Universität Basel

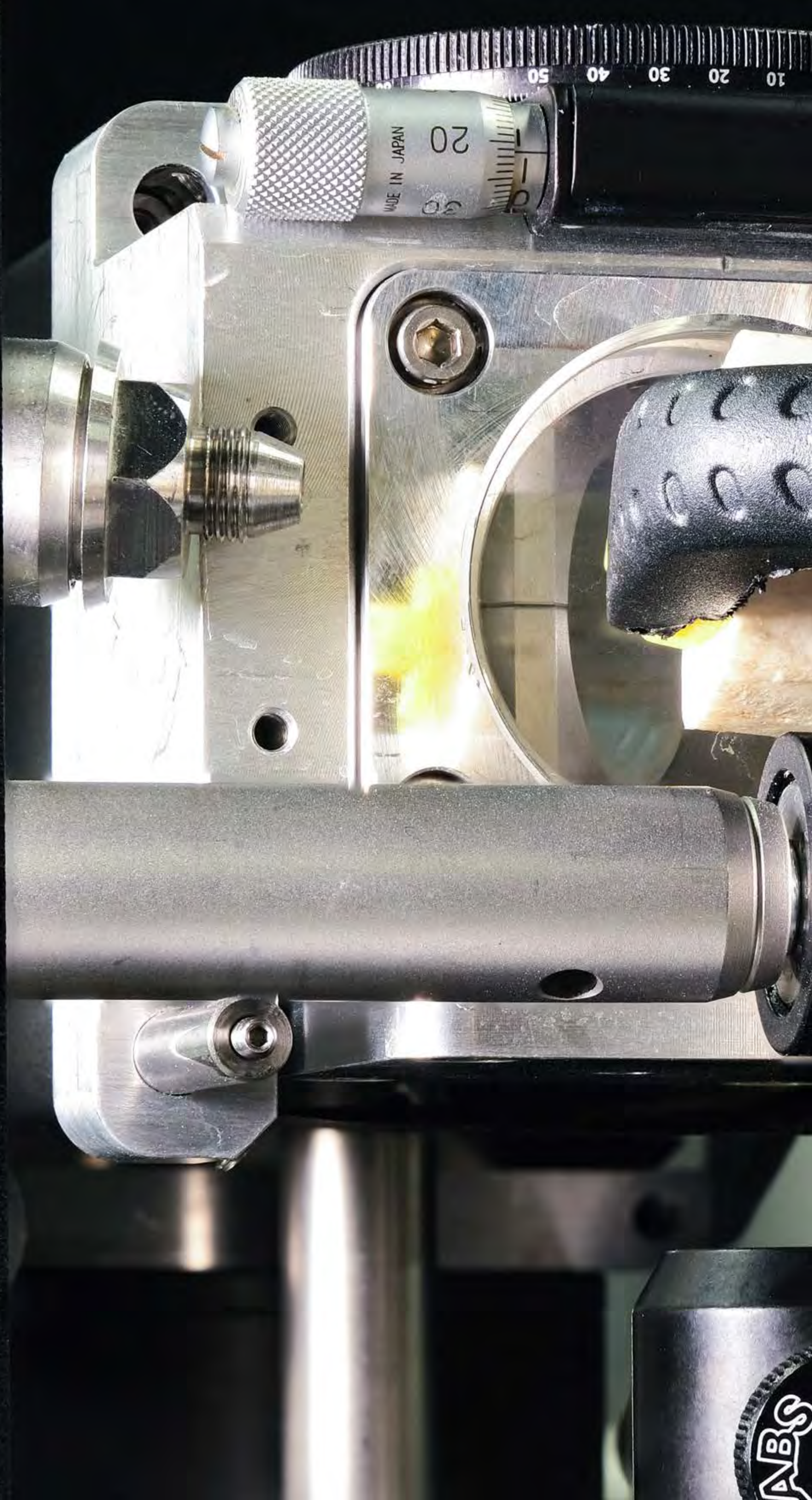
Departement of
Biomedical Engineering

FACULTATIS MEDICINAE BASILIENSIS 1460

Department of Biomedical Engineering

Annual Report 2019

150



University of Basel

Department of Biomedical Engineering

Content

SpectoVR: Planning surgical interventions in virtual reality. (Picture: F. Brüderli)

6-DoF haptic input device that can be used as a teleoperation master device. (Picture: E. Zoller)

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Overview


Robotic endoscope tip with laser bone saw. (Picture: F. Brüderli)


Anatomy of the human foot, 3D-printed in the DBE Core facility 3D Print Lab. (Picture: R. Wendler)

For the Department of Biomedical Engineering, 2019 again was a successful year regarding third-party funding: an SNSF Eccellenza professorship grant for M. Sarracanie plus three more SNSF-projects were won. Prof. Mathieu Sarracanie's Eccellenza research on «Acute Stroke MRI Exploiting the Physics of Low-field Regimes» is embedded in the AMT-Center, which already 2016 won an SNSF Eccellenza professorship.

Within the frame of an SNSF-Agora project, the DBE got the chance to present part of its research to the public. In collaboration with the Pharmacy Museum a multimedia exhibition «Inside Motion – Medicine in the Fourth Dimension» was presented.

The research developments of the DBE generally attracted considerable interest of the public: it has been visited by many politicians and business representatives, and Swiss TV SRF broadcasted a report on Virtual Reality to prepare surgery.

Further, one of the DBE's spin-offs was crowned with success: «AOT» was accredited for first-in-human operation and at the University Hospital Basel the world's first contact-free maxillary correction with a cold laser osteotome was performed by a robot.

The DBE's Master Program of Biomedical Engineering finished its first full circle of courses and will, in the coming year, optimize the program according to the learnings. By the end of the report year, already 24 students have subscribed to the next cycle of the BME Master Program.

For the DBE's successful grant acquisition, continuous growth and its implications for the future see the separate factsheet.

