many situations thanks to MAS, combined with analytical data management thanks to CBR is an efficient way of analyzing the state of the system and predicting its evolution. Beyond this architecture, decision support tools have been integrated to classify the behavior of entities and predict their evolution. The results presented in these articles show that our model can manage alert thresholds in an environment that manages data as disparate as infectious agents, patient's vitals, and human fatigue. In addition, they reveal that the thresholds proposed by the system are more efficient than the predefined ones. These results tend to prove that our simulator is an effective alert generator.

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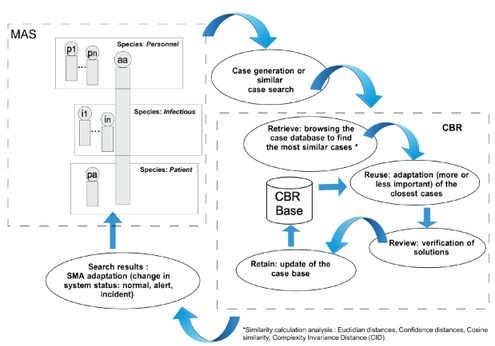
**References:**

B. Perez et al., Expert systems with applications 184, 115506 (2021) https://doi.org/10.1016/j.eswa.2021.115506

B. Perez et al. Computers in Biology and Medicine 128, 104040, (2021) https://doi.org/10.1016/j.compbiomed.2020.104040

B. Perez et al., Expert systems with applications 184, 115506 (2021) https://doi.org/10.1016/j.eswa.2021.115506




Global architecture of the MASSAI platform based on Case-Based Reasoning and Multi-Agent System.

## STUDY OF THE SOCIO-TECHNICAL IMPACT OF A SMART BRA FOR THE EARLY DETECTION OF CANCER OF THE BREAST

Zeina Al Masry, Florence Bazzaro, Katy Cabaret, Olivier Dembinski, Bénédicte Rey, Nicolas Simoncini, Mathieu Triclot, Noureddine Zerhouni

**AS2M, RECITS, APPLIED MECHANICS, DISC**

This paper has the novelty of being co-authored by researchers in humanities and engineering sciences. It presents the results of one of the technological projects that this association of disciplines allows within FEMTO-ST: SBRA (Smart Bra). Funded by a French-Swiss Interreg, with the collaboration of the Hôpital Nord Franche-Comté, this project aimed at developing a smart bra, combining sensors for measuring skin temperature and electrical impedance, which can be used in breast cancer screening, as an alternative to mammography or self-palpation.

The paper presents the results of the study aimed at anticipating the barriers to use and acceptance with respect to breast cancer screening practices of health professionals and patients. It suggests ways of modifying the form and functions of the device to facilitate its potential insertion in the health care system, based on a qualitative survey with about 40 interviews with hospital and private healthcare professionals and women who have or have not had breast cancer, who practice screening or who refuse it.

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**References:**

Z. Al Masry et al. Santé publique, 33-4, 473 (juillet-août 2021). https://www.cairn.info/revue-sante-publique-2021-4-page-473.htm

For a popularized presentation : Z. Al Masry, « Cancer du sein: demain, un soutien gorge connecté grâce aux maths ? », The Conversation, 8 octobre 2021, https://theconversation.com/cancer-du-sein-demain-un-soutien-gorge-connecte-grace-aux-maths-168306

# RESEARCH HIGHLIGHTS

## AN OPEN-SOURCE FENICS-BASED FRAMEWORK FOR HYPERELASTIC PARAMETER ESTIMATION FROM NOISY FULL-FIELD DATA: APPLICATION TO HETEROGENEOUS SOFT TISSUES

Aflah Elouneg, Arnaud Lejeune, Jérôme Chambert, Emmanuelle Jacquet

### APPLIED MECHANICS

A finite-element method of updating-based open-source framework (available online) has been developed by Biomechanics of Soft Tissue's team, in collaboration with the Legato Team from The University of Luxembourg. Its main function is identifying mechanical parameters of heterogeneous hyper-elastic materials. The framework was validated in silico generated full-field data. The numerical process simulates an in vivo uniaxial tensile experiment performed with an extensometer on a model composed of a keloid scar surrounded by healthy skin. The artificial input data represent reaction forces and displacement fields, which were captured by, respectively, force sensor and Digital Image Correlation techniques. By using a nonlinear FEM algorithm and an inverse method, the model parameters were assessed through a constrained optimization function with no quadratic penalty term. As a result, four material parameters related to the Gent model can be identified from a uniaxial test. The originality of this work lies in two major elements: (i) developing a low-cost technique able to characterize the mechanical properties of highly heterogeneous soft tissue, and (ii) exploring the model accuracy via a detailed study of the interplay between discretization error and the error due to measurement uncertainty.

https://github.com/aflahelouneg/inverse_identification_soft_tissue.

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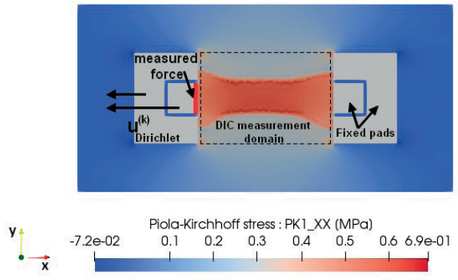
**References:**

J. Chambert, et al., J. Mech. Behavior of Biomedical Materials 99, 206 (2019). https://doi.org/10.1016/j.jmbbm.2019.07.025




Keloid-skin model undergoing large deformation in an uniaxial test secured by an Ultra-light extensometer.

## HYDROGEN ENERGY SYSTEMS: A CRITICAL REVIEW OF TECHNOLOGIES, APPLICATIONS, TRENDS AND CHALLENGE

Meiling Yue, Hugo Lambert , Elodie Pahon, Robin Roche, Samir Jemei, Daniel Hissel

### ENERGY

The global energy transition towards a carbon neutral society requires a profound transformation of electricity generation and consumption, as well as of electric power systems. Hydrogen has the important potential of accelerating the process of scaling up clean and renewable energy, however its integration in power systems remains little studied. This paper reviews the current progress and outlook of hydrogen technologies and their application in power systems for hydrogen production, re-electrification and storage. The characteristics of electrolysers and fuel cells are demonstrated with experimental data and the deployments of hydrogen for energy storage, power-to-gas, co- and tri-generation and transportation are investigated using examples from worldwide projects. The current techno-economic status of these technologies and applications is presented, in which cost, efficiency and durability are identified as the main critical aspects. This is also confirmed by the results of a statistical analysis of the literature. Finally, conclusions show that continuous efforts on performance improvements, scale ramp-up, technical prospects and political support are required to enable a cost-competitive hydrogen economy.

https://www.sciencedirect.com/science/article/pii/S1364032121004688

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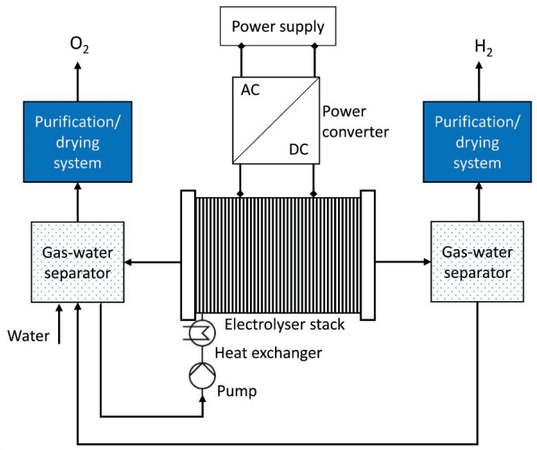
**References:**

M. Yue et al., Renew. Sustain. Energy Rev. 146, 111180 (2021). https://doi.org/10.1016/j.rser.2021.111180




Electrolyser system structure



## DESIGN AND PLANNING FOR HYDROGEN CONSUMPTION AND SUPPLY

Marwa Haddad, Ayham Kassab, Jean-Marc Nicod, Marie-Cécile Péra, Laurent Philippe Veronika Rehn-Sonigo, Christophe Varnier, Hervé Manier, Marie-Ange Manier

### DISC, AS2M, FCLAB

Several projects focus on infrastructures using or providing renewable energy like hydrogen. One of them concerns the design and scale of green data centers. Binary search algorithms were developed to determine the IT equipment for processing tasks, and to scale the supplying electrical infrastructure using various sources including a hydrogen system. Experiments with real IT workload traces and actual meteorological data illustrate the provided methodology to decision makers for appropriately configuring their data center, depending on their workload and location.

The energy consumption and carbon footprint of such Information and Communications Technology structures are also on the rise. Then the scheduling of independent tasks is tackled on a multi-core machine within a predicted renewable power envelope that varies over time. The complexity of instances and the performance of several scenarios are evaluated.

Another area of application is the Hydrogen Supply Chain network. It is to determine simultaneously the location of hydrogen fuelling stations (HFSs) and routing decisions for hydrogen delivery trucks. The HFS network is determined while maximizing the fuelling demand flow captured and minimizing the total daily cost. Managerial insights and metaheuristic algorithms' performances are discussed in a case study in Bourgogne-Franche-Comté, regarding the role of fleet composition and physical forms of hydrogen.

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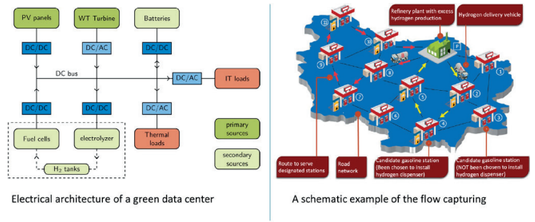
**References:**

M. Haddad et al., Sustain. Comput.: Informatics and Syst. 30, 100505 (2021) https://doi.org/10.1016/j.suscom.2020.100505

A.Kassab et al., Sustain. Comput.: Informatics and Syst., 31, 100590 (2021) https://doi.org/10.1016/j.suscom.2021.100590.

