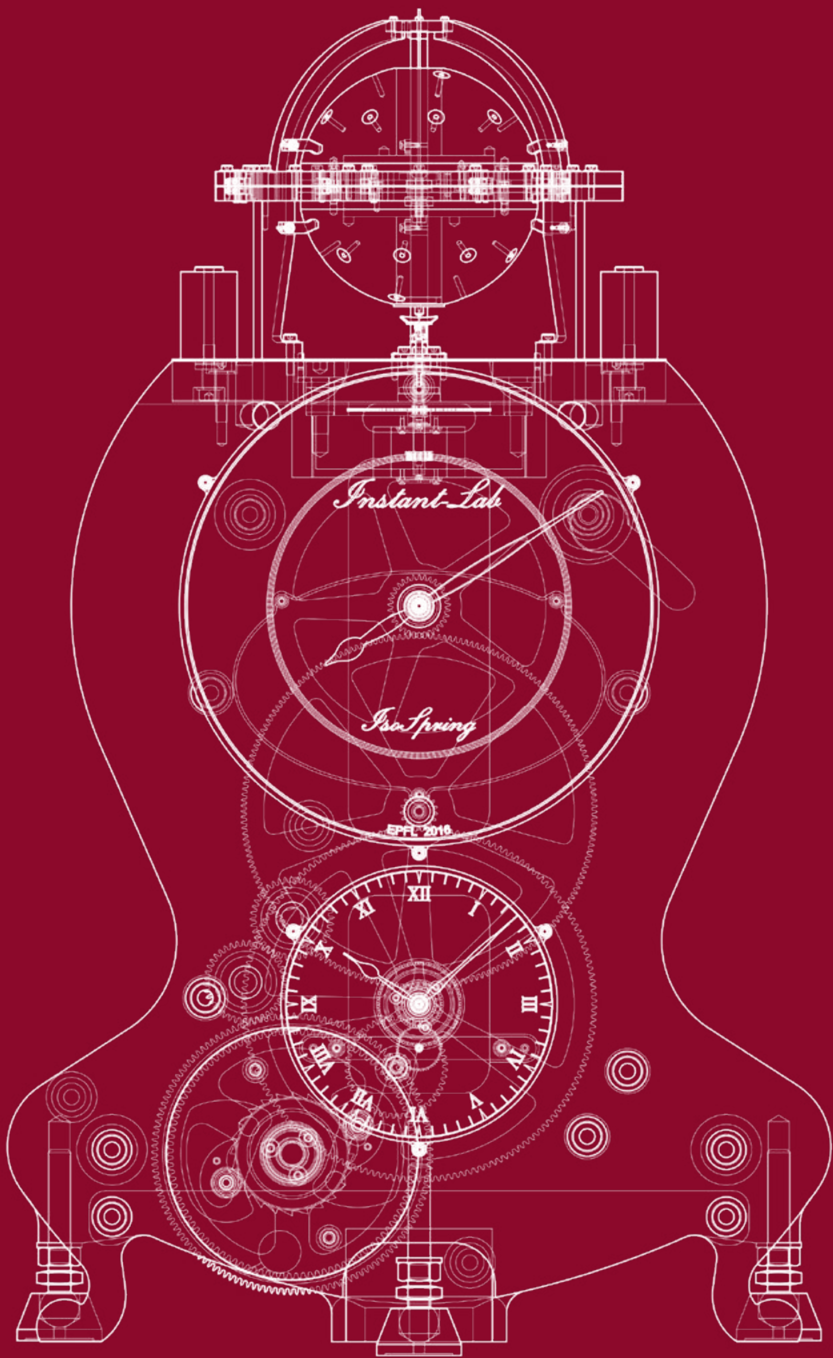
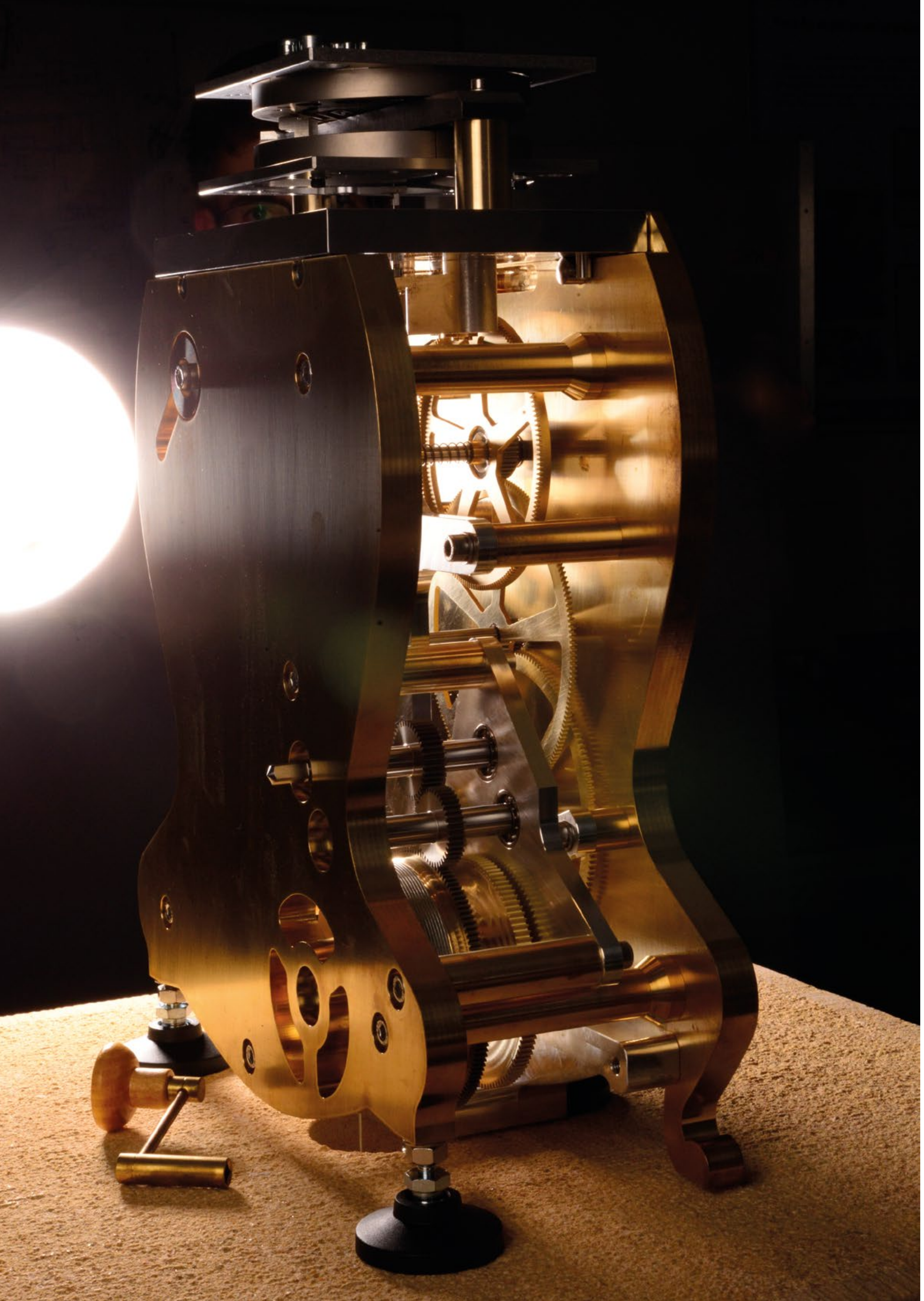
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Patek Philippe Chair