Main Funding:

University of Basel

FNSNF Swiss National Science Foundation

WSS Werner Siemens-Stiftung

Department Head:
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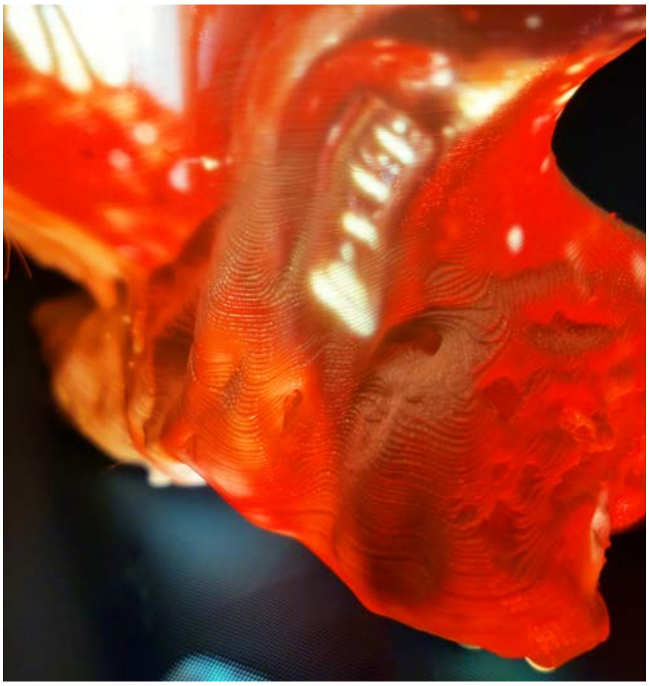
University of Basel

Department of Biomedical Engineering

About the DBE

The DBE headquarters in Allschwil (Picture: M. Geering)



3D printed hip used for experiments in the Planning & Navigation Team of the Focal Area Imaging, Modelling & Diagnosis (Picture: R. Wendler)

Patient-specific research for science-based treat-ment

The Department of Biomedical Engineering bridges the gap between natural sciences and medicine. Our researchers come from a range of different disciplines and countries. They are aiming – in close collaboration with physicians of the University Hospital Basel, the University Children's Hospital Basel and others – for feasible, problem-based and solution-oriented tools for patient-specific research and science-based treatment.

The DBE organizes about 130 researchers in four Focal Areas:

- Biomechanics & Biomaterials
- Imaging Modelling & Diagnosis
- Medical Lasers & Robotics
- Regenerative Surgery

The MIRACLE-project synergizes excellence from different Focal Areas in the challenge to develop a mimimally invasive robot-assisted and computer-guided laserosteotome. Since 2013 the DBE hosts a PhD program, and, since 2017, also a Master of Science program that attracts young researchers to the rapidly evolving field of biomedical engineering. Moreover, the department is place of origin for a number of award-winning MedTech spin-offs.

Funding partners:

Universitätsspital Basel

UKBB kompetent & menschlich

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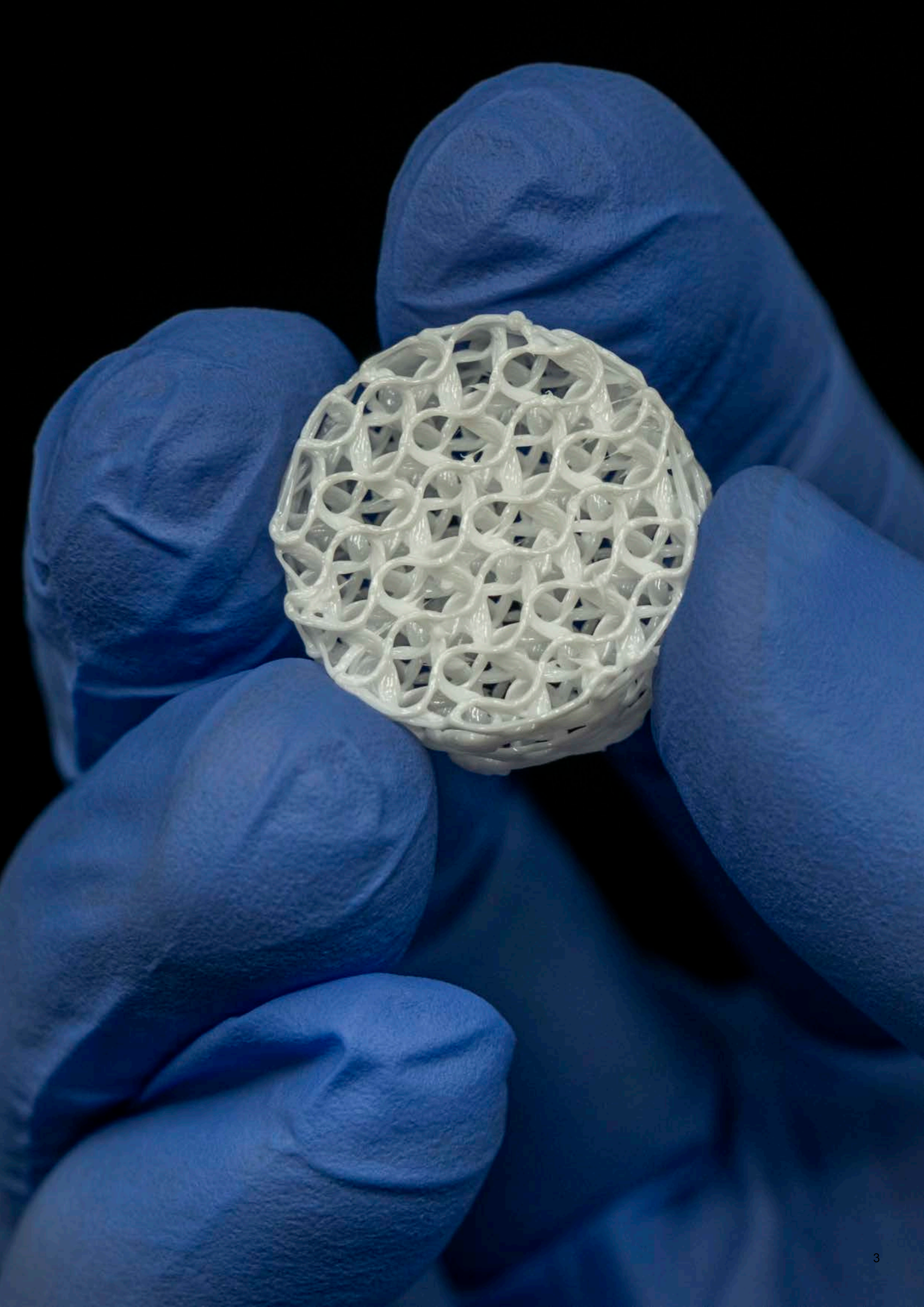

University of Basel

Department of
Biomedical Engineering

Focal Area Biomechanics & Biomaterials

Two researchers of the Biomaterials Science Center at the polymer station (Picture: D. Ettlin)

Soft plasmonic nanosensor (Picture: T. Töpper)

The Focal Area Biomechanics & Biomaterials hosts a spectrum of research groups reaching from movement analysis to artificial tissue. All these efforts aim at a new image of the healthy and pathological human body based on the firm ground of the laws of physics.