L. Li et al., Transport. Research Part E: Logistics and Transport. Rev. 152, 102384 (2021) https://doi.org/10.1016/j.tre.2021.102384




Electrical architecture of a green data center



A schematic example of the flow capturing

Infrastructures consuming or supplying hydrogen.

# RESEARCH HIGHLIGHTS

## FRENCH VITAL RECORDS DATA GATHERING AND ANALYSIS THROUGH MACHINE LEARNING ALGORITHM AND IMAGE PROCESSING FEATURES RECOGNITION

Laurent Heyberger

### RECITS

Teaching through research and collaboration between computer sciences (CS) and humanities and social sciences (HSS) are at the heart of the "Techn'Hom Time Machine (THTM)" project, which aims at digitally reconstructing not only the building evolution and the equipment of the Alstom-SACM and DMC factories of Belfort, but also the demographic behaviours of the population of the adjoining working-class district of the « Vosges ». As in many other HSS projects, the reconstitution of the behaviours and socio-biological trajectories of the Belfort population from birth to death here requires the analysis of handwritten serial archives. This article written by students in collaboration with a researcher in computer science and a researcher in history is a first step to fully automate the process of processing vital records by AI. The longer-term goal is to develop a process that can be replicated in other DH (Digital Humanities) research programs.

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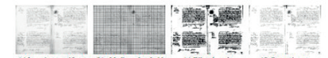
**References:**

C. Plateau-Holleville et al., J. Data Mining and Digital Humanities (2021) : https://doi.org/10.46298/jdmdh.7327 and https://hal.archives-ouvertes.fr/hal-03189188v3

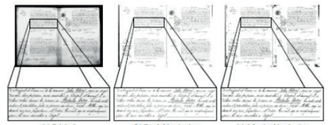


(a) Input image without background (b) Median threshold blocks (c) Dilated mask (d) Output image

Figure 5: Adaptive local binarization process

This method requires, however, to parameterise the size of the blocks that lead it to be less robust to strong image changes. This requires specific tests to properly set the values according to input image properties.

Finally, figure 6 shows the result of the full preprocessing pipeline and illustrate how the chosen adaptive binarization performs compared to the method introduced by Otsu [1979]. The latter can erase more noise than the one we selected, however, letter shapes are less eroded which enables better readability.



(a) Original (b) Otsu's binarization (c) Adaptive binarization

Figure 6: Comparison of Otsu's and adaptive binarization on the full preprocessing pipeline

Teaching through research and collaboration between CS and HSS are at the heart of the THTM project.

## PLANNING AND SCHEDULING FOR TRANSPORT ACTIVITIES

Ali Skaf, Zaher Al Chami, Emma Laajili, Sid Lamrous, Hervé Manier, Marie-Ange Manier, and Jean-Marc Nicod

### DISC, AS2M

The quoted published papers in 2021 illustrate the research conducted in the field of planning and scheduling of transport activities for several logistic application areas. Operational Research based models and algorithms were developed to address integrated optimization problems, like:

- Logistic activities in maritime ports like the port of Tripoli-Lebanon, formulated as a Quay Crane and Yard Truck Scheduling Problem;
- Goods transportation in smart cities, studied in the form of a Robust Selective Pick up and Delivery problem, with uncertain travel times. The robustness consists in finding a solution which remains feasible over all scenarios;
- Joint design and operation problems in industrial workshops, among which we focus on a Cyclic Hoist Design and Scheduling Problem, where the hoists must avoid collisions while moving products from one machine to another one.

One of the challenges is to overcome scientific blockages such as the synchronization of the transport resources, the multi-objective characteristics, and sometimes the low number of feasible solutions in the research space. Several efficient exact and hybridized metaheuristic methods were proposed (Mixed Integer Linear Programs, Genetic based algorithms, Variable Neighborhood Search based algorithm…) with the goal to solve realistic large size instances.

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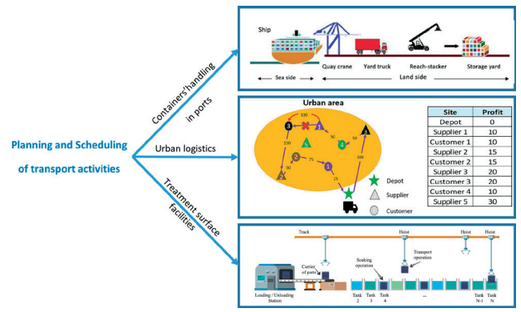
**References:**

• A. Skaf et al., Computers & Industrial Eng. 159, 107448 (2021). https://doi.org/10.1016/j.cie.2021.107448
• Z. Al Chami et al., Int. J. Production Research (2021). https://doi.org/10.1080/00207543.2021.1933236.
• E. Laajili et al., Computers & Industrial Engineering 157, 107225 (2021), https://doi.org/10.1016/j.cie.2021.107225




Examples of transport application areas of our research on optimization problems in Planning and Scheduling.

## MULTI-PHYSICS MODELLING PERFORMED IN THE MAGNETIC REFRIGERATION DOMAIN

Julien Eustache, Antony Plait, Frédéric Dubas, Raynal Glises

### ENERGY

In the last few decades, there has been particular interest in the field of magnetic refrigeration. Indeed, an increasing number of magnetic refrigeration prototypes based on the principle of active magnetic regenerative refrigeration (AMRR) have been built and tested. A lot of studies have been carried out to obtain more efficient devices. Thus, the modeling is a crucial step to perform a preliminary study and optimization. In this paper, a state-of-the-art of multi-physics modelling of an AMRR cycle is carried out.

The figures show a theoretical schematic view of a magnetic refrigeration device, an experimental device developed at the FEMTO-ST Institute and accompanied by a comparison between simulation results and experimental measurements.

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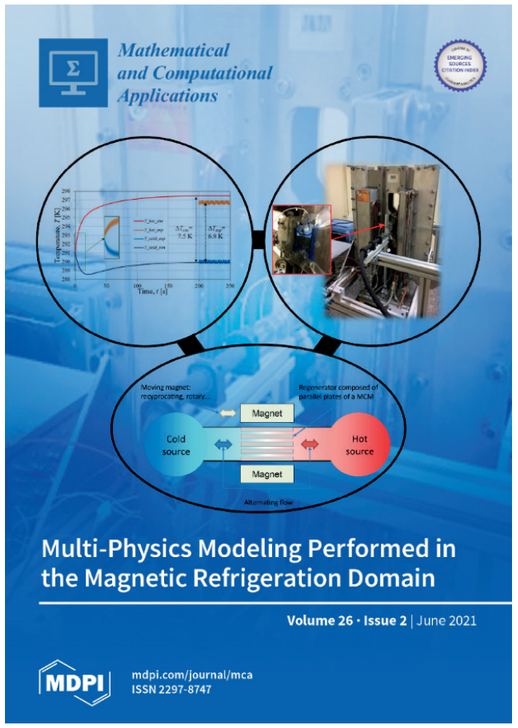
References:

J. Eustache et al., Math. Comput. Appl. 26 (2), 47 (2021) https://doi.org/10.3390/mca26020047



# BOOKS


## JEAN-PIERRE CHEVÈNEMENT. THE LAST OF THE JACOBINS :

The first scientific book entirely dedicated to the itinerary and thought of a major actor of the Fifth French Republic.

Laurent Heyberger and Pierre Lamard

### RECITS

Jean-Pierre Chevènement has left his original mark on French political life for more than forty years. Noting the gap between the importance of the functions he held and the real knowledge of his action and influence, two historians from RECITS, in association with colleagues from the University of Haute-Alsace, organized a symposium in 2019 in Sevenans and Mulhouse from which this book is drawn. Jean-Pierre Chevènement, le dernier des jacobins (Jean-Pierre Chevènement, the last of the Jacobins) is the first scientific work entirely dedicated to the itinerary of this major actor of the Fifth Republic, based on unpublished sources, including those of Chevènement himself. The authors critically analyze his struggles for the Republic, the Nation, and the Left, his industrialist project based on a strategic vision of the State, his desire to raise the status of the "Republican school", and finally his singular vision of the place and role of France at the international and European levels, from his first steps in politics to his candidacy in the 2002 presidential election.

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Pierre.lamard@utbm.fr

**References:**

Régis Boulat, Renaud Meltz (eds.), in collaboration with Laurent Heyberger, Jean-Pierre Chevènement. Le dernier des jacobins, Paris, Nouveau Monde éditions, 2021.


## LA FIN DU GAME? : LES JEUX VIDÉO AU QUOTIDIEN

Mathieu Triclot

### RECITS

The book "La fin Game : les jeux vidéo au quotidien" delivers the results of a research project, funded by the ANR Ludespace, on the practices of video game players in France. The book is not a collection of individual chapters. It was written collectively by the team, which includes sociologists, ethnologists, linguists, geographers, specialists in the sciences of education and the philosophy of technology.

The first aim of the book is to provide information on state of the art practices of players in France. The diversity of these practices are not well known and cannot be reduced to the stereotype of the adolescent male playing shooting games for hours. Video games are an ordinary activity that takes place in the free time of daily routines. They are interwoven into lifestyles and socialising.