Micromechanical and Horological Design Laboratory
INSTANT-LAB

Annual Report 2016





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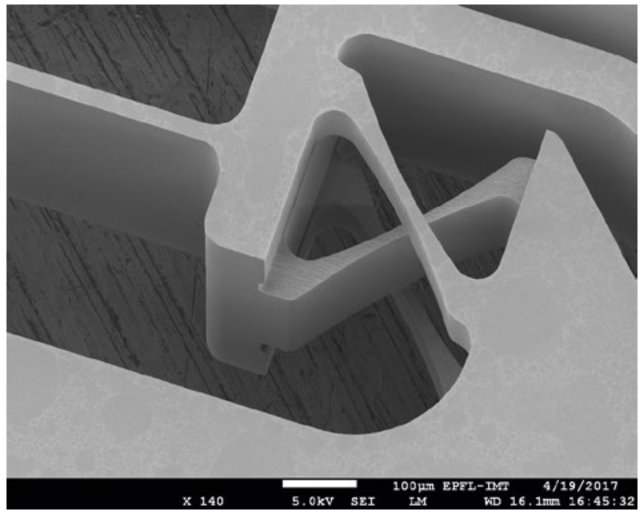
INTRODUCTION

Following the April 2012 announcement of a partnership between watchmaking manufacture Patek Philippe and the EPFL, the Patek Philippe Chair in Micromechanical and Horological Design was established on November 1, 2012, with the nomination of Professor Simon Henein. Instant-Lab, the name chosen for the new laboratory, is located in Microcity, the EPFL Microtechnology centre in Neuchâtel, Switzerland. As of 2016, Instant-Lab has 19 collaborators: Professor Henein, an administrative assistant, 2 senior scientists, 2 postdoctoral scholars, 3 Ph.D. students, 8 scientific assistants and 2 technicians.

The laboratory specializes in creating new mechanisms featuring kinematic and technological innovation at the centimeter scale using a scientific approach inspired from mechanical design in fields such as classical horology, robotics and aerospace. Current projects apply to mechanical watchmaking and biomedical instrumentation, these fields being quite close, both technologically and in their industrial fabric. Beyond its academic mission to pursue excellence in fundamental research and teaching, the laboratory is also committed to establish ties with Swiss watchmaking culture and welcomes industrial collaboration with all Swiss watchmaking companies.



TEAM

Director


Prof. Simon Henein


Karine Frossard
Administrative assistant

Post-Docs


Dr Roland Bitterli


Dr Mohammad Kahrobaiyan

Scientific Assistants

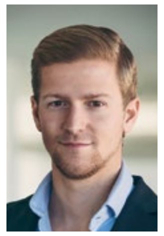

Marine Clogenson


Billy Nussbaumer


Laura Convert


José Rivera


Nicolas Ferrier


Arno Rogg


Cédric Hentsch


Etienne Thalmann

Ph.D. Students


Johan Kruis*


Mohamed Zanaty


Sebastian Fifanski

Senior Scientists


Dr Charles Baur


Dr Ilan Vardi

Technicians


Romain Gillet


Arnaud Maurel

Interns

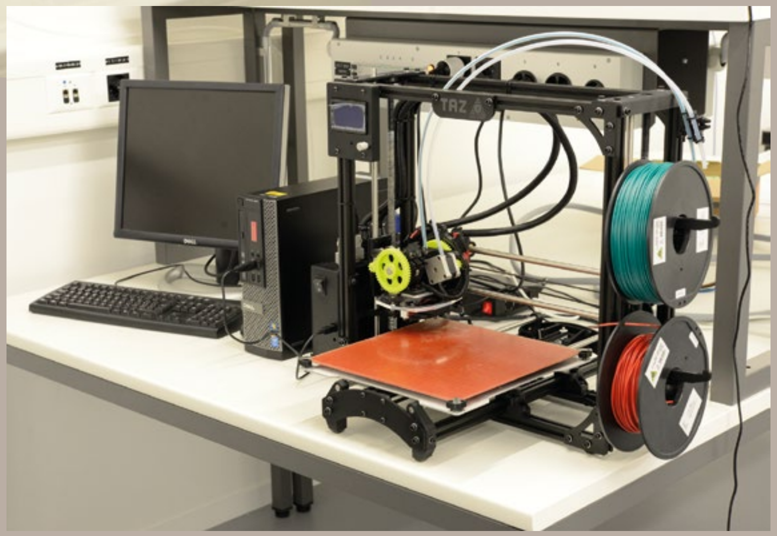

Benoît Dubath

Visiting Professors


Prof. Sonny Chan
University of Calgary, CAN


Prof. Pierre-Yves Donzé
Osaka University Graduate School of Economics, JPN

*External



INFRASTRUCTURE AND EQUIPMENT

Offices : 136 m²
Laboratories : 171.5 m²
Grey room : 51 m²

Major equipment acquired in 2016 :

- Real-Time acquisition system PXIe-8135 RT, Quad core i7-3610QE, 2.3 GHz, 4 Go RAM DDR3 with a PXIe-1082 chassis PXI Express 3U with 8 slots of 2 Go/s bandwidth modules :

  Module 1 : PXIe-6614, eight 32 bit, 80 MHz counters/timers, 40 DIO @ 10 MHz, OCXO oscillator @ 10 MHz with 0.075 ppm stability

  Module 2 : PXI-7841R, FPGA LX30 Virtex-5, eight AI, +/-10 V @ 200 kS/s/channel, 8 AO, +/-10 V @

  1 MS/s/channel, 96 DIO @ 40 MHz, 96 counters/timers @ 40 MHz

- Kistler 9207 tension-compression uniaxial force sensor

  Force ranges : -50 N to 50 N, -5 N to 5 N, -0.5 N to 0.5 N. Linearity : ±1 % FSO, sensitivity : -119.1 pC/N

- Trotec Speedy 360 flexx laser cutting marking and engraving machine

  Work space : 813 x 508 mm, max. height : 280 mm, speed : 355 cm/s (CO2) and 200 cm/s (fiber), positioning precision : 5 um, repeatability :

  <±15 um, vacuum table, honeycomb cutting tabletop, aluminum slat cutting table

  Aspiration system 2 x 330 m³/h ATMOS Duo

  Materials : aluminum, stainless steel, brass, copper, precious metals

  CO2 : wood, MDF, Plexiglas, PC, ABS, PE, PES, PS

- Linktronix PWS4323 single-channel programmable DC Power Supply

  0-32 VDC output voltage, 0-3 A output current, 96 W.