By developing new technologies like biosensors and big data tools for movement analysis, DBE researchers are creating the very basis of patient-specific and therefore substantially enhanced treatment of many bone and joint diseases. Other groups are investigating the possibilities of artificial tissue, both mechanically manufactured and 3D printed. These technologies allow for better materials, coating and fixing technologies for implants. Further, this Focal Area aims for the Virtual Patient, an individualized, patient specific assembly of data for a tailored treatment, which we consider as the future of medical treatment. Anonymized, these data sets can be used to teach students how to perform diagnosis, how to plan a treatment or an operation. They also serve for longitudinal studies, in which the characteristics of a pathology and the effect of a treatment can be studied over an extended time period.

Facts & Figures

In 2019, the Focal Area Biomechanics & Biomaterials consisted of seven research groups with more than 30 researchers. Most of them are located at the DBE in Allschwil and at the University Hospital Basel, thus reinforcing the intricate translational relation between these two institutions and ensuring the applicability of our research output.

Funding:

FNSNF
Fonds National Suisse
Schweizerischer Nationalfonds
Fondo Nazionale Svizzero
Swiss National Science Foundation

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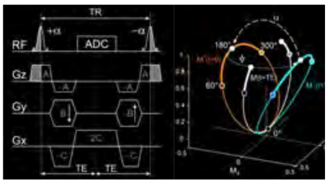
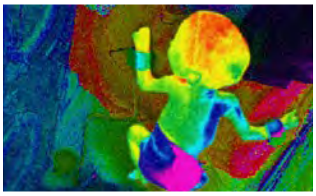
Department of Biomedical Engineering

Focal Area Imaging, Modelling & Diagnosis

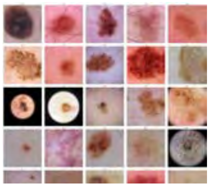

Center for medical Image Analysis & Navigation



Magnetic Resonance Physics & Methodology

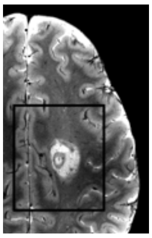

Computational Physiology & Biostatistics


Adaptable MRI Technology


Digital Dermatology


Inst. Forensic Medicine


Translational Medicine Breath Research


Quantitative BioImaging Group (qbig)


Biomaterials science Center


Human Optics Lab


Translational Imaging in Neurology (ThINk)

The Focal Area Imaging, Modelling & Diagnosis aims at shaping the future of medical diagnostics by combining unique skills and expertise in the fields of magnetic resonance imaging, X-ray tomography, optics, disease phenotyping, mass spectrometry, big data, deep learning and virtual reality. The research we perform is application-driven, addressing scientific questions that lie at the cross-section between fundamental research and translation to clinical settings.

Research interests in this focal area span a broad spectrum of activities ranging from the development of methods and hardware, to advanced software tools for image analysis, navigation, data-driven disease phenotyping, and patient tele-monitoring. We continuously reach out to practitioners to enable clinical translation of novel imaging technology, being in adults or children practice, or oriented towards forensic medicine.
Key to all research led in this focal area is the leitmotiv that progress in imaging, diagnostic tools and disease phenotyping will foster advances in personalized medicine and provide a deeper understanding of the structure and function of the human body.

Facts and Figures

In 2019, the Focal Area Imaging, Modelling & Diagnosis consisted of 15 research groups and about 60 researchers. They are located at the DBE in Allschwil, the University Hospital, the University Children's Hospital, and at the Institute of Forensic Medicine.

Funding:

FNSNF
Fonds National Suisse
Schweizerischer Nationalfonds
Fondo Nazionale Svizzero
Swiss National Science Foundation

NOVARTIS

WSS
Werner Siemens-Stiftung

fondation BOTNAR

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Facultatis Medicinae Basiliensis 1460

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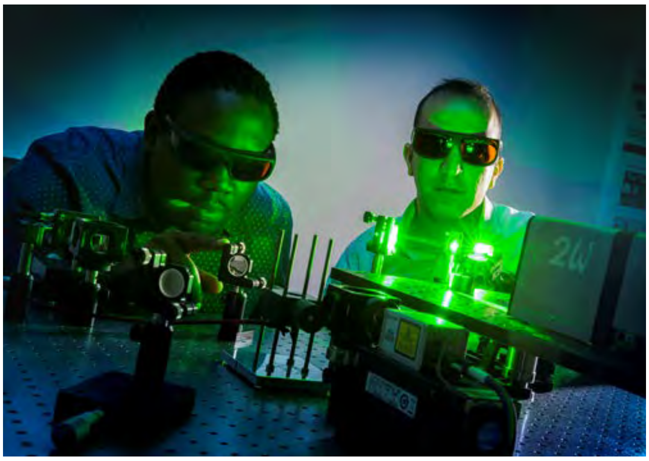
University of Basel

Department of
Biomedical Engineering

Focal Area Medical Lasers & Robotics

Innovative robotics and laser technology (Picture: R. Wendler)



Laser experiment (Picture: F. Brüderli)

Lasers and robots enable minimally invasive diagnostics and treatments, highly repeatable performance, faster healing and real-time data exchange with new safety standards. The Focal Area Medical Lasers & Robotics at the Department of Biomedical Engineering merges these technologies in a novel platform for semi-autonomous robotic laser surgery for ablation of bone tissue.

The Focal Area Medical Lasers & Robotics is located at the intersection of the natural sciences, engineering sciences and medicine. Its teams work on cutting bones with a minimally invasive robot and laser technology which allows for pre-manufacturing of personalized implants since they will fit accurately into their cut counterparts. In addition, researchers of the focal area are developing and patenting novel navigation technology in order to control the robot-assisted laser system during surgery. The ultimate project's goal is to develop an integrated, and interconnected real-time system that will broaden the scope of surgical procedures in at least two dimensions: the size of the surgical sites that can be treated, and the age limit for admitted patients can be increased towards elderly patients with reduced overall health.

Facts & Figures

In 2019, the Focal Area consisted of four research groups with about 40 researchers. Most of them are located within the laboratories of the MIRACLE-Project in Allschwil, working in close cooperation with several surgeons at the University Hospital.