The second contribution of the book is its methodological innovations. Not only does the book combine traditional methods of social sciences, based in particular on a statistical survey supplemented by qualitative interviews, but it also presents the results of innovative methods, based on video observations or mental maps drawn by the players, which make it possible to study the more intimate experience of gaming.

https://pufr-editions.fr/produit/la-fin-du-game/

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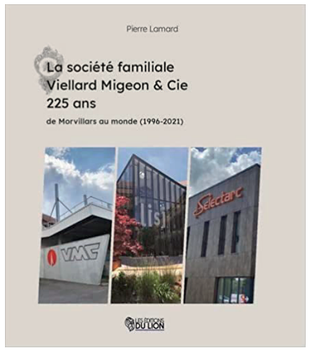
**References:**

H. Ter Minassian, V. Berry, M. Boutet, I. Colon de Carvajal, S. Coavoux, D. Gerber, S. Rufat, M. Triclot, V. Zabban, La fin du game ? : les jeux vidéo au quotidien, Presses Universitaires François Rabelais, 2021






## LA SOCIÉTÉ FAMILIALE VIELLARD-MIGEON ET CIE, 225 ANS.

De Morvillars au monde (1996-2021)

Pierre Lamard

### RECITS

This book testifies to the drive of a family business over the long term in the light of the global economy. Its aim is to provide the keys to understanding an unconventional industrial journey by retracing the history of the last 30 years of a company founded 225 years ago in Morvillars, based on forging and wire-drawing. On the one hand, the author places the holding company in its regional, ancestral and cultural environment, the cradle of which remains the Allaine valley. On the other hand, its industrial activities are seen through its subsidiaries (LISI, VMC-Pêche and Selectarc) against the international economic backdrop of a 21st century jolted by powerful upheavals.

Pierre Lamard takes a look at a strategy based on judicious industrial alliances leading to a major change of scale, on controlled technological risk-taking, and finally on innovation and the creation of value. The company's attachment to steel-wire processing activities has allowed it to face globalization in all its pervasiveness and to resist the phenomenon of de-industrialisation and its corollary, the degradation of industrial employment. Faced with the major structural and economic trends which cross industry and the business world, Viellard-Migeon & Cie embodies a form of salutary but discrete capitalistic stability in the shadow of much more emblematic trade names.

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**References:**

Pierre Lamard, La Société familiale Viellard-Migeon et Cie, 225 ans. De Morvillars au monde (1996-2021), Editions du Lion, 2021


## DÉMOCRATIE TECHNIQUE EN TRAVAIL

Pierre Lamard

### RECITS

After the publication of two initial works, Elements of Technical Democracy (2015) and For an education in technology (2017), this third contribution comes from a session of the 45th symposium of the International Committee for the History of Technology organised in 2018. The aim of the work is to highlight the extremely "proteiform" nature of the concept of technical democracy in the workplace as well as in everyday life.

Whether free or controlled, these activities always involve technical issues and integrate a wide range of content and operations on different scales. Constantly in operation, they are perpetually modified by those who actually do the work, and not only by those who design or "manage" them.

We are at the heart of the history of a socio-technical process which queries the methods of governability of science and technology, the roles of the stakeholders and the structure of decisions within the processes of design and ultimately of innovation ... but whatever the forms of appropriation, transgression, consultation and above all of choice, the concept of technical democracy can only come to life if people at large continue to be trained to become technically discerning and competent.

This work hopes to contribute to that necessary awareness.

https://www.utbm.fr/editions/les-derniers-ouvrages/

pierre.lamard@utbm.fr

**References:**

Pierre Lamard, Pierre-Yves Lequin (dir.), Démocratie technique en travail, Pôle éditorial UTBM, 2021

# ACADEMIC COLLABORATIONS

## EURAMET NEXTLASER DEVELOPMENT OF NEXT-GENERATION ULTRA-STABLE LASERS

Vincent Giordano, Yann Kersalé, Clément Lacroûte, Jacques Millo

### TIME & FREQUENCY

The frequency stability of todays' most stable lasers is based on the length stability of well-isolated Fabry-Perot Cavities and is ultimately limited by the fundamental thermal noise affecting the distance between the cavity mirrors. To date, record results were demonstrated by a 50 cm long cavity using an ultralow expansion glass spacer, or by a 21 cm cavity using a silicon spacer cooled at 124 K, reaching both fractional frequency stabilities in the 4-6 x $10^{-17}$ range at 1 s.

The EURAMET NEXTLASER project aims to develop the next generation of ultra-stable lasers, with targeted frequency instabilities below $1\times10^{-17}$. The solutions developed, which aim to reduce both the fundamental and technical noise sources, will be combined in operational systems that will be applied for improved tests of fundamental physics.

FEMTO-ST is involved in the integration of closed-cycle cooling for continuous cryogenic operation of optical cavities at 124 K, 4 K and below. The knowledge gained in this project will have an impact on a wide range of applications, including optical telecommunication, radar systems, long-distance fibre links, synchronization of telecommunication networks, satellite navigation and optical sensing.

14 kg, 18 cm long single-crystal silicon cylinder that will constitute the spacer of a sub-1 K Fabry-Perot cavity. Optical contacting attachment of the cavity mirrors will be performed at FEMTO-ST.

**Facility:** Oscillator IMP

https://www.ptb.de/empir2021/nextlasers/home/

Partners : Physikalisch-Tech. Bundesanstalt (DE), INRIM (IT), LNE (FR) Observatoire de Paris (FR), VTT (FN), RISE (SE), CNRS (FR) Heinrich-Heine Univ. Düsseldorf (DE) LINKS (IT), Lunds Univ. (SE) Tech. Univ. Braunschweig (DE), Univ. Mikolaja Kopernika w Toruniu (PL).

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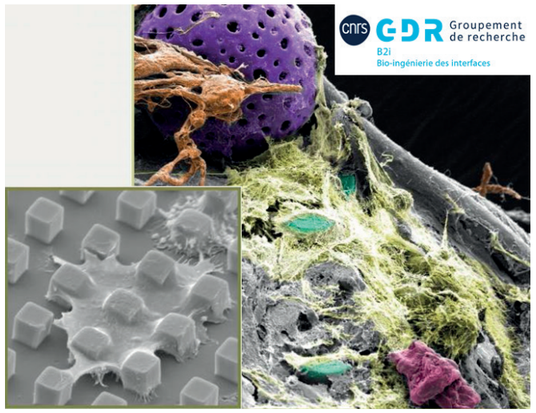
## GDR CNRS B2I BIOENGINEERING OF INTERFACES

Vincent Humblot, Wilfrid Boireau, Céline Elie-Caille, Annie Frelet-Barrand, Therese Leblois, Alain Rouleau

### MN2S




Biofilms on micronanostructured substrates

Objectives of the B2i network:

The mission of the GDR B2i, coordinated by FEMTO-ST, is to federate the French and French-speaking European communities around a multidisciplinary theme whose research activities focus on biointerfaces. It is composed of 230 researchers involved in 55 academic laboratories (France, Belgium, Luxembourg, Switzerland and Italy).

The purpose of the GDR B2i is to encourage synergies between the different disciplines in order to allow the emergence of innovative and interdisciplinary projects. Faced with current public health challenges, medical devices (biomaterials, implantable devices), biochips, Lab-on-a-chips, biosensors and nanomaterials are used in a wide range of applications ranging from medical to environmental analysis to food control (dosage of GMOs, mycotoxins, pathogens, etc.).

The bioengineering of interfaces therefore aims to control the physical, chemical and biochemical properties at the interfaces of materials in order to control their stealth and specificity.

Through the B2i network, several thematics are developed:

- Development of complex biointerfaces: functionalization, printing and nano-structuring
- Characterization of biointerfaces, opportunities and perspectives: towards operando characterizations and in silico calculations
- Biointerfaces at the heart of medical devices
- Transversal action: a major issue: microorganism / surface interactions

https://events.femto-st.fr/GdR_B2i/fr

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## THE FR SPE PHOTOEMISSION SPECTROSCOPY RESEARCH FEDERATION

Vincent Humblot, Thomas Baron, Virginie Blondeau-Patissier

### MN2S, TIME & FREQUENCY

The FR SPE Photoemission Spectroscopy Research aims to structure the scientific community around photoemission and related spectroscopies by sharing the very diverse


XPS apparatus

expertise present in laboratories in the national territory. The project of a Research Federation in the various fields covered by Photoemission Spectroscopies is the result of a broad upstream reflection, initiated by the CNRS Institute of Chemistry.

In order to be able to take on the scientific challenges of tomorrow, in a context of global competitiveness, the national photoemission spectroscopy community must know how to pool its instrumental capacities. In addition it must share and disseminate its knowledge and structure its practices and methodologies according to a coherent plan.

The Federation organizes and coordinates visible and ambitious actions, with the permanent concern of promoting interdisciplinarity between its staff, currently belonging to 43 CNRS laboratories. They come from several CNRS Institutes of Chemistry (INC), Physics (INP) and Engineering and Systems Sciences (INSIS) as well as a CEA and IFPEN Laboratories. A total of 280 Researchers Engineers and Technicians from a multitude of backgrounds are part of this open structure.

In general, the Federation works on the scientific challenges identified, by creating very strong thematic synergies between teams or even laboratories. It also invests in training programs adapted to the different needs of the scientific community. It is an ideal place for reflection on the structuring of the community of the laboratory spectrometer network, as well as through the establishment of open platforms. Finally, it coordinates new, sometimes unique, shared and expensive equipment projects.