  ±0.03 % basic voltage output accuracy and ±0.05 % basic current accuracy

RESEARCH PROJECTS

IsoSpring : continuous mechanical time

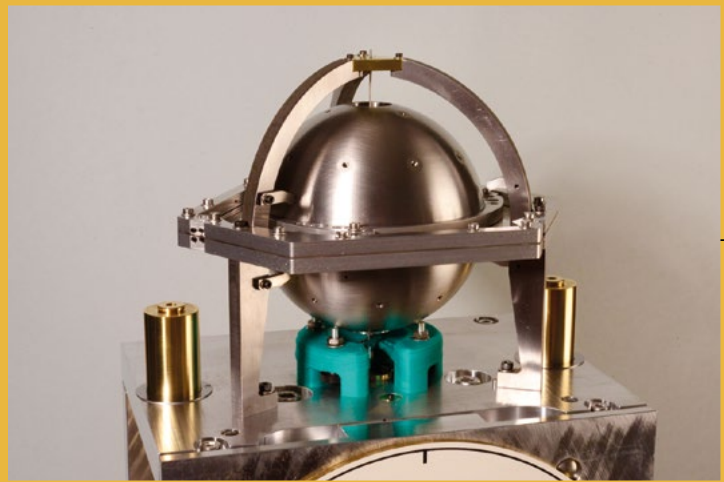
Mechanical timekeeping began in the Middle Ages with the invention of the escapement. After the introduction of oscillators in the 17th century, mechanical clocks and watches continued to rely on escapements. Despite numerous technical advances, today's escapements suffer from reduced mechanical efficiency. The IsoSpring project exploits ideas dating back to Isaac Newton to create a new time base which can be driven continuously, without the stop-and-go "ticking" of traditional mechanical clocks and watches. This solves the escapement problem by completely eliminating it : the mechanical watch can work without an escapement !

The result is a simplified mechanism having greatly increased efficiency and chronometric accuracy. This project is based on a new family of oscillators and maintaining mechanisms patented by Instant-Lab.

In 2013 a successful proof of concept was achieved, leading to an industrial project in 2014. In 2016, variations of the original concept were realized as fully functional clocks. As an homage to the horological tradition of the region, the shape of the clocks is based on the famous Neuchâteloise clock design. Since December 2016, the City of Neuchâtel has exhibited the first prototype in its renovated City Hall.

Current research is focused on miniaturizing to the watch scale.

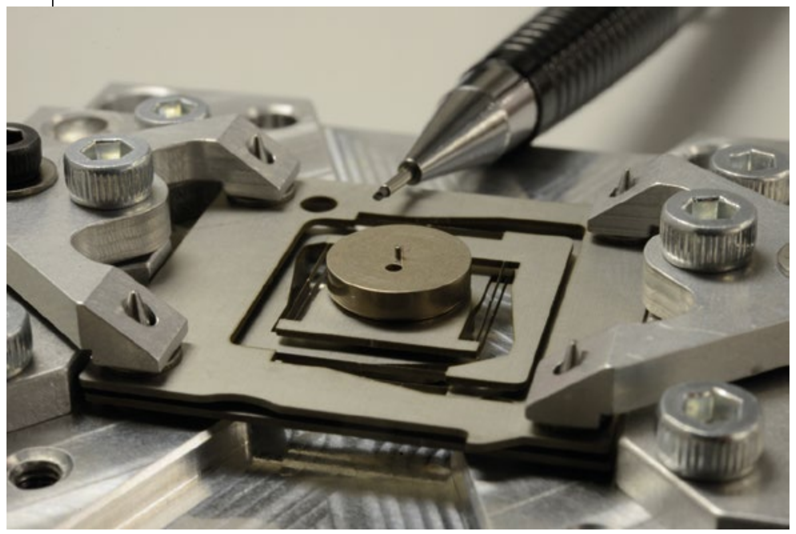


Prototype "Neuchâteloise" clocks with translational oscillator (left) and rotational oscillator (right)

IsoSpring team at the Neuchâtel City Hall inauguration

Towards watch scale IsoSpring

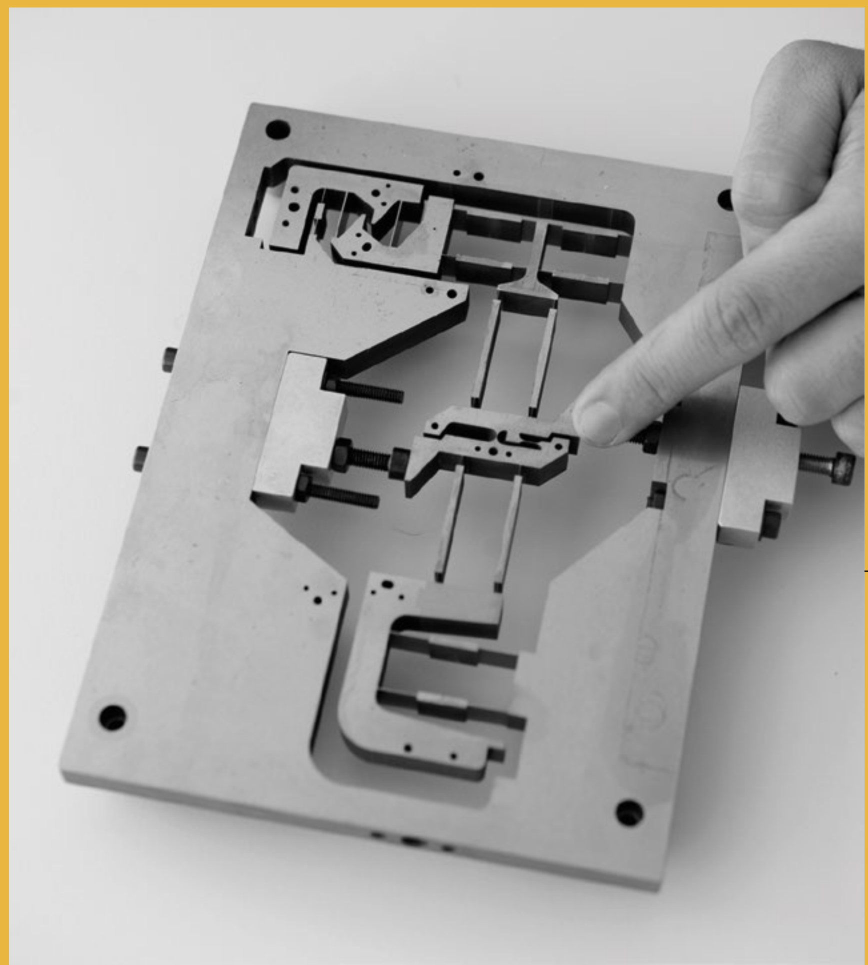


RESEARCH PROJECTS

High quality factor oscillators for wrist watches

Current mechanical wrist watches have an oscillator consisting of a balance wheel mounted on jewelled bearings and a hairspring. The use of flexure bearings instead of traditional pivots leads to a significant increase in quality factor, i.e., reduced energy loss. As a result, power reserve can be significantly increased and chronometric precision can be improved thanks to reduced oscillator perturbation. However these new oscillators are sensitive to gravity and have isochronism defects. This project explores novel flexure-based pivots minimizing these issues.

Gravity insensitive flexure pivot (GIFP) demonstrator



Programmable multistable energy storage mechanisms

Flexure based mechanisms can produce strongly non-linear spring behavior. Machined in Silicon or innovative spring alloys, they enable completely new functionalities at the centimeter scale. This project aims at exploring the fundamental principles of elastic energy storage mechanisms, their production methods and their integration into functional devices.

T-shaped multistable mechanism programable to have 1 to 4 stable positions

Audemars Piguet research project

Instant-Lab and Audemars Piguet continued the project initiated in 2014.