Funding:

WSS
WERNER SIEMENS-STIFTUNG

Project MIRACLE
Minimally Invasive Robot-Assisted Computer-guided LaserosteotomE

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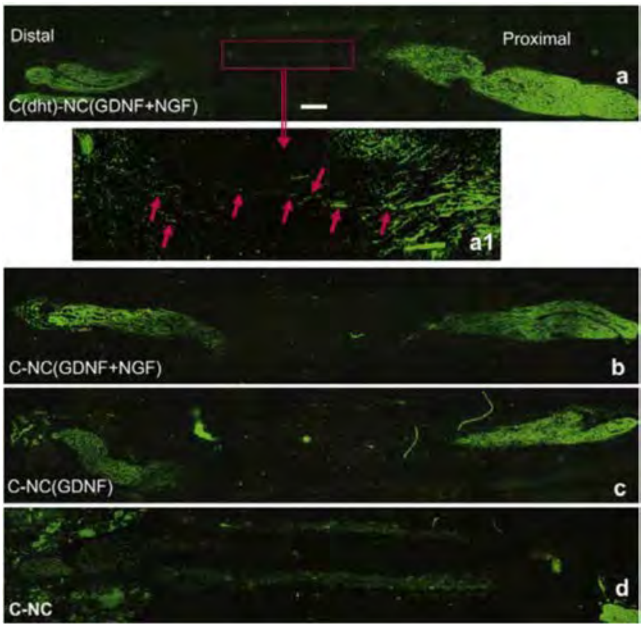
University of Basel

Department of Biomedical Engineering

Focal Area Regenerative Surgery

Tissue engineered cartilage (Picture: I. Martin)



Longitudinal sections of regenerating nerve inside the NCs histochemically stained fo. (Picture: S. Madduri et al. (1))

The Focal Area Regenerative Surgery covers a field of research and clinical applications that aims to repair, replace, or regenerate tissue to restore organ function. This rapidly emerging field does not focus on classical forms of surgery, but on regenerative interventions in the case of congenital defects, damage, trauma or aging.

The Focal Area Regenerative Surgery integrates surgical and regenerative medicine research groups specialized in the development of new technologies for the engineering of tissue grafts and for surgical manipulation of the implantation site. In addition to research activities directly aimed at clinical applications, the focal area also develops 3D culture systems as in vitro model systems to study tissue or tumor biology. Possible applications include the targeting of skeletal tissue, the peripheral nervous system, or muscle. Research in this focal area involves highly interdisciplinary activities in biological, engineering, and pharmaceutical sciences. It is linked in many ways with technologies developed within other focal areas at the Department of Biomedical Engineering.

Facts & Figures

In 2019 the Focal Area Regenerative Surgery consisted of five research groups with about 30 researchers, located to almost equal parts in Allschwil and in the University Hospital Basel, thus entertaining constant exchange and ensuring the medical feasibility of the research performed.

Funding:

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

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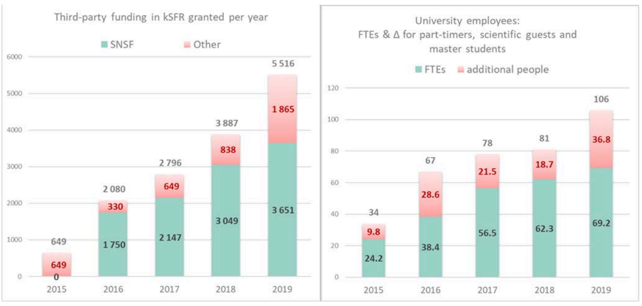
University of Basel

Department of
Biomedical Engineering

Finances, Personnel and Resources

Who	Grant	k SFR
Sarracanie, Mathieu	SNSF Eccellenza	1'682
Mündermann, Annegreth	2 SNSF Projects	1'113
Müller, Bert; Müller-Gerbl M	SNSF Project	855
Bieri, Oliver; Granziera C, Stjelties B	Foundation*	617
Osmani, Bekim	Gebert Rüf Stiftung	300
Cattin, Ph; Guzman R	Uniscientia Foundation	291
Jud, Ch; Cattin, Ph	Industry support	139
Stübinger, Stefan	KTI-Project	56
Cattin, Ph; Bieri, O; Stieltjes, B	Foundation*	50
Salameh, Najat	Med. Fac. Supp. for Postdoc	200
Granziera, Cristina	Med. Fac. Supp. for PhD-Stud	210
TOTAL		**5'513**

Granted funding 2019.
*Stiftung zur Förderung der gastroenterologischen und allgemeinen klinischen Forschung sowie der medizinischen Bildauswertung – For Feasibility study, final project (open): 500 k SFR.



Growth in third-party funding (left) accompanied by increasing employee numbers.

The Department of Biomedical Engineering is a young and still growing department at the Medical Faculty. The growth is reflected by the steadily increasing number of employees, professors, submitted projects and granted funds, but also PhD and master students and participants at the research day.

Funding applications from end of 2018 to end of 2019 resulted in CHF 5.5 Mio grants, thereof 3.6 Mio granted by the SNSF alone. This again led to a further increase of the number of employees to 70 FTEs but also to an increase of guest researchers.

The University of Basel, on the other hand, granted a considerable amount for equipment (410 kSFR), allowing the DBE to further expand its infrastructure. Especially notable is the new precise and contactless tracking system that can be synchronized with other systems e.g. robots and applied in MRI environments for performance evaluation for example of the MIRACLE osteotome.

Despite this growth, only part of the space formerly rented by the University Hospital for the DBE has been taken over by the University of Basel at the end of 2019, hence all research groups located on this area had to concentrate on the remaining space. This reduction was mitigated, however, by the University of Basel's commitment that the DBE would move to GRID (grand réseau d'innovation et de développement) at the beginning of 2023 and there receive tailor-made research facilities.

Funding:

University of Basel

WSS
WERNER SIEMENS-STIFTUNG

FNSNF
SWISS NATIONAL SCIENCE FOUNDATION

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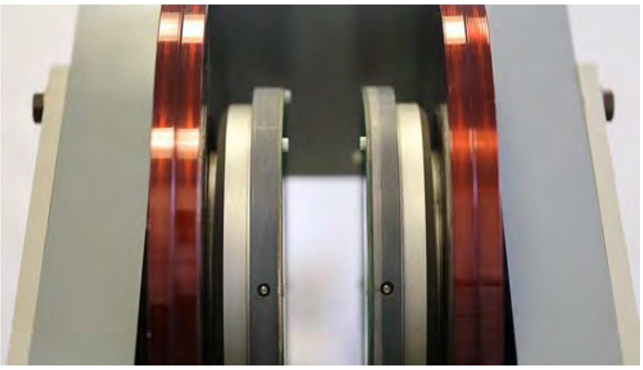
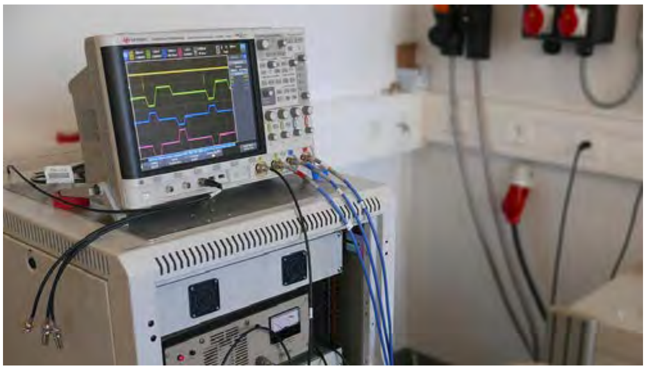
SNSF-Eccellenza Grant: Acute Stroke MRI Exploiting the Physics of Low-field Regimes


Experimental low-field MRI system. (Picture: AMT Center)


Running experiment in the labs of the AMT Center. (Picture: AMT Center)

When stroke strikes, every minute counts. Today, the greatest challenges in the management of stroke patients are 1) to rapidly separate between ischemic and hemorrhagic events which call for completely opposite treatments, and 2) to establish robust new markers of ischemia in the first three hours offering the best patient outcomes, potentially leading to full functional recovery. This project will develop MRI technology tailored to the assessment of acute stroke in the time window 0-3h after onset.