**Facility:** MIMENTO

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https://fr-spe.cnrs.fr/

# ACADEMIC COLLABORATIONS

## UNIVERSITÉ LIBRE DE BRUXELLES

ULB: Pierre Lambert

FEMTO-ST: Antoine Barbot, Michaël Gauthier, Aude Bolopion

### AS2M

The collaboration merges the competences of FEMTO-ST in micro/nanorobotics and the know-how of ULB in using surface tension as a micro-actuation principle. For 10 years, we have been proposing original robots working at the air-liquid interface. Indeed several robotic micromanipulation methods have been developed to position micro-objects mostly in air and in liquids. The air-water interface is a third medium where objects can be manipulated, offering a good compromise between the two previously mentioned. Objects at the interface are not subjected to stick-slip due to dry friction in air and profit from a reduced drag compared with those in water. We have recently published in Science Robotics the ThermoBot, a microrobotic platform dedicated to the manipulation of objects placed at the air-water interface. For actuation, ThermoBot uses a laser-induced thermocapillary flow, which arises from the surface stress caused by the temperature gradient at the fluid interface. The actuated objects can reach velocities up to 10 times their body length per second without any on-board actuator. We illustrated the ThermoBot's capabilities through three examples: simultaneous control of up to four spheres, control of complex objects of both position and orientation, and directed self-assembly of multiple pieces.

https://plambert.ulb.be/team/

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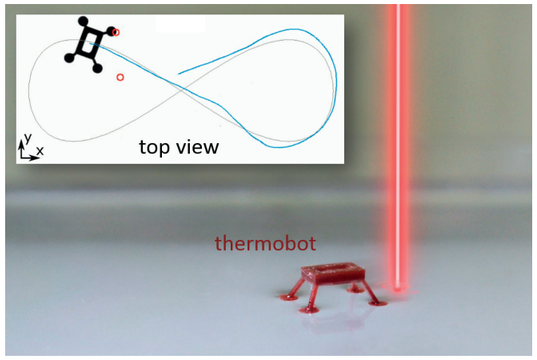
**Facilities:** MIMENTO, Micro Nanorobotic centre

**References:**

F. Piñan Basualdo et al., Sci. Robot. 6(52) (2021) www.doi.org/10.1126/scirobotics.abd3557
F. Piñan Basualdo et al., Physics of fluids, 33(7), 072106 (2021) www.doi.org/10.1063/5.0055373




BVA-type resonator. The two electrode holders are placed on either side of the resonant cavity: the electrodes are a few microns from the sensitive part.

## UNIVERSITY OF WESTERN AUSTRALIA

UWA: Michael E. Tobar

FEMTO-ST: Serge Galliou

### TIME AND FREQUENCY

This Collaboration was initiated in the frame of the 2015 scientific exchange program of the French Embassy in Australia. It was then reinforced by an international program granted by the Australian Research Council, ARC (Grant No. DP160100253, "Precision Tests of Fundamental Physics at the Electroweak Unification Scale," 2016-2019), later followed by an ongoing ARC discovery project (DP190100071).

Studies are based on 5-200 MHz bulk acoustic wave cavities dedicated to pick up unusual weak signals useful for scientific experiments. Recently, a few unexpected events, that could be attributed to High Frequency Gravitational Waves, have been detected from such a cavity connected to a SQUID amplifier operating at 4 Kelvins, along a 5-months long measurement run. These observations have been reported and discussed in a publication entitled "Rare Events Detected with a Bulk Acoustic Wave High Frequency Gravitational Wave Antenna" (M. Goryachev et al., PRL, 127, 071102, 2021).

This recent paper has gained some public interest: https://aps.altmetric.com/details/100000007/news.

A video is also available on the web for more information: https://www.youtube.com/watch?v=1nSgR7lQz9Y

https://www.qdmlab.com/

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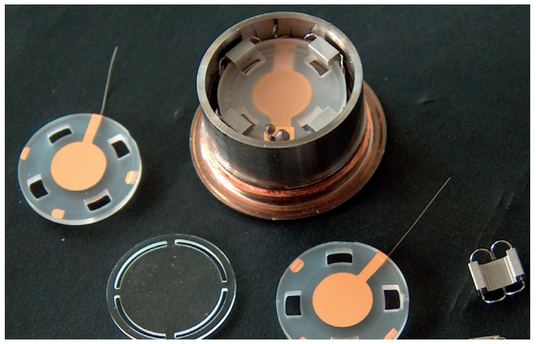
Facilities: Oscillator IMP

**References:**

M. Goryachev et al., Phys. Rev. Lett. 127, 071102 (2021). https://doi.org/10.1103/PhysRevLett.127.071102



A Thermobot moving on a liquid surface using thermocapillary effect. The microrobot is actuated via a laser (side view) enabling it to follow trajectories (top view).

## WARSAW UNIVERSITY OF TECHNOLOGY [1]

## POLISH ACADEMY OF SCIENCES [2]

## UNIVERSITY OF LUXEMBOURG [3]

Jakub Lengiewicz [1,2], Paweł Hołobut [2], Paweł Chodkiewicz [1], Pr. Stéphane P.A. Bordas [3]

FEMTO-ST: Julien Bourgeois, Benoît Piranda

### DISC

The work presented here is the result of several years of collaboration between the teams of Professors Jakub Lengiewicz and Julien Bourgeois in the framework of the Programmable Matter consortium. Several visits to the Institute of Fundamental Technological Research/ Polish Academy of Sciences in Warsaw have been organized: Benoît Piranda in May 2017, Julien Bourgeois in May 2018 and Jakub Lengiewicz was welcomed at FEMTO-ST in September 2017.

During this collaboration we developed a distributed framework for predicting whether a planned reconfiguration step of a modular robot will mechanically overload the structure, causing it to break or lose stability under its own weight.

The distributed algorithm is executed by the modular robot itself and based on a distributed iterative solution of mechanical equilibrium equations derived from a simplified model of the robot. The model treats inter-modular connections as beams and assumes no-sliding contact between the modules and the ground. We also provide a procedure for simplified instability detection.

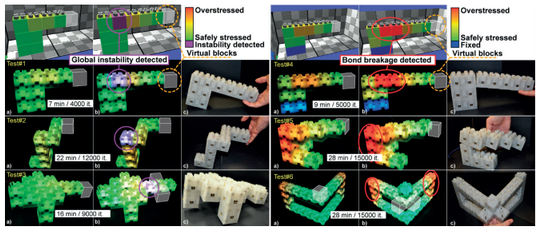
The algorithm has been verified in the Programmable Matter simulator VisibleSim on many different configurations, and in real-life experiments on the modular robotic system Blinky Blocks.

https://www.programmable-matter.com/

benoit.piranda@femto-st.fr

**References:**

B. Piranda, IEEE Transactions on Robotics 37 (6), 2226 (2021) www.doi.org/10.1109/TRO.2021.3074085




Experiments using our method in the simulator (VisibleSim) and on Blinky Blocks hardware. Computation times and iteration numbers are shown in insets.

## UNIVERSITY OF CALIFORNIA, BERKELEY

Berkeley : Sayeef Salahuddin

FEMTO-ST: Ausrine Bartasyte, Samuel Margueron

### TIME & FREQUENCY

This collaboration was initiated during the EMRS meeting in Poland 2018 and it was reinforced during the invited visit of Ausrine Bartasyte at Berkeley in spring 2019. The two teams collaborated on the resonant interaction between surface acoustic waves (SAW) (expertise of FEMTO-ST) and ferromagnetic thin films (expertise of Berkeley), a phenomenon known as acoustically driven ferromagnetic resonance (ADFMR). This provides a way to control magnetic resonance with a purely voltaic excitation. However, devices have historically been operated at harmonic frequencies, leading to large insertion losses. Thanks to this collaboration, we have demonstrated a harmonic-free drive of ADFMR devices where the strain reaches very high values, comparable to the saturation magnetostriction of the magnetic element. The acoustic energy transfer is highly efficient and reaches almost 99.9%. Furthermore, we have observed the presence of multiple absorption maxima across the range of applied magnetic fields, a property not previously reported in the literature.

https://leed.eecs.berkeley.edu/?_ga=2.117246598.1020782604.1651077528-17432128.1651077528

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**Facility:** MIMENTO

**References:**

A. Jung et al., Appl. Phys. Lett. 119, 142403 (2021); https://doi.org/10.1063/5.0054543

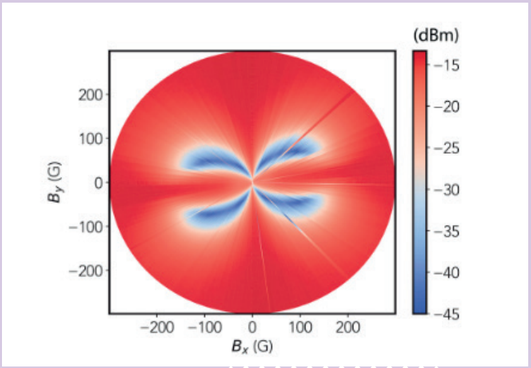



Diagram of the device and PCB mount. Angular field sweep of a 20 nm thick Ni film at an applied input power of 0 dBm (X direction represents the propagation direction of the SAW).