RESEARCH PROJECTS

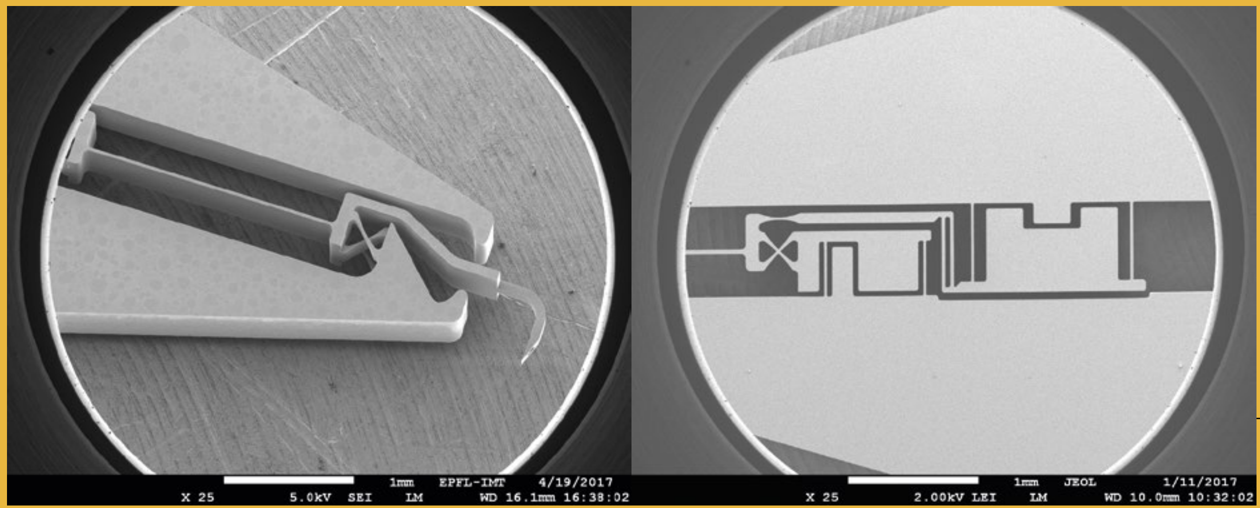
CTI Miniature flexure structures for multi-degree of freedom contact force sensing (VIVOFORCE)

The project developed active surgical tools fitting microsurgery requirements, e.g., eye and brain surgery. Combining flexible structure technology provided by Instant-Lab together with Sensoptic SA's in-house optical fiber based sensing technology which has been successfully used in heart, ear, nose and throat surgery. Providing surgical instruments that are force sensitive at the tool tip allows precise and reliable surgical gestures far exceeding current practice. Watchmaking applications are also foreseen. This project was funded by Sensoptic SA and the Commission for Technology and Innovation CTI (Switzerland) and run in collaboration with Pr. Th. Wolfensberger, Hôpital Ophtalmique Jules-Gonin, Lausanne. The project was completed within budget in November 2016 successfully satisfying the goals set by all partners.

Retinal surgery with force sensitive peeling hook

CTI Safe Puncture Optimized Tool (SPOT) for retinal vein cannulation

Retinal Vein Occlusion is a vascular disorder causing severe loss of vision. Retinal vein cannulation and injection of therapeutic agents in the affected vein is a promising treatment. The small size and fragility of retinal veins as well as the surgeon limited hand gesture precision and force perception makes this procedure too delicate for routine operations. The project aims at providing a compliant mechanical tool relying on a bistable mechanism to safely cannulate veins. The feasibility of this project was demonstrated by a prototype made by femto-laser printing, one of the first buckled mechanisms made in glass.



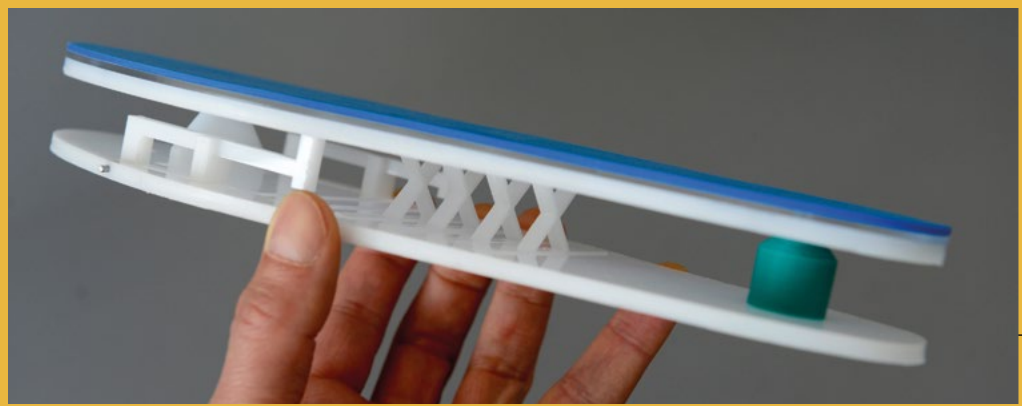
Glass needle for retinal vein puncturing (left) and its bistable mechanism (right)

SNSF Adjustable midsole intervention footwear for patients with medial compartment knee osteoarthritis (ADVANCER)

This project consists of a geometrically adjustable shoe orthotic to balance knee and hip loads which could otherwise lead to cartilage wear and tear, thus avoiding surgical intervention. Our proposed solutions are based on flexible elements developed at Instant-Lab. This Swiss National Science Foundation project is a collaboration with CHUV (Centre Hospitalier Universitaire Vaudois).

STI Enable SOLE Project

The object of the SOLE project is to produce ADVANCER prototypes and to test them on CHUV patients. The project is funded by the EPFL STI (School of Engineering) Enable Initiative.



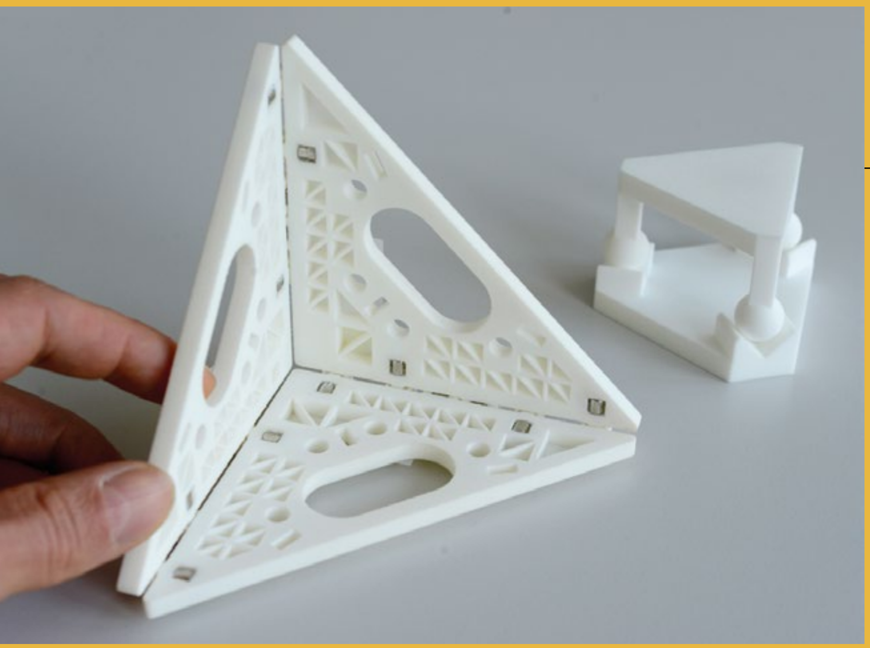
Adjustable midsole intervention footwear (orthotic) for patients with medial compartment knee osteoarthritis