The proposed project comprises three aims that include 1) the development of imaging tools in magnetic fields compatible with mobile and portable designs, 2) the validation of simultaneous multi-parametric imaging that quantifies stroke related metrics, and 3) in vivo investigation of contrast and specificity of low-field MRI in acute stroke.

Over the last 30 years, MRI has developed to become the modality of choice in radiology thanks to unmatched contrast and spatial resolution. Yet, due to high costs and siting requirements MRI is less available or flexible than X-ray based or ultrasound (US) imaging. Lowering magnetic fields to envision agile, «point-of-care» devices is a concept that has gained considerable momentum over the last three years and yet few of this work reports on imaging performance and focuses predominantly on hardware. The present project proposes to combine synergistically high-performance imaging in low-sensitivity and inhomogeneous regimes with the uncovering of new metrics to quantify the earliest phase of stroke unique to low magnetic field physics.

The expected long term societal and economical outcomes in the context of stroke is a radical improvement of recovery and survival rates in stroke patients from accelerated decision making and future devices sited in the field, reducing drastically the cost of health inherent to stroke patient management.

Funding:
FNSNF
Swiss National Science Foundation

Project Leader:
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University of Basel

Department of Biomedical Engineering

Exhibition Inside Motion

Philippe with students in the VR (Picture: S. Hanselmann)

Students playing with haptic ultrasound (Picture: S. Hanselmann)

From April 26 to June 2 the Center for medical Image Analysis & Navigation presented an exhibition on medical imaging at the Pharmaziemuseum Basel. The show was called «Inside Motion – Medicine in the Fourth Dimension» and was funded by SNF within the Agora-Scheme from 1st of June 2018 until 31st of May 2019.

The show consisted of seven stations, including CIAN's SpectoVR, a visualisation of a moving heart with a Zoetrope, an ultrasound installation, films, holograms and interactive settings. The seven stations were accompanied by additional exhibits like a historical wall, displaying images which show major paradigm shifts within the field of anatomical and medical imaging, starting with the anatomical Atlas ‹De Humani Corporis Fabrica› by Andreas Vesalius, printed in 1543 in Basel, historical microscopes and books. The exhibition was complemented by an extensive exhibition program, consisting of workshops, evening lectures and guided tours.

The Pharmaziemuseum Basel has counted almost 3000 visitors. This great success was possible due to an obvious public interest in the topics of the future of medicine and images of the living body. The three workshops with two school classes from Sekundarschule Gelterkinden and one from Theresia-Scherer-Schule in Rheinfelden-Herten, Germany were attended by around 100 pupils. The evening lectures addressed another target audience. Here, around 70 visitors were considerably older than in the workshops and the usual visitors.

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FNSNF

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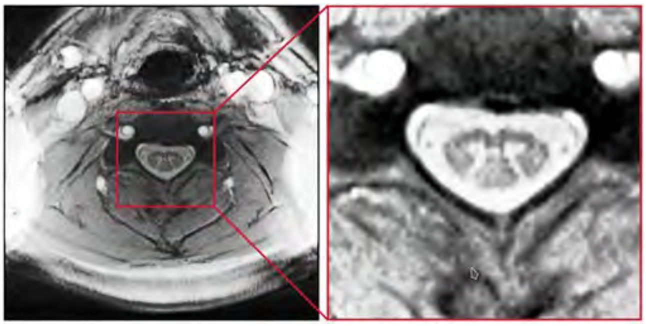
KUKA

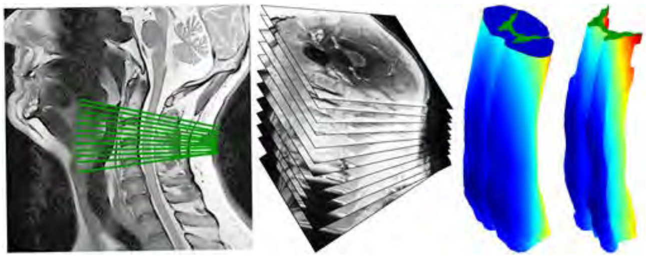
University of Basel

Department of
Biomedical Engineering

Segmentation and Quantification of Spinal Cord Gray Matter–White Matter Structures in MRI



Full view on an exemplary axial AMIRA image and a zoomed view of the SC's cross section (Picture: A. Horváth)



The AMIRA imaging protocol with 12 axial slices perpendicular to the SC, the resulting stack of slices, and 3D visualizations of the segmented SC and GM. (Picture A. Horváth)

PhD Thesis of Antal Horváth at CIAN.

This thesis (1) focuses on finding ways to differenti-ate the gray matter (GM) and white matter (WM) in magnetic resonance (MR) images of the human spi-nal cord (SC).

The aim of this project is to quantify tissue loss in the GM and WM compartments to study their implications on the progression of multiple sclerosis. To this end, we pro-pose segmentation algorithms that we evaluated on MR images of healthy volunteers.
Segmentation of GM and WM in MR images can be done manually by human experts, but manual segmen-tation is tedious and prone to intra- and inter-rater varia-bility. Therefore, a deterministic automation of this task is necessary. We experiment with various automatic segmentation algorithms on axial 2D images acquired with a recently proposed MR sequence called AMIRA. We first use variational model-based segmentation ap-proaches combined with appearance models (2, 3) and later directly apply supervised deep learning to train seg-mentation networks (4). Evaluation of the proposed methods shows accurate and precise results, which are on par with manual segmentations.
We test the developed deep learning approach on im-ages of conventional MR sequences in the context of a GM segmentation challenge, resulting in superior perfor-mance compared to the other competing methods (4). To further assess the quality of the AMIRA sequence, we apply an already published GM segmentation algo-rithm to our data, yielding higher accuracy than the same algorithm achieves on images of conventional MR se-quences (3).
From the methodical point of view, this work provides an introduction to computer vision, a mathematically fo-cused perspective on variational segmentation ap-proaches and supervised deep learning, as well as a brief overview of the underlying project's anatomical and medical background.