# EVENTS

### MARCH 9 (ONLINE)

Workshop on Capillary Micromanipulation

50 participants

Antoine Barbot, Franco Pinan Basualdo, Aude Bolopion, Michaël Gauthier
AS2M
In collaboration with Tips lab from Université Libre de Bruxelles (ULB)

https://events.femto-st.fr/wcm/en
WCM@femto-st.fr

### JUNE 1-3 (BELFORT)

29e Congrès Français de Thermique

192 participants

François Lanzetta (General Chair), and Valérie Lepiller, Sylvie Begot, Philippe Baucour (General Co-chairs)
ENERGY

https://www.sft.asso.fr/congres-2021.html

francois.lanzetta@univ-fcomte.fr

### SEPTEMBER 28-29 (BESANÇON)

Technical meeting of the CNRS association of research engineers in electronics (RdE)

12 participants

Patrick Nectoux
AS2M

https://www.electroniciens.cnrs.fr/
patrick.nectoux@femto-st.fr

### NOVEMBRE 2-5 (BESANÇON, ONLINE)

21st International Symposium on Optomechatronic Technology, ISOT 2021

98 participants
19 countries

Philippe Lutz, Nadège Courjal, Cédric Philippe
AS2M, OPTIQUE, MN2S

https://isot2021.sciencesconf.org/
isot2021@femto-st.fr

### DECEMBER 13 (BESANÇON, ONLINE)

Photonics day 2021

40 participants

OPTICA, IEEE, SPIE, and EIPHI BFC.

https://www.femto-st.fr/fr/L-institut/evenements/photonics-day-2021#
studentchapter@femto-st.fr
https://www.femto-st.fr/fr/L-institut/FEMTO-ST-Student-Chapter)

### MARCH 9 (ONLINE)

Hamlyn Symposium Workshop on Advancements on Micro-Nanorobotics for Medical Applications

80 participants (United Kingdom, USA, South Korea, China, Switzerland, France)

Kanty Rabenorosoa
AS2M
In collaboration with Univ. Essex and SIAT(CN)

kanty.rabenorosoa@femto-st.fr

### MARCH 12 & NOVEMBER 23 (PARIS/ ONLINE)

Two days of the working group LVP (Langages et Vérification de Programmes)

50 and 74 participants

Alain Giorgetti
DISC

https://groupes.renater.fr/wiki/lvp/public/2103journee
https://groupes.renater.fr/wiki/lvp/public/2109journee

alain.giorgetti@femto-st.fr

### OCTOBER 28 (SEVENANS)

Workshop “Hydrogen and human and social sciences (HSS)”

26 participants

Nicolas Simoncini, Nathalie Kroichvili
RECITS

nicolas.simoncini@utbm.fr

### NOVEMBER 25-26 (ONLINE)

Annual SAGIP seminar of STP (Sciences et Techniques de la Production) and Automatic control

192 participants

Zeina Al Masry Yongxin Wu et Noureddine Zerhouni
AS2M

https://sagip.org/fr/node/1074
zeina.al.masry@ens2m.fr;
yongxin.wu@femto-st.fr

# FACILITIES HIGHLIGHTS

FEMTO-ST key facilities are grouped into centres in order to make them accesible not only to FEMTO-ST members, but also to teaching activities and to regional, national and international industrial and academic partners for their research and/or development projects:

- **CLIPP** (Clinical Innovation Proteomic facility)
- **FLUIDIX** (Facility for fluidic and thermal characterization of complex flows)
- **SMARTLIGHT** (Formation-Research-Innovation using Light facility)
- **MIFHySTO** (Micromanufacturing, mechanics, micromachining, powder injection molding, metal additive manufacturing, surface treatment, filled polymers, metrology, material characterization)
- **MIMENTO** (Microfabrication for Mechanics, Nanosciences, Thermal Science and Optics)
- **Center for Micro-Nano- Robotics**
- **Oscillator-IMP** (Oscillator Instability Measurement facility)
- **Hydrogen-Energy** (Fuel Cell systems, Hydrogen and Power Electronics)
- **SURFACE** (Development and characterization of thin-film materials)
- **AMETISTE** (mechanical characterization of materials, surfaces and structures)
- **FRANCHE-COMTE MESOCENTRE** (Numerical simulation, High Performance Computing)

**References**

https://www.femto-st.fr/fr/Plateformes-technologiques/Mimento-presentation

https://www.femto-st.fr/fr/Plateformes-technologiques/autres-plateformes

## A WORLD'S FIRST HYDROGEN-POWERED SEMI-TRAILER CONCEPT: HYD-DRIVE

DjerdirAbdesslem, Laghrouche Salah, Chabane Djafar, Salhi Issam, Ndiaye Abdoul, Vienot Clément

### ENERGY

**Facility: Hydrogen Energy**

The LAVOISIER project funded by the BPI of the Bourgogne-Franche-Comté region in February 2021, aimed to create a new market for smart hydrogen propulsion trailers. The trailer becomes propulsive and significantly reduces the energy consumption of the tractor. Electrification is obtained by installing a 40 kW fuel cell generator, its feeding hydrogen tanks, a high-voltage pack battery and the power electronics converters, under the floor of the trailer. A fuel cell hybrid source enables the electrical supply to the rear electrical axle of this, the world first hydrogen-powered semi-trailer concept: the "Hyd-drive.

The FEMTO-ST institute has contributed to two main tasks of this project based on the Hydrogen Energy platform. The first one concerned the fuel cell hybrid propulsion chain where the FEMTO-ST researchers provided their expertise in modelling, numerical simulations, sizing, harness design and experimental tests. The second contribution concerns numerical communications with the semi-trailer, the safety and control of the propulsion chain according to different hydrogen operating modes (refuelling, drive and maintenance). This work has involved developing and implementing the vehicle's electrical harness and helping the partners (FRUEHAUF and H2SYS) in implementing a human-machine interface (HMI) allowing efficient and safe control of the vehicle.

Abdesslem.djerdir@utbm.fr


The Hyd-drive semi-trailer vehicle - test track in Lure

## MECHANICAL TESTER MODEL MACH-1 V500C

Tiguida Kadiakhe, Marine Lallemant, Emmanuelle Jacquet, Jérôme Chambert, Stani Carbillet

### APPLIED MECHANICS

**Facility: Ametiste - EFS**

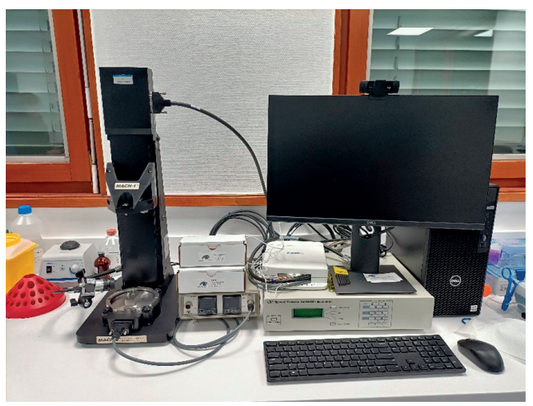
The Mach-1 mechanical tester is an all-in-one device designed for compression, tension, shear, bending, puncture and indentation. It performs uniaxial high-precision testing in compression and tension, in various modes including dynamic, static, and waveform loading. It can be upgradabled and adapted to a large variety of materials and test configurations and is compatible with a wide range of load cells (currently used: 1.5N, 10N, 250N).

The mechanical tester comes with a computer (Windows 10 Pro, Acquisition card, Webcam, etc.) and software (Mach-1 Motion & Mach-1 Analysis). The user-friendly software allows effective data collection and simplified analysis of experiments but also allows data to be imported into third-party software for further analysis. The Mach-1 mechanical tester accurately characterizes specimens with low mechanical properties or with dimensions falling within the micrometer to centimeter range. The accessories include grips designed for tension testing of soft sheet material like biological tissues. Their C-shaped cavities, coupled with the screw-threaded stainless-steel bar, solidly lock the sample in the grip. Also included is a test chamber with sealed transparent walls allowing tests on submerged samples. The test chamber is suitable for use with saline water without the risk of oxidation. A temperature control module can also be mounted with the chamber for complete control of the liquid temperature. The equipment does not require lubrication or complex maintenance and occupies minimal laboratory space.

https://www.biomomentum.com/mechanical-testers/

info@biomomentum.com

**References:** Biomomentum catalogue (2018).



Mach-1 mechanical tester setup.

## FASTER, HIGH RESOLUTION LITHOGRAPHY BRINGS THE NM SCALE WITHIN REACH

Roland Salut, Guillaume Jutzi

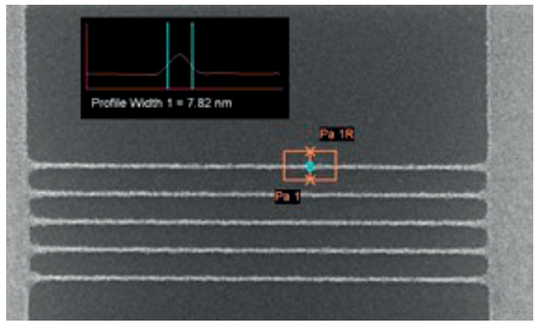
**Facility: MIMENTO**

This year the MIMENTO cleanroom facility has improved its nano and micro patterning capabilities by installing two new state of the art lithography systems:

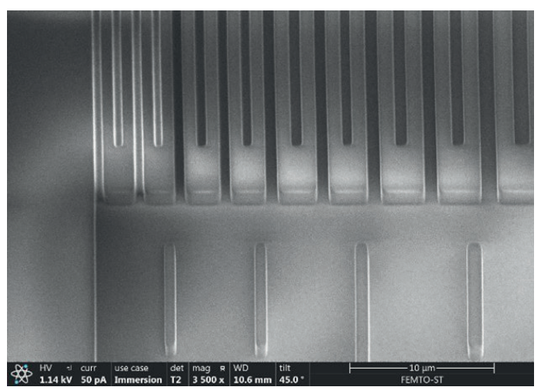
- The first Raith Voyager installed in France is now accessible at FEMTO-ST This new electron beam lithography system has been developed for high resolution (down to 8 nm) and high speed (1 $cm^2$/h). The workflow is optimized with a loadlock, automatic beam alignment and automatic height sensing of the substrate. These unique features now allow exposure of small chips (few $cm^2$) and full wafers (4 and 6 inch) with high flexibility. In addition, compared to previous generation of e-beam systems, the running costs are reduced and more accessible to the budget of an academic lab.
- The Heidelberg Mask Less Aligner (MLA 150) brings new laser lithography at sub-µm resolution to FEMTO-ST. The machine not only has a fast writing speed and makes standard photolithography masks, but also directly writes patterns on substrates, for fast development with resolution down to 0.6µm. In high-resolution mode, 0.8 µm lines and spaces can be written in 75 minutes on a 100x100 $mm^2$ area and it takes only 30 minutes for 1.5 µm lines and spaces. Its two laser diodes (375 and 405 nm) allow matching to the UV sensitivity of many photoresists in a large range of thickness.

https://platforms.femto-st.fr/centrale-technologie-mimento/

mimento@femto-st.fr




8 nm photoresist lines with e-beam lithography




Chirped SAW pattern with laser lithography (wmin = 0.6 µm)

# INNOVATION

# FEMTO ENGINEERING

## FEMTO ENGINEERING

The engineering Centre of the FEMTO-ST Institute offers industrial companies high level engineering developments based on the research conducted at FEMTO-ST.