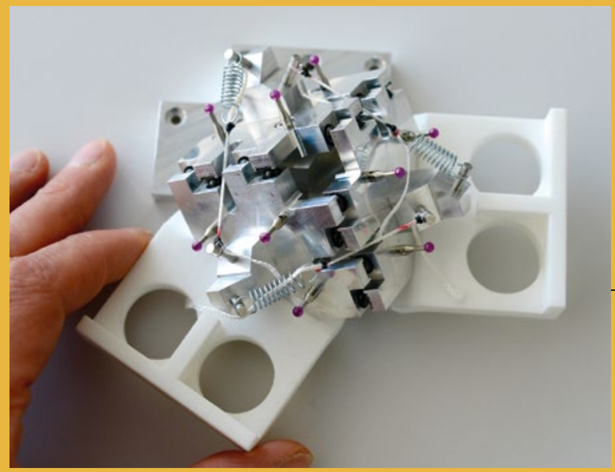
Spinal screw placement tool

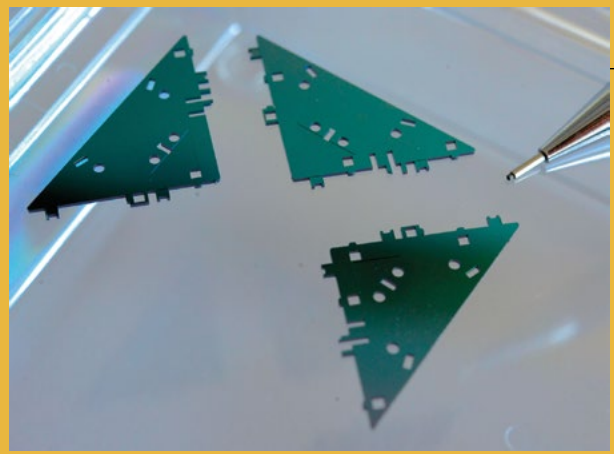
This Instant-Lab project develops low cost passive alignment tools for spinal pedicle screw placement. The goal is to improve the surgeon's ability to accurately insert a pedicle screw following a predetermined trajectory. This reduces the risk of plunging which can damage soft tissue, nerves, or the spinal cord.

Flexure based level indicating tilt angle for pedicle screw placement

RESEARCH — PH.D. THESES





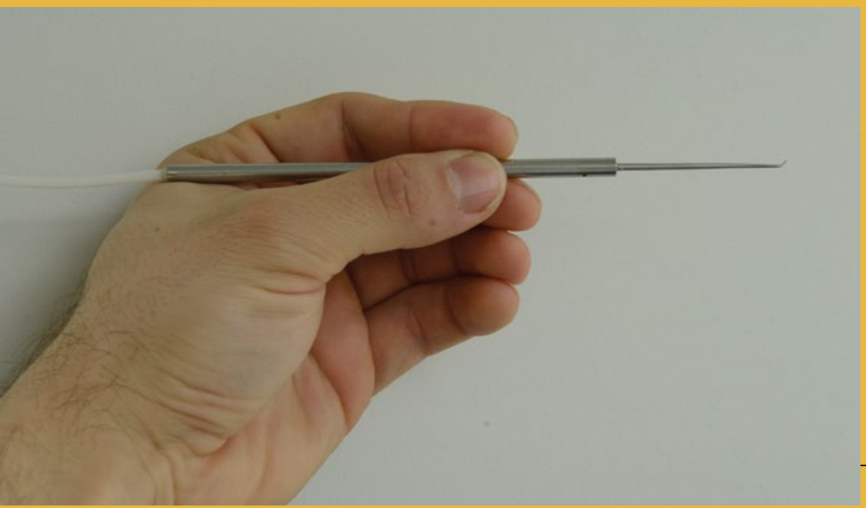


Johan Kruis, thesis title: *Design, analysis, testing and applications of two-body and three-body kinematic mounts*.
Completed August 2016.

3-body kinematic mount (left) and classical 2-body kinematic coupling (right)

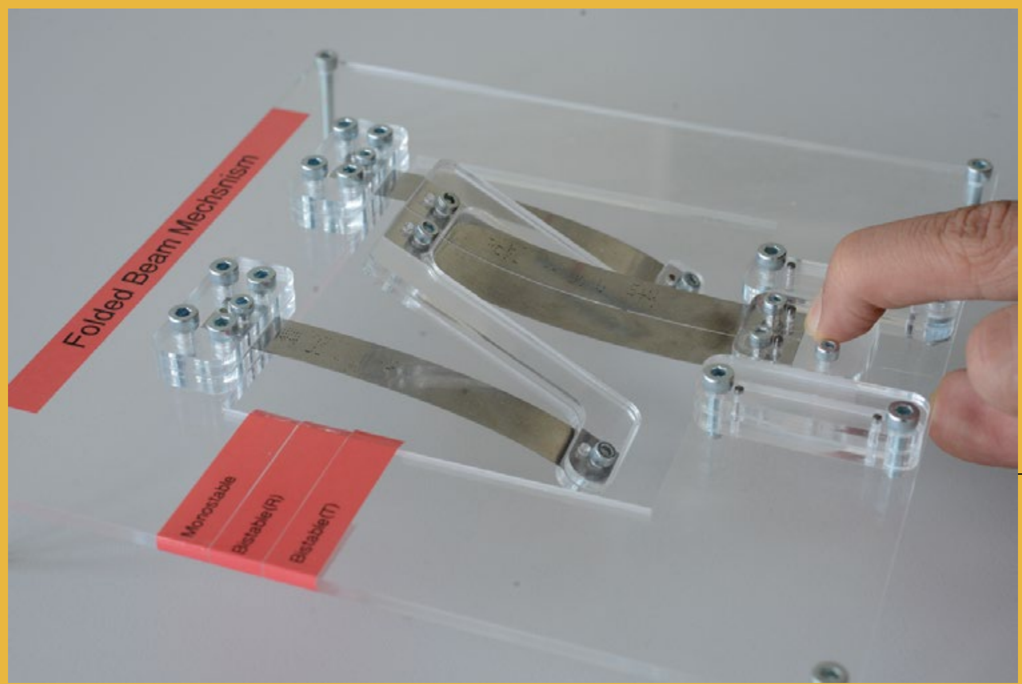
Centimeter-scale 3-body kinematic mount for assembly repeatability measurements

Millimeter scale silicon 3-body kinematic mount for assembly repeatability measurements (courtesy of CSEM)



Sebastian Fifanski, preliminary thesis title: *Miniature flexure structures for contact force sensing in pointed tools*.
Expected completion August 2018.

Hand held surgical tool equipped with 3 degree-of-freedom force sensor



Mohamed Zanaty, preliminary thesis title: *Programmable multistable mechanisms*.
Expected completion August 2018.