Funding:

FNSNF Swiss National Science Foundation

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PD Dr. Katrin Parmar
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References:
(1) Antal Horváth. *Segmentation and Quantification of SC GM-WM structures in MRI.* Doctoral Thesis, University of Basel, 2019.

(2) Horváth et al. *Variational Segmentation of GM-WM in the SC using a shape prior.* MICCAI CSI, 2016.

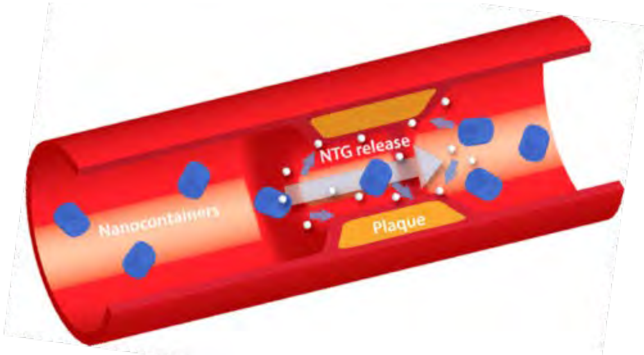
(3) Tsagkas et al. *Automatic SC GM Quantification: A Novel Approach.* AJNS, 2019.

(4) Horváth et al. *SC GM-WM segmentation on AMIRA images with MDGRU.* MICCAI CSI, 2018.

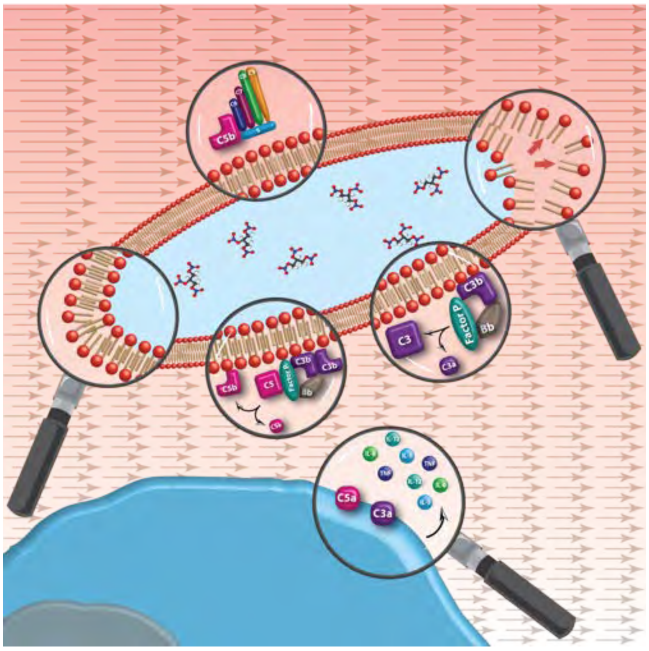
University of Basel

Department of
Biomedical Engineering

Mechano-responsive nanometre-size lipo-somes



Schematic representation of nitroglycerin (NTG) release from mechano-responsive liposomes about 100 nm in diameter owing to the forces in blood flow at constriction. (Picture: S. Matviykiv)



Schematic representation of a nitroglycerin-loaded Rad-PC-Rad liposome that circulates the vascular system. At atherosclerotic constrictions, the significantly increased wall-shear stress permits the cargo release. These liposomes barely demonstrate immune reactions *in vitro* in terms of complement system activation and cytokines production. (Picture: S. Matviykiv)

PhD-Thesis by Sofiya Matviykiv at BMC.

Currently, the emergency treatment of atherosclerotic cardiovascular diseases involves the systemic administration of vasodilator drugs. This results in a widening of the entire blood vessel system associated with a severe drop of blood pressure. We have proposed a nanometre-size drug delivery system built out of artificial phospholipids, a.k.a. liposomes, encapsulating an established vasodilator drug for the emergency treatment of myocardial infarction (1). These nanocontainers are responsive to the forces at vessel constrictions.

Physicochemical characterization of a series of mechano-responsive liposomes including size, shape and thermal stability within the clinically relevant temperature range was performed using dynamic light scattering, transmission electron microscopy and small-angle neutron scattering. The study has shown that the originally proposed Pad-PC-Pad liposomes become unstable above 37 °C, whereas Rad-PC-Rad are an appropriate alternative even for elevated body temperatures (2). To improve the clinical translation of this drug delivery platform, we have investigated *in vitro* immunocompatibility of liposomes (3). To evaluate the risk of a hypersensitivity reaction, we detected the concentrations of activated complement proteins and cytokines using enzyme linked immunosorbent assays and flow cytometry. Within the restricted number of individuals both the Pad-PC-Pad and Rad-PC-Rad liposomal formulations exhibited low-to-moderate levels of complement proteins compared to the FDA-approved liposomal drugs. Overall, results indicate that Rad-PC-Rad liposomes are promising mechano-responsive nanocontainers suggesting them for future *in vivo* experiments. A related start-up company, Acthera Therapeutics AG, was founded in September 2019.

Funding:

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

BMC Biomaterials Science Center

University of Basel

Supervisor:
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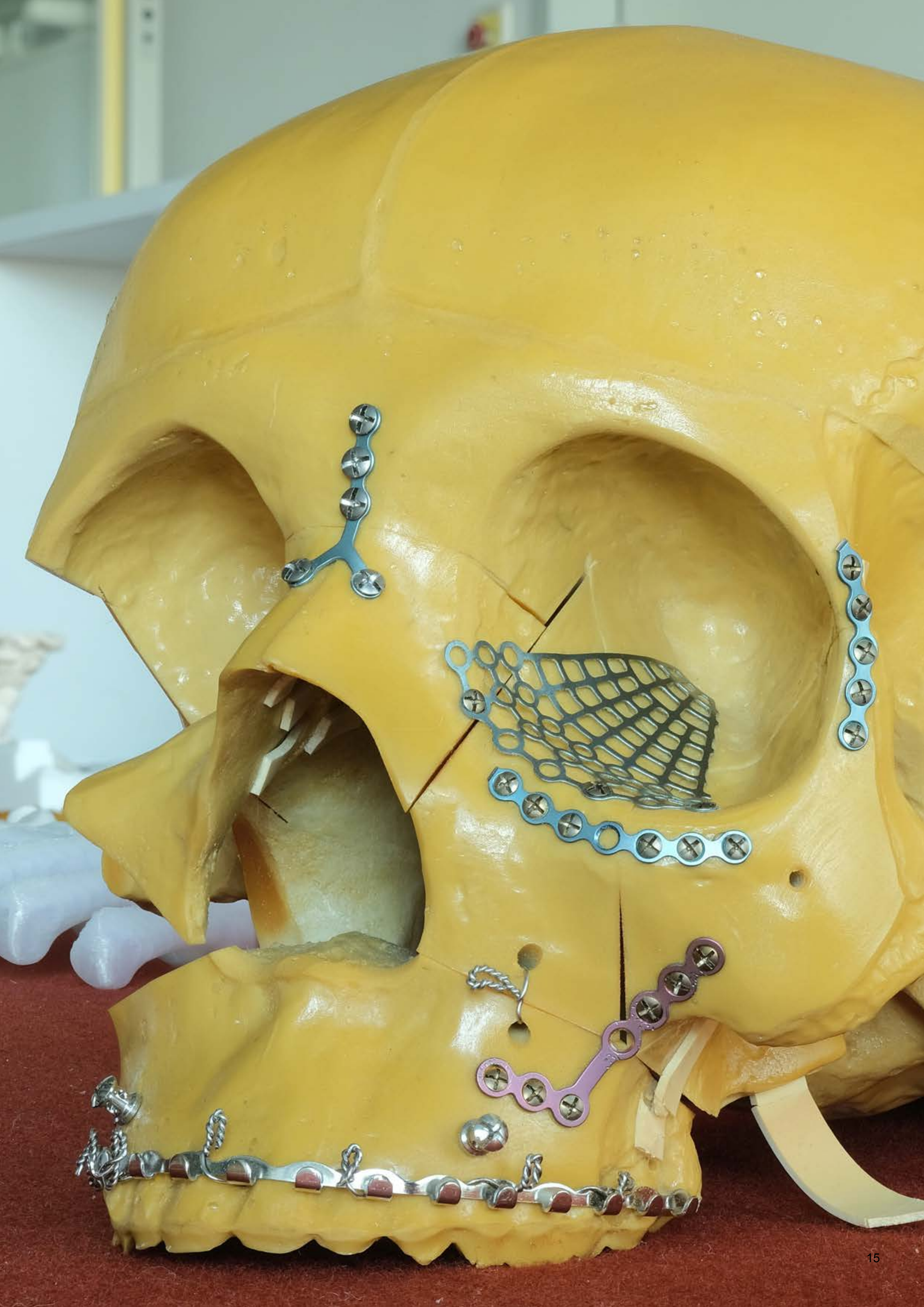
References:

(1) T. Saxer, A. Zumbuehl, B. Müller: *The use of shear stress for targeted drug delivery*, Cardiovascular Research **99** (2013) 328-333.

(2) S. Matviykiv, et al.: *Small-angle neutron scattering study of temperature-induced structural changes in liposomes*, Langmuir **35** (2019) 11210-11216.

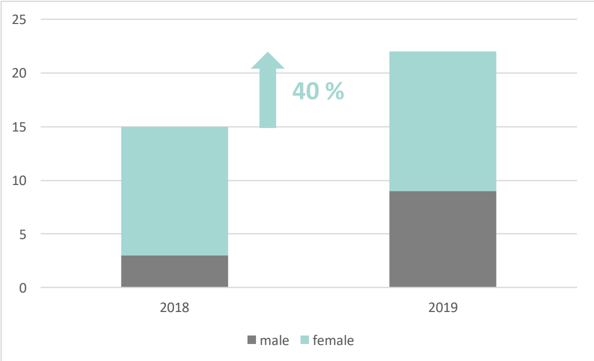
(3) S. Matviykiv, et al.: *Immunocompatibility of Rad-PC-Rad liposomes in vitro, based on human complement activation and cytokine release*, Precision Nanomedicine **1** (2018) 45-67.



University of Basel

Department of
Biomedical Engineering

Teaching in the Master of Science in Biomedical Engineering



Number of new master students in the first (2018) and second (2019) year of the Master's program.

Master students working with a molecular beam deposition system to fabricate nanometer-thin polymer films used for artificial muscles, nanosensors and neural interfaces. (Picture: F. Moritz)

In autumn 2018 the Department of Biomedical Engineering offered for the first time a Master's program. Already in 2019 this Master's program in Biomedical Engineering started with increased student numbers compared to the number of students starting in 2018.

The Master's program in Biomedical Engineering is tailored for students holding a Bachelor's degree of various backgrounds like engineering, natural sciences, medicine or health sciences. In the first semester, students acquire basic knowledge in biomedical engineering and follow courses to equilibrate their skills in all disciplines (mathematics, mechanics and programming, or anatomy, physiology and biology of tissues). In the second semester, students will focus on one of the two major modules (Image-Guided Therapy or Biomaterials & Nanotechnology) including courses in materials science, principles of nanotechnology, characterization of biomaterials, engineering of 3D tissue culture models, medically relevant imaging, medical robotics, medical laser physics as well as signal and image processing.

From the start, the Master's program was carefully monitored by the teaching committee and evaluated by the new master students. This feedback was incorporated in summer 2019 in a new version of the «Wegleitung» to optimally guide students in their master study. The overall feedback of the master students was very positive with high satisfaction on the teaching contents (4 out of 5) and a promising recommendation rate (8 out of 10).

The first Master students are expected to finish in spring 2020 and we are looking forward to seeing their developments in the future.

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University of Basel

Department of
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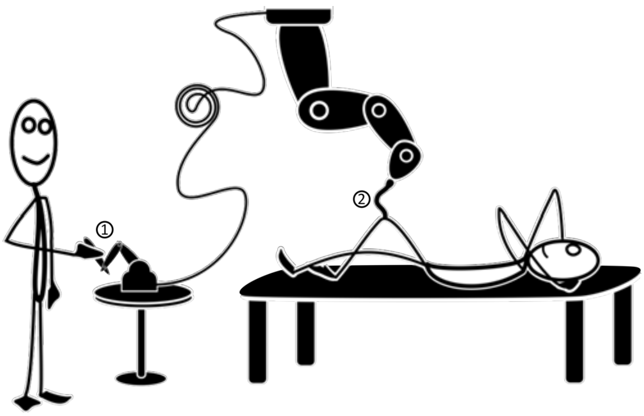
Enhancement of Telemanipulation – A Survey on Haptic Guidance for a 6-DoF Robotic Endoscope



Teleoperation setting for robot-assisted surgery: The motion of the surgeon is recorded by the master device ① and transferred to the operating robot ②. (Picture: Esther Zoller)

6-DoF haptic input device that can be used as a teleoperation master device. (Picture: Esther Zoller)

Master Thesis by Tim Dürrenberger (Universität Basel) at BIROMED-Lab.

When manipulating an object, we are naturally capable of controlling its position and orientation using haptic information. However, in robot-assisted minimally invasive surgery, haptic feedback is lost. Consequently, researchers have to find new ways to assist surgeons so that they can regain control when operating. Set up as software-generated constraints, virtual fixtures either encourage the surgeon to move the robot along a pre-defined path or prevent the robot from entering so-called forbidden regions. In robot-assisted minimal invasive laser osteotomy, virtual fixtures have been considered to assist surgeons when moving an endoscopic end-effector to a specific orientation. It is, however, unclear how to implement virtual fixtures feasibly and safely.
To provide an overview on current orientational control strategies, a systematic literature research was carried out. The metrics chosen to evaluate the investigated orientational constraint methods are task completion time and task precision.
All encountered orientational control strategies showed an increase in task precision when compared to unconstrained test runs. Also, most orientational constraints led to a reduced operation time.
Wide-ranging control methods that guide the user along the entire manipulation show best results in operator performance. However, when only alignment of the end-effector is desired, it is up to debate if local orientational control already meets the demands of tele-manipulated surgery. Dissipative control strategies that act passively and redirect the surgeon's energy may offer the best answer yet on how to implement orientational virtual fixtures.

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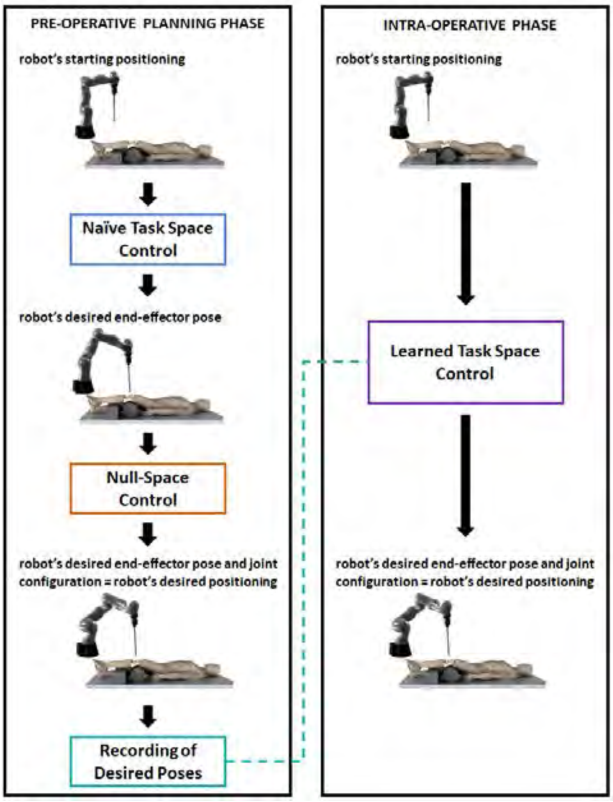
Department of Biomedical Engineering

Reducing Time and Surgeon Mental Workload for Robot Positioning in Operating Room using Learned Desired Null-Space Joint Configurations

Robotic arms in surgery (Picture: BIROMED-Lab)



Proposed control system usage in a surgical setting (Picture: Riccardo Parini)

Master Thesis by Riccardo Parini (Politecnico di Milano) at BIROMED-Lab.

The main advantages in applying robot-assisted surgical systems in clinical practice are the perfect symbiosis between the strengths of humans, namely surgeons or their assistants, and robots. While surgeons are versatile, sensitive, ethical and able to acquire qualitative information, robots provide high accuracy, multitasking capabilities, and various types of control schemes.

However, the functionalities that would allow a surgeon to optimally collaborate with the robot are still missing. Certainly, one of these missing functionalities is the possibility for the surgeon to position the surgical robot correctly in the operating room during the intra-operative phase without wasting time and exerting unnecessary mental workload.

In this work, we implemented a novel control system for a surgical robotic arm, which allows reducing the time and the mental workload required from a surgeon to position the surgical robot in the operating room at the onset of the intra-operative phase. The proposed control system was used to telemanipulate a 3D model of a KUKA LBR iwaa 14 robotic arm holding an actuated endoscope used to perform minimally invasive laser osteotomy at the level of the patient's knee (1). The proposed control system was evaluated in a study that showed a reduced overall effort for operators compared to a standard control system.

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References:
(1) Karnam, M., Parini, R., Eugster, M., Cattin, P., Rauter, G., Gerig, N.: An intuitive interface for null space visualization and control of redundant surgical robots. In: Automation in Medical Engineering. Infinite Science Publishing (2020)

University of Basel

Department of
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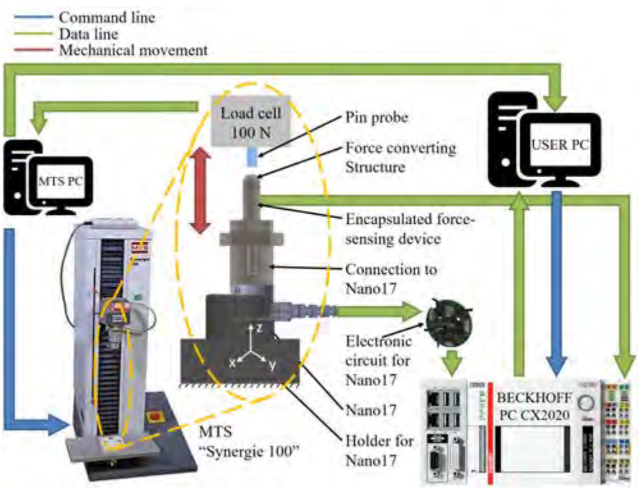
Development of an Encapsulated Force Sensor for Endoscopic Palpation

(a) (b)

(a) Assembled encapsulated tri-axial force sensor for soft tissue palpation in neurosurgery (picture: Luca Marco Pavone), (b) Printed circuit board with the force sensors mounted on it - the core of the encapsulated force sensor (Picture: WSS/F. Brüderli/Longhini)



The interaction of the different systems used for the characterization of the encapsulated force sensor and the data flow (Picture: Luca Marco Pavone).

Master Thesis by Luca Marco Pavone (Eidgenössiche Technische Hochschule Zürich – ETHZ) at BIROMED-Lab.

A minimally invasive examination allows medical doctors or surgeons to probe inner tissues of the human body using endoscopes. However, surgeons can only base their examination on visual observations of structures, color, and tissue shape. Further, endoscopic palpation of the tissue's mechanical properties (e.g. tissue stiff-ness) is infeasible in comparison to open surgeries where surgeons use their fingers to perform palpation. To re-establish the sense of touch to the surgeons in en-doscopic procedures, we first aim to measure contact forces in three directions (one normal and two shear forces) at the tip of the endoscope. Additionally, the pos-sibility of force measurement between the surface of en-doscopic devices and tissue may increase safety in en-doscopic procedures. If forces between endoscope and tissue exceed a certain threshold, a surgeon would be notified and possible tissue damage during both guiding and palpation phases may be avoided.

The aim of this thesis is the improvement of the encapsulated force-sensing device reported by Ivan Susic *