FEMTO Engineering has sixteen employees and cooperates directly with the research groups within the FEMTO-ST Institute.

FEMTO Engineering contributed to the development of technologies from the laboratory (called proprietary technologies) and concluded contracts with both local companies and large international groups.

Technological fields of concern:

- Energy
- Optics, photonics and laser machining
- Electronics and hyperfrequencies
- Cleanroom micro-technologies
- Robotics
- Artificial intelligence
- Mechanical characterization

Facilities: MIMENTO, CMNR, OSCILLATOR-IMP, AMETISTE, MIFHySTO

### Development of micro-fabrication processes on 6-inch substrates

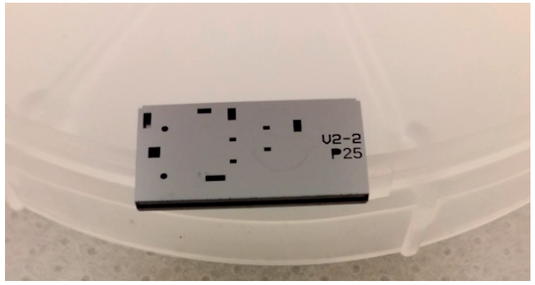
From TRL4 up to TRL7-8

MIMENTO, the microfabrication facility is dedicated to the manufacture of MEMS components on 6-inch substrates. Based on the expertise of MIMENTO engineers, FEMTO Engineering has developed new processes on 6-inch substrates to meet industrial demands:

- Photolithography to define patterns in resist
- Deposition of electrodes
- Bonding of wafers by thermo-compression and anodic bonding
- Engraving to structure the material

a) Silicon MEMS

By combining electrode structuring and silicon etching, we have succeeded in manufacturing electrically controllable silicon micro-supports.




b) Wafer Level Packaging

In order to integrate several functionalities into a microsystem, such as for example sorting and detection for a microfluidic system, a wafer assembly technology has been implemented using wafer-bonding equipment. It is possible to weld plates together by using different types of bonding: thermo-compression, anodic or molecular ones. For micro-fluidic sensors, we focused on Silicon/Glass/Silicon anodic bonding.

This work has already given rise to the development of a prototype for an industrial partner company to be continued with small series production.

www.femto-engineering.fr

contact@femto-engineering.fr



# TRANSFER SUCCESS STORIES

## IQUPHOS : HIGH-PERFORMANCE ENTANGLED PHOTON SOURCE

EU Call: SAGA : ESA's programme of Advanced Research in Telecommunications Systems (ARTES) 4.0

The aim of the project is to provide space components for future Euro Quantum Communication Infrastructure (Euro-QCI). In particular the project is focused on the implementation of high performance! (compact, high brightness >1Gpairs/s) space based entangled photon sources (EPS) used for quantum key distribution (QKD) Safety and Security (4S). This activity is related to the Secure And cryptoGrAphic (SAGA) project under the ARTES 4.0 program.

AUREA Technologie (Coordinator), Airbus Defense and Space ADS (France-Subcontractor), FEMTO-ST (France)

Jean-Marc Merolla CNRS researcher, scientific expert in Quantum Key Distribution architecture.

jean-marc.merolla@femto-st.fr

https://artes.esa.int/

## COMETE PROJECT (FRANCE RELANCE)

In order to address the economic consequences of COVID-19, the French government set out its "France Relance" recovery plan. France will support the thermal renovation of buildings, the decarbonization of industry, green hydrogen, cleaner transport and the transformation of the agricultural sector.

The COMETE project (COnvertisseur thermo MEcanique haute TEmpérature) concerns the decarbonization of industry by way of cogeneration, also known as combined heat and power (CHP). CHP is the use of a power station to generate both electricity and useful heat. CHP uses heat that would be wasted in a conventional power plant, potentially reaching a total efficiency of up to 80%, compared with 60% for the best conventional plants. This means less fuel needs to be consumed to produce the same amount of useful energy. ANANKE developed a novel CHP system in collaboration with the THERMIE research team and the COMETE project will focus on the improvement of heat exchange at high temperature and high pressure.

FEMTO-ST: francois.lanzetta@univ-fcomte.fr

ANANKE: brice.bryon@ananke.eu)

https://www.ananke.eu

# INDUSTRIAL PROJECTS

## SYMBIO

Christophe Vacquier

David Bouquain, Daniel Hissel, Elodie Pahon, Samir Jemei, Nadia Steiner, Noureddine Zerhouni, Julie Aubry, Fabian Van Der Linden, Jérémy Villaume

### ENERGY, AS2M

The research collaboration between FEMTO-ST and the SYMBIO company is focused on the development of new generations of proton exchange membrane fuel cell stacks and systems. The FEMTO-ST contribution deals with the analysis of performance of a proton exchange membrane fuel cell in an automotive application framework and especially during highly degraded operating modes, as for instance start/stop phases. Indeed, start-stop cycles are one of the main sources of degradation for fuel cell systems, embedded in the automotive applications, among other dynamic conditions as idling, load cycling or high power. In this collaborative work, large-scale experimental characterization campaigns (including the measuring of polarization curves and electrochemical impedance spectra, and using 3 PEM fuel cell test benches with electric powers from 5kW to 120kW) are used to analyse the degradation mechanisms inside the fuel cell stack during those operating conditions. Moreover, this experimental work is completed by three PhD thesis focusing on specific common topics of interest such as cold-start of PEM fuel cell systems, and prognostic & health management of fuel cells. The collaborative work started in 2019 and is still currently ongoing.

www.symbio.one

david.bouquain@univ-fcomte.fr
daniel.hissel@univ-fcomte.fr

Facility: Hydrogen-energy and fuel cell platform / FCLAB

**References:**

E. Pahon et al., J. Power Sources 510, 230385 (2021). https://doi.org/10.1016/j.jpowsour.2021.230385

PEM fuel cell test benches

## ORANGE BUSINESS SERVICES / FLUX VISION

Denis Xavier Renaud

Jean-François Couchot, Heber Hwang Arcolezi

### DISC

Started in November 2017, the collaboration with OBS/Flux Vision has continued to grow. During the 2017 International University Music Festival and based on connections to Orange network antennas, Flux-Vision estimated and then published aggregated anonymous indicators (real data not being accessible and the anonymization process not being disseminated) about categorical data such as socio-professional categories, departments/countries of origin, and the number of people present during this festival during defined time slots. A first collaboration consisted in building a dataset of virtual people whose global characteristics were the closest to the indicators provided by this company, going against the classical approach which consists in having the raw dataset, and studying its characteristics to deduce a synthetic dataset. Subsequently, new sanitization methods for categorical data (as is the case here) have been proposed based on local differential privacy and by significantly improving the most proven algorithms of the community (Basic RAPPOR of GOOGLE particularly).

The work continues today with a CIFRE thesis between Orange INNOV/IT-S, FEMTO-ST and Les Mines-Paristech on the creation of specific road freight transport indicators from the signalling data of a telecommunication network and in conditions compatible with the RGPD.

https://www.orange-business.com/fr/produits/flux-vision

couchot@femto-st.fr

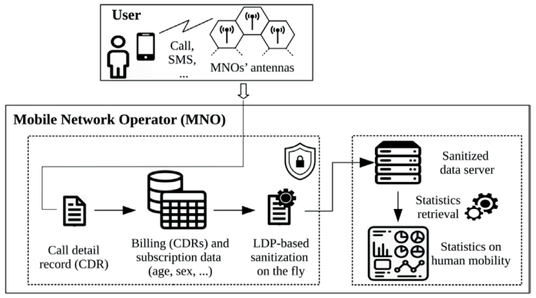
**References:**

H.H. Arcolezi et al., Proceedings CIKM '21 (2021).