Folded-Beam programmable bistable mechanism with blades under tension (no buckling)

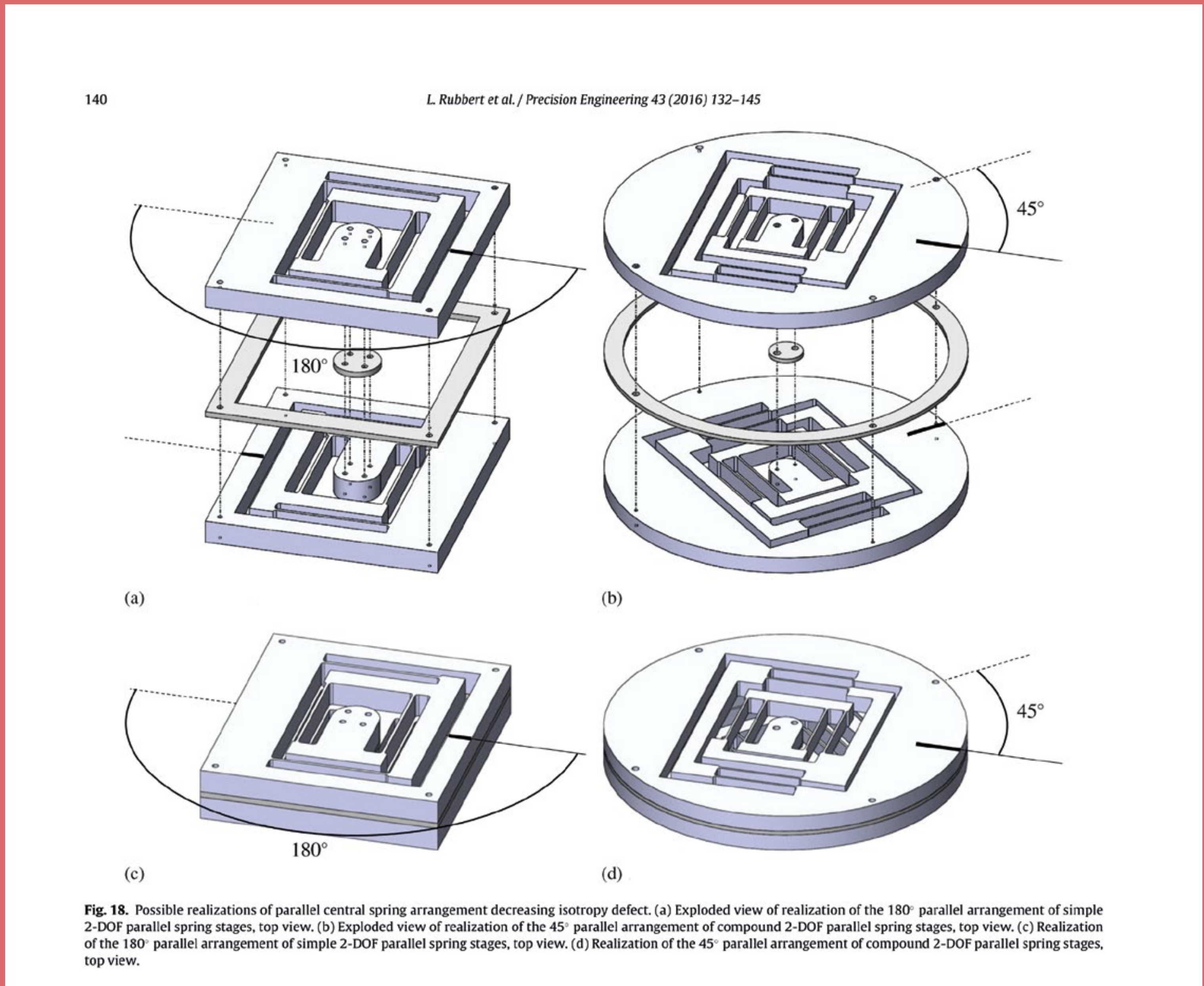
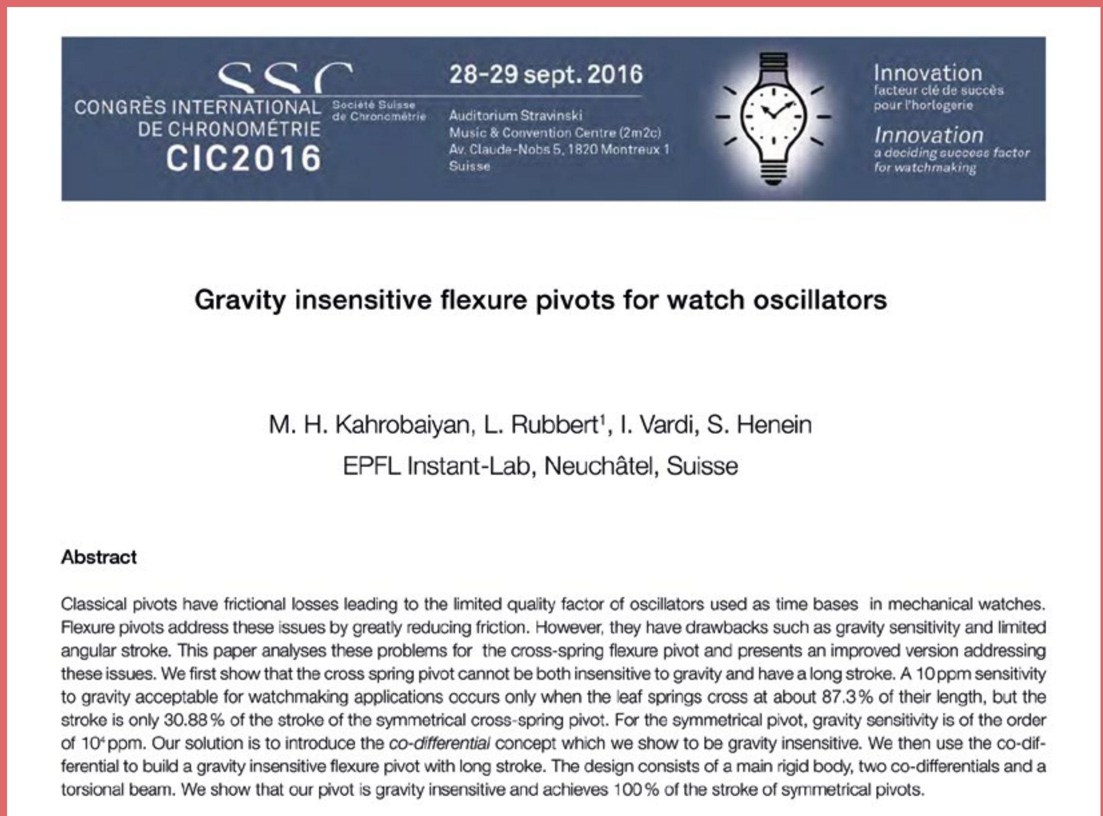


Fig. 18. Possible realizations of parallel central spring arrangement decreasing isotropy defect. (a) Exploded view of realization of the 180° parallel arrangement of simple 2-DOF parallel spring stages, top view. (b) Exploded view of realization of the 45° parallel arrangement of compound 2-DOF parallel spring stages, top view. (c) Realization of the 180° parallel arrangement of simple 2-DOF parallel spring stages, top view. (d) Realization of the 45° parallel arrangement of compound 2-DOF parallel spring stages, top view.