H.H. Arcolezi et al., Proceedings IWCMC, 1689 (2020)

H.H. Arcolezi et al., arXiv preprint arXiv:2111.04636 (2021)

H.H. Arcolezi et al. 15th Int. School "Privacy and Identity Management", 4057 (2021, Springer)




Local differential privacy based sanitization methods for categorical data applied to CDR for human mobility statistics

## SIEMENS FRANCE

Matthieu Ponchant

Fei Gao

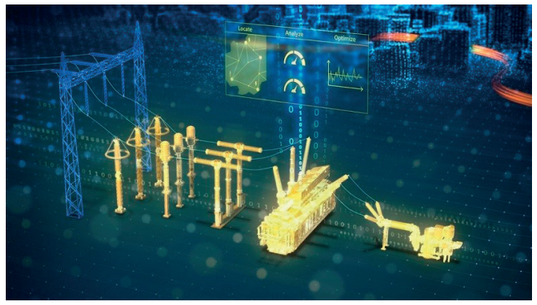
### ENERGIE

Collaboration framework (common projects, collaboration duration) & key common results description (200 words):

Since September 2021, researchers from the FEMTO-ST Energy department have been working with the R&D division of SIEMENS Industry Software France (located in the city of Lyon) to together develop new digital twin technologies for modern electric power grids. This research partnership was initiated under a European project grant, and quickly extended to a joint research agreement between the two parties. Digital twins play an important role in our energy transition to more reliable and more sustainable power grids. They are the virtual (mathematical) "twins" of physical counterparts (power plants, transmission lines, end users, etc.), being used to understand, predict and optimize in real-time the power grid operation. Compared to existing products on the market, the main ambition of this research partnership between FEMTO-ST and SIEMENS is to deploy new Artificial Intelligence (AI) and Big Data tools in the concept of power grid digital twins, which allow customers to consider socioeconomical factors to find the best tradeoff among consumer energy costs, quality of service, operating costs, and environmental impact. The first product is expected to be released on the European market for 2024.

https://www.plm.automation.siemens.com/global/en/

fei.gao@utbm.fr



Digitalization of Transformers using a comprehensive digital twin (SIEMENS website)

# INDUSTRIAL PROJECTS

## THALES LAS FRANCE

Eric Collard, Charles Arnould
Kévin Jaboviste, Emmanuel Bachy, Emeline Sadoulet-Reboul,
Gaël Chevallier
Nicolas Peyret, Supmecan, Quartz EA 7393

### APPLIED MECHANICS

Thales Land and Air Systems (LAS) is specialized in surface radar defence systems for the Navy, Air Force and Army, as well as air traffic control systems and civilian radars. These products embed optronic systems whose positioning must be precise, which requires the fine control of vibrations, for variable conditions and in various environments. Several research projects have been undertaken over the last 6 years between THALES LAS and the FEMTO Institute. They have focused on damping and absorption with the development of modelling tools for viscoelastic materials, the development of networks of multiple absorbers, and the design of a non-linear friction absorber. This collaboration is fruitful for the company and for the research department, it allows the former to reinforce its scientific and technological competence around innovative vibratory control that can be integrated into future industrial developments, and it offers students the opportunity to develop fundamental and applied research activities by benefiting from the laboratory's resources and advances and the technical expertise of the industrial partner. The results have led to the publication of two patents and several joint publications in national and international journals and conferences. The collaboration continues with the start of a new thesis in 2022.

https://www.thalesgroup.com/fr

gael.chevallier@univ-fcomte.fr

**References:**

K. Jaboviste et al., Mech. Syst. Signal Process. 119 (2019). https://doi.org/10.1016/j.ymssp.2018.08.061

E. Bachy et al., Mech. Syst. and Signal Process. 170 (2022). https://doi.org/10.1016/j.ymssp.2022.108830

Patent FR2019000132

Patent WO2020165128

## INDUSTRIAL DATA SCIENCE FOR SYSTEM HEALTH ASSESSMENT

Zeina Al Masry, Jean-Marc Nicod, Christophe Varnier,
Noureddine Zerhouni

### AS2M

In addition to academic collaborations, the PHM team is involved in working with socio-economic players such as industry and hospitals. In 2021, a record of 5 industrial PhD funding projects are ongoing in collaboration with big and small-medium enterprises such as Schlumberger, Mitsubishi, FIVES, SCODER and Amarob (the latter three with roots in the Bourgogne-Franche-Comté region). These projects, which are all set in the general context of industry 4.0 and company digitalization, allow researchers to apply the theoretical and methodological corpus of the PHM team (diagnostic, prognostics and decision algorithms) to real-world data, and optimize data and system health decisions that have real socio-economic impact. In turn, the reality of data collected at industrial sites creates new scientific challenges, as an essential part of all these projects is to handle data abnormality and uncertainties in order to efficiently exploit data for system health assessment. These collaborations therefore are particularly interesting because they allow us to renew and identify new scientific barriers that are directly relevant to industrial issues.

https://www.femto-st.fr/en/Research-departments/AS2M/Research-groups/PHM

zeina.almasry@femto-st.fr

**References:**

N. Omri et al. Computers in Industry 127 (2021): 103414. https://doi.org/10.1016/j.compind.2021.103414

L. Pasaguayo et al. Proceedings 31st EU Safety and Reliability Conf. (2021).

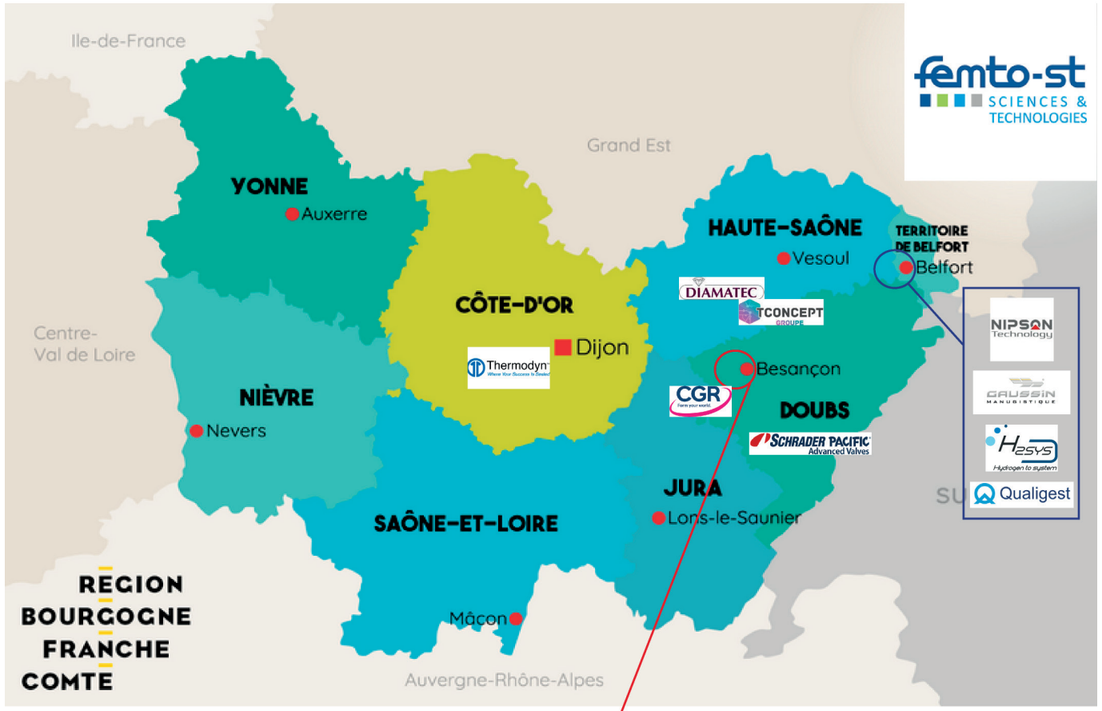
https://www.rpsonline.com.sg/proceedings/9789811820168/html/214.xml

M. Nazar et al., Microelectronics Reliability 114, 113824 (2020) https://doi.org/10.1016/j.microrel.2020.113824

N. Omri et al., J. Manufact. Syst. 56, 23 (2020) https://doi.org/10.1016/j.jmsy.2020.04.002

Bien traiter les informations pour la bonne santé des équipements industriels, En Direct (2020). https://endirect.univ-fcomte.fr/publication/bien-traiter-les-informations-pour-la-bonne-sante-des-equipements-industriels/

## COLLABORATIONS OF FEMTO-ST INSTITUTE WITH INDUSTRY OF BOURGOGNE-FRANCHE-COMTÉ REGION




# SCIENCE FOR SOCIETY

## FEMTO-ST INSTITUTE FOSTERS RESEARCH AND INNOVATION TO ADDRESS THE SOCIETAL CHALLENGES

### HEALTH AND WELL-BEING

- Therapy
- Diagnosis, screening and biological qualification
- Ethics and acceptability

### CLEAN, SAFE & EFFICIENT ENERGY

- Hydrogen energy
- Energy harvesting
- Energy efficiency of systems

### ENVIRONMENT

- Environmental sensors
- Geodesy
- Water and air treatment
- Vibration and noise protection
- Preservation of resources

### INTELLIGENT SYSTEMS

- Artificial Intelligence: distributed systems, diagnosis and prognosis
- Smart Objects & Complex Systems
- Ethics

### COMMUNICATION AND INFORMATION

- Ultra-localized optics
- Quantum technologies
- Telecommunication systems and materials

### INDUSTRY OF THE FUTURE

- New Materials and Processing
- Sensors and actuators
- Factory 4.0

### DEFENSE - SECURITY

- Network and software security
- Intelligent Systems for Defense

# SCIENCE FOR SOCIETY

## FUTUROBOT – ROBOTICS ON SOCIAL NETWORKS AND THROUGHOUT FRANCE

Aude Bolopion

### AS2M

FEMTO-ST took part to the FutuRobot events, a series of events organized by CNRS and dedicated to Robotics on social networks and on sites throughout France. The goal was to present to the general public recent advances in all the fields of robotics, and to answer common questions about robots. FEMTO-ST participated to this event in Nancy, in November and proposed a 15 minutes talk on microrobotics in the Centre des Congrès. This FutuRobot evening show gathered 4 researchers, Aude Bolopion (FEMTO-ST), Pierre Renaud (ICube), Serena Ivaldi (Loria) and Jean-Baptiste Mouret (Loria) and was organized by the délégation Centre-Est of CNRS, the centre Inria Nancy- Grand-Est and the Université de Lorraine. Various aspects of robotics, ranging from microrobots to macroscale medical and humanoid robots were presented to 150 participants. Aude Bolopion (FEMTO-ST) focused on microrobots and showed that predominant forces in micrometer scale drastically differ from what is commonly considered in our macroscale world, which necessitates a complete rethink about robots at this scale. Rich discussions between scientists and the public have helped to deconstruct received opinion, and have highlighted the current possibilities and limitations, as well as the challenges of robotics.