SSC
CONGRÈS INTERNATIONAL DE CHRONOMÉTRIE CIC2016
Société Suisse de Chronométrie
28-29 sept. 2016
Auditorium Stravinski
Music & Convention Centre (2m2c)
Av. Claude-Nobs 5, 1820 Montreux 1
Suisse
Innovation
facteur clé de succès pour l'horlogerie
Innovation
a deciding success factor for watchmaking

Gravity insensitive flexure pivots for watch oscillators

M. H. Kahrobaiyan, L. Rubbert[1], I. Vardi, S. Henein
EPFL Instant-Lab, Neuchâtel, Suisse

Abstract

Classical pivots have frictional losses leading to the limited quality factor of oscillators used as time bases in mechanical watches. Flexure pivots address these issues by greatly reducing friction. However, they have drawbacks such as gravity sensitivity and limited angular stroke. This paper analyses these problems for the cross-spring flexure pivot and presents an improved version addressing these issues. We first show that the cross spring pivot cannot be both insensitive to gravity and have a long stroke. A 10 ppm sensitivity to gravity acceptable for watchmaking applications occurs only when the leaf springs cross at about 87.3 % of their length, but the stroke is only 30.88 % of the stroke of the symmetrical cross-spring pivot. For the symmetrical pivot, gravity sensitivity is of the order of 10^4 ppm. Our solution is to introduce the *co-differential* concept which we show to be gravity insensitive. We then use the co-differential to build a gravity insensitive flexure pivot with long stroke. The design consists of a main rigid body, two co-differentials and a torsional beam. We show that our pivot is gravity insensitive and achieves 100 % of the stroke of symmetrical pivots.

PUBLICATIONS

Patents

M. Zanaty, C. Baur, S. Henein, *Device for controlled puncturing of a bodily vein*, EP 16180443.0, July 2016

S. Henein, L. Rubbert, M. Kahrobaiyan, *Gravity-insensitive flexure pivots*, CH 01255/16, September 2016

M. Kahrobaiyan, I. Vardi, S. Henein, *Two degree of freedom mechanical oscillator*, EP 16205254.2, December 2016

Conference proceedings

M. Kahrobaiyan, L. Rubbert, I. Vardi, S. Henein, *Gravity insensitive flexure pivots for watch oscillators*, Actes du Congrès International de Chronométrie de la SSC, Montreux, September 28-29, 2016, pp. 49-55

S. Fifanski, J. Rivera, M. Clogenson, C. Baur, A. Bertholds et al., *Flexure-based multi-degrees-of-freedom in-vivo force sensors for medical instruments*, Euspen 16th International Conference, Nottingham, May 30-June 3, 2016, pp. 333-334

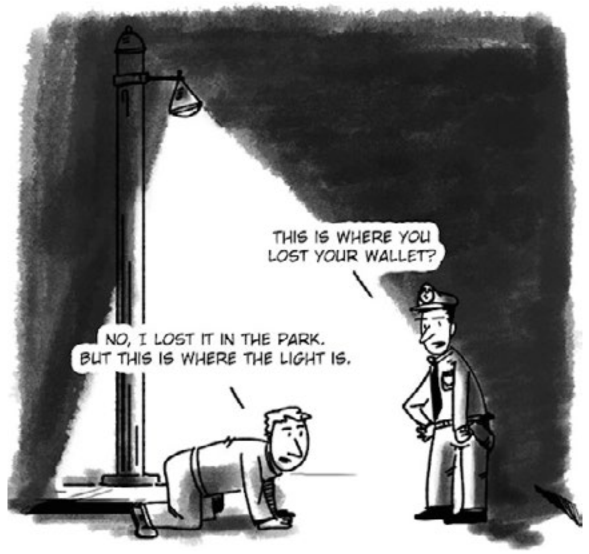
Journal articles

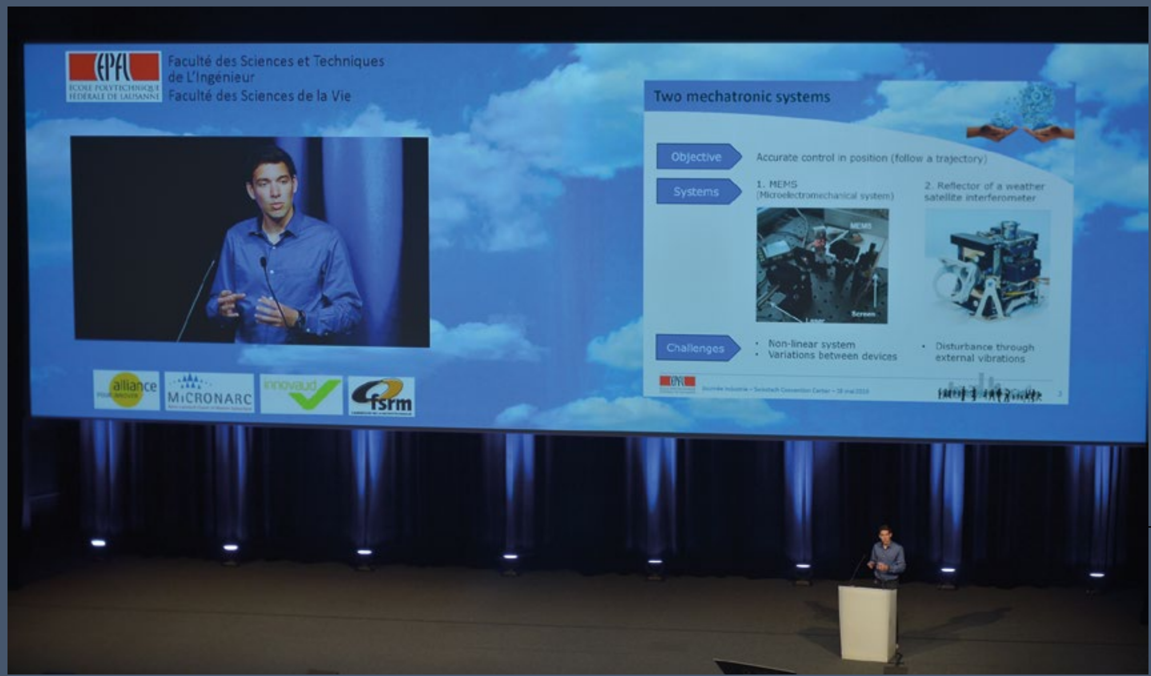
T. Fujita, J. E. Shin, M. Cunnane, K. Fujita, S. Henein, D. Psaltis, K. Stankovic, *Surgical anatomy of the human round window region : implication for cochlear endoscopy through the external auditory canal*, Otology and neurotology, 37 (2016), pp. 1189-94

L. Rubbert, R. Bitterli, N. Ferrier, S. Fifanski, I. Vardi, S. Henein, *Isotropic springs based on parallel flexure stages*, Precision Engineering, 43 (2016), pp. 132-145

R. Vatankhah, M. Kahrobaiyan, *Investigation of size-dependency in free-vibration of micro-resonators based on the strain gradient theory*, Latin American Journal of Solids and Structures, 13 (2016), pp. 498-515

M.-S. Kim, T. Scharf, S. Mühlig, M. Fruhnert, C. Rockstuhl, R. Bitterli, W. Noell, R. Voelkel, H. P. Herzig, *Refraction limit of miniaturized optical systems: a ball-lens example*, Optics Express, 24 (2016), pp. 6996-7005





LECTURES, INVITED TALKS, POSTERS

ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Boston, August 21-24, 2015, M. Kahrobaiyan, I. Vardi, M. T. Ahmadian, S. Henein, *Investigating the size-dependent static and dynamic behavior of circular micro-plates subjected to capillary force*, Lecture by M. Kahrobaiyan

HUG Genève, Colloque du département de chirurgie, January 11, 2016, lecture by C. Baur, *Utilisation de lames flexibles et outils chirurgicaux : évolution ou révolution ?*

Colloque EPFL Microcity, Neuchâtel, February 24, 2016, I. Vardi, *Me and the Lamppost*

Conférence publique FSRM, Neuchâtel, March 9, 2016, S. Henein, *Les ressorts intimes du temps*

EPFL, Lausanne, May 18, 2016, lecture by E. Thalmann, *Two mechatronic systems*

EPFL Microcity, Neuchâtel, May 19, 2016, lecture by S. Chan, *Robotic Neurosurgery and Haptics for Surgical Rehearsal*

Swiss MedTech Day, Bern, June 7, 2016, lecture by S. Fifanski, J. Rivera, C. Baur, *Force sensitive hook for epiretinal membrane peeling in eye surgery*

CADFEM users conference, Lausanne, keynote address, September 13, 2016, I. Vardi, *Nouveaux concepts en horlogerie traditionnelle*

EPFL, Lausanne, September 15, 2016, S. Henein, *Invention de l'horloge mécanique sans échappement : exemple de processus créatif collectif*

EPFL Microcity, Neuchâtel, September 21, 2016, lecture by P.-Y. Donzé, *La globalisation des systèmes de production dans l'industrie horlogère*

Congrès International de Chronométrie CIC2016, Montreux, September 28-29, 2016, M. Kahrobaiyan, L. Rubbert, I. Vardi, S. Henein, *Gravity insensitive flexure pivots for watch oscillators*, Lecture by M. Kahrobaiyan

MICRO16, IsoSpring poster presentation, Microcity, September 10, 2016

DISSEMINATION

Visits

Professors and Chiefs of Staff of Service de Chirurgie viscérale et transplantation, Hôpitaux Universitaires de Genève, visit, Microcity, March 4, 2016

University of San Francisco students, Microcity, May 25, 2016

Instant-Lab Zytglogge tour, Bern, August 30, 2016.

Newspaper articles

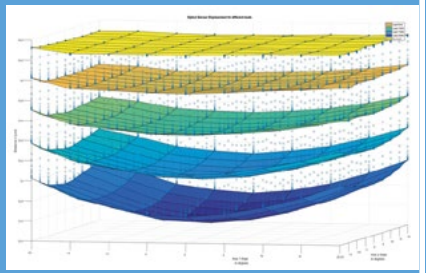
Une pendule révolutionnaire exposée,
Nicolas Heiniger, L'Express, December 9, 2016

Une révolution copernicienne,
Aline Botteron, Vivre la ville !, n° 40, December 14, 2016

Press conferences

L'horloge IsoSpring, au mécanisme révolutionnaire, mise en valeur à l'Hôtel de Ville, C. Gaillard, City Councillor (Conseillère communale), S. Henein, I. Vardi, December 8, 2016

Above documents available online
instantlab.epfl.ch/Media



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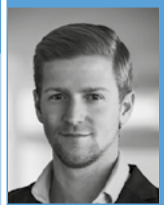

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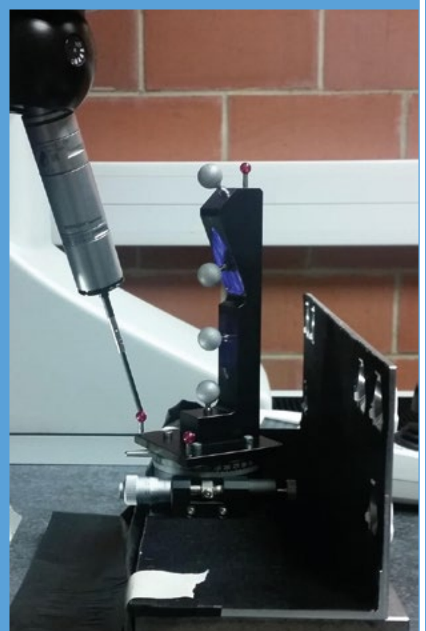

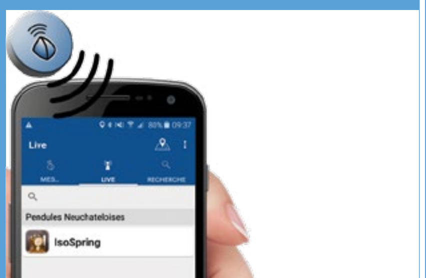

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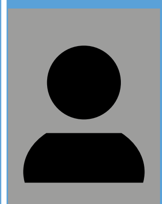

e

TEACHING

The laboratory is strongly involved in teaching. Focus is on training creative design and learning the analytical tools necessary to model, simulate and predict mechanism behavior.

EPFL

Mechanism Design I & II / Conception de mécanismes I & II (2016-2017)
Lecturer : Prof. S. Henein ; Section : Microtechnique (150 students) ; Bachelor semesters 2 and 3 ; three hours per week.

Watt balance for project-based learning (Spring semester)

Elements of mechanical design I & II / Construction mécanique I & II (2016-2017)
Lecturers : Course under the responsibility of Prof. S. Henein and Prof. J. Schiffman taught by two external lecturers ; Sections : Microtechnique / Génie mécanique (500 students) ; Bachelor semesters 1 and 2 ; three hours per week.

Industrial and applied robotics / Robotique industrielle et appliquée (2016)
Contributions to the course by Prof. S. Henein and Dr C. Baur ; Flexure mechanisms
Design of mechanisms for vacuum application ; Medical robotics ; Section : Microtechnique (60 students) ; Master semester 2.

Semester (S) and master (M) projects

a. Force displacement transducer using flexible structure, Frédéric Junod (S)
b. Micro-torque test bench validation, Benoît Ellenrieder (S)
c. Rover-drill mechanical interface for autonomous Mars analog missions, Arno Rogg in collaboration with NASA Ames Research Center USA (M)
d. Développement d'une plateforme pour application mobile en utilisant la technologie Beacon, Anthony Prudhomme en collaboration avec EPF Montpellier (M)
e. Plug-in(s) to connect Atracsys optical trackers to third-party software, Charlotte Evequoz in collaboration with Atracsys Puidoux (M)

CONCLUSION AND PERSPECTIVE

In 2014, Prof. Simon Henein announced the IsoSpring project to make the first mechanical watch without escapement. This led to patents and a large-scale industrial project. In the 2016, the laboratory succeeded in realizing a number of fully functional clock prototypes based on different embodiments of the IsoSpring concept. One of the prototypes was loaned to the Neuchâtel City Hall where it exhibited to the public. This led to significant media attention in Switzerland and beyond. In 2017, the laboratory is continuing work on this research project with a watch-scale prototype as its goal.

In November 2016, Instant-Lab successfully completed its first CTI project within budget and with promising results.

A second CTI project has been launched as well as an SNSF project, both in the medtech field.

The laboratory organized two visiting professorships resulting in a fruitful collaboration and a joint publication.

The Instant-Lab team continues to employ 18 collaborators covering a full range of skills.

Perspective for 2017

Two new Ph.D. projects will be launched in 2017 with very talented candidates and the possibility of a new industrial partnership.

Preparation of a second phase of existing industrial projects ending in 2017.

Publication in academic journals of 2015 and 2016 research, patents and Ph.D. work.

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FÉDÉRALE DE LAUSANNE

Micromechanical and Horological Design Laboratory — Patek Philippe Chair
EPFL STI IMT INSTANT-LAB, Microcity, Rue de la Maladière 71b, CH-2000 Neuchâtel