Facility: Micro and NanoRobotic Center

https://www.centre-est.cnrs.fr/fr/evenement/futurobot-percez-les-secrets-de-la-robotique

aude.bolopion@femto-st.fr

**References:**

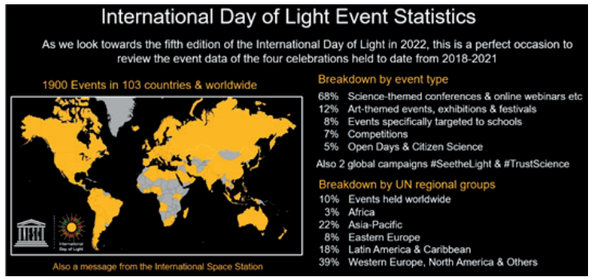
F. N. Piñan Basualdo et al., Science Robotics 6 (52), 1 (2021). https://www.science.org/doi/10.1126/scirobotics.abd3557

## INTERNATIONAL DAY OF LIGHT AND TRUST IN SCIENCE

John Dudley

### OPTICS

The International Day of Light is an annual United Nations celebration showcasing how light science and technology impacts society and sustainable development. Since its first proclamation in 2018, the International Day of Light has operated a Secretariat Node at FEMTO-ST, where John Dudley from the Optics Department chairs the Steering Committee. A review of International Day of Light Activities took place in 2021, and has shown how the initiative has reached an audience of millions, with 1900 events taking place in more than 100 countries. In 2021, a central theme was to improve societies trust in science. Crises such as the coronavirus pandemic clearly demonstrate the importance of scientific research, but at the same time as the world looks to science to find solutions, there has been global loss of confidence in science because of failures in communication between scientists and society. The International Day of Light Trust Science campaign in 2021 raised awareness and promoted debate, encouraging scientists to engage with their communities to explain the methods of science and the need for decision-making based on evidence. Support was received from Nobel laureates, UNESCO award winners, and celebrated international science advocates and communicators.




The four editions of the International Day of Light since 2018 have seen over 1900 events take place worldwide. FEMTO-ST hosts one of the Secretariat Nodes.

lightday.org

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References:

J. M. Dudley, Advancing Trust in Science. Optics and Photonics News 32 (9) 18-20 (2021)

https://www.optica-opn.org/home/articles/volume_32/september_2021/departments/advancing_trust_in_science/

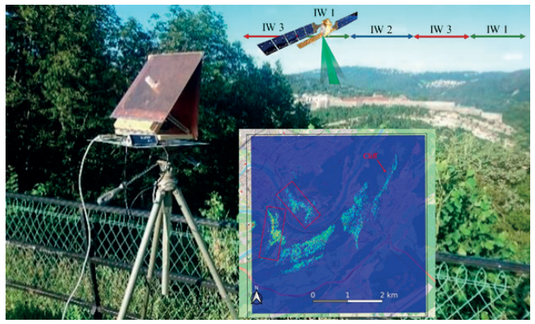


## SPACEBORNE RADAR SENTINEL1 RAW RADIOFREQUENCY SIGNAL PROCESSING

Jean-Michel Friedt, Philippe Abbé

### TIME & FREQUENCY

The time and frequency department claims to be developing high stability oscillators for RADAR applications with the pulse repetition interval defining the frequency offset at which phase noise is relevant. To assess such characteristics, the raw radiofrequency signals of the C-band (5.405 GHz) Sentinel1 spaceborne RADAR are analysed both through the raw IQ data freely available from ESA or by recording signals from the ground using dual channel Software Defined Radio (SDR) receivers. This allows for the achievement of results beyond range and azimuth compression as classically performed with Synthetic Aperture RADAR (SAR) processing, including passive RADAR analysis and ground based radiofrequency interference emissions detected from space during the rank echo period (when no signal transmitted by the satellite is received). The flexibility and stability of the SDR approach are emphasized by ESA in their dual frequency transposition scheme using a second digital processing step to avoid IQ imbalance issues, and by our demonstration of using the radiofrequency signal emitted from space beyond RADAR mapping capability. Further investigations include the development of cooperative targets allowing the recovery, by analyzing the physical characteristics of the backscattered signal, of ground based physical quantities in addition to the classical sub-wavelength position resulting from InSAR processing.




Main elements of the passive bistatic radar analysis of Sentinel1 spaceborne RADAR, with the embedded SDR platform in foreground and processing result at bottom right.

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**References:**

W. Feng, J.-M Friedt, P. Wan, MDPI Remote Sensing 14(1), 221 (2022). https://www.mdpi.com/2072-4292/14/1/221

J.- Friedt, P. Abbé, GNU/Linux Magazine 246 (2021) https://connect.ed-diamond.com/GNU-Linux-Magazine/glmf-246/parler-a-un-radar-spatioporte-traitement-et-analyse-des-donnees-de-sentinel-1

# SCIENCE FOR SOCIETY

## INTELLIGENT MONITORING OF MULTI-AXIS ROBOTS FOR ONLINE DIAGNOSTICS OF UNKNOWN ARM DEVIATIONS

Moncef Souahli

**AS2M**

In multi-axis machining robots, the arm deviations from the nominal positions are one of the crucial degradations that must be cautiously tracked. Indeed, a small deviation in the robot positioning may significantly affect security and product quality. Hence, it is necessary to develop an efficient monitoring methodology to detect and diagnose the origin of the drifts. Thus, a new methodology for online diagnostics of the origin of the robot axis drifts using an information fusion procedure of direct and indirect monitoring techniques is proposed. Its main contributions are summarized as follows:

• An efficient classification of robot axis drifts using tool condition monitoring.

• Proposals of reliable health indicators constructed from the encoder measurements of each robot's axis to identify the origin of the drifts.

• Construction of a new fusion procedure between direct and indirect monitoring for efficient diagnostics of unknown robot axis drifts.

https://rdcu.be/cEJWo

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**References:**

M. Soualhi et al., J. Intelligent Manuf. (2022). https://doi.org/10.1007/s10845-021-01882-0

## VISITE INSOLITE DU CNRS – PRIVILEGED FACE TO FACE WITH THE FEMTO-ST SCIENTISTS

Annie Frelet-Barrand, Aurélie Sabanovic, Aude Bolopion

**AS2M, MN2S**

In October 2021, the CNRS launched the 2nd edition of its intimate, interactive and exceptional event 'Visites Insolites' giving access to its research laboratories to a restricted number of people. The goal is to let the public discover exceptional installations/equipment and experiments face-to-face with scientists. The FEMTO-ST Institute participated in this event by presenting the project called MiMedI. Launched in December 2017 for 5 years, MiMedI involves 9 regional partners (5 companies, 3 laboratories and 1 transfer company) with a global cost of 15 M€ (75% provided by the European FEDER program and the Regional Innovation Fund). This project aims at rationalizing the production of Advanced Therapy Medical Products (ATMPs), which recently emerged to provide new therapy solutions for patients in therapeutic failure. These ATMPs rely on the use of "drug cells" exhibiting new physiological functions, biological characteristics or reconstitution properties directly inspired by natural processes occurring in human organisms. During one day, 10 people, from school children to retirees, have had the possibility to feel "like a cell", running several experimental set-ups to perform cell characterization and counting, as well as highly selective cell sorting inside microfluidic chips and having extensive and unique discussions with the scientists.

Facilities: MIMENTO, Micro NanoRobotic center

https://projects.femto-st.fr/mimedi/

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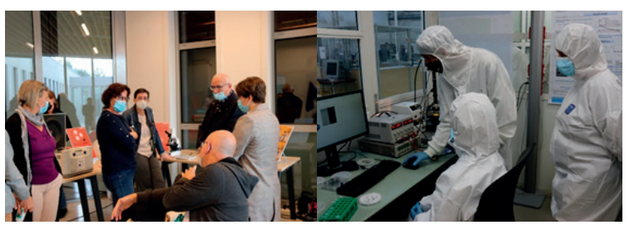
**References:**

B. Ahmad et al., IEEE Trans. Robotics, 1 (2021).
https://hal.archives-ouvertes.fr/hal-03433996/document



Participants of the Visite Insolite having privileged exchanges with scientists of the FEMTO-ST Institute

## WOMEN CHAPTER

Women Chapter is a social network of our Institute composed of women exclusively. It aims to improve the integration and understanding of issues related to gender in the specific context of research, by proposing actions, a guide of good practices, a follow-up of the situation, a support/coaching for the women colleagues. Women chapter is financially supported by Institute and CNRS QVT project (Quality of Life at Work, project that was laureate during the year 2021 with a mention of favorite project of the jury 2021):

· It proposes convivial actions (lunches, dinners, trips, laser/escape game) which are essential activities to create cohesion and a sense of belonging, to fight isolation and loneliness (especially for new members), allow free discussions, and share experience;

· It organizes celebrations of International Women's Day (8th March), the International Day of Women and Girls in Science (11th February);

· It communicates and promotes of scientific careers for young girls in high schools / colleges and especially in primary schools (before the formation of stereotypes);

· It takes part to debates with public authorities (rectorate, prefecture, universities, engineering schools);

· It manages Women Chapter website, containing emergency contact details able to deal with cases of harassment or sexual and gender-based violence;

· It proposes specific trainings (self-esteem, etc.) and presentations on a regular basis during the general assembly or annual seminar of the Institute, to raise awareness about parity, equality and diversity.

In 2021, Women chapter members gave a training on the parity for the candidates of the contest "International ambassadors of the Peace" organized by "ONU Femmes" (Women UNO) and ONUWAS.

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https://events.femto-st.fr/Women-Chapter/fr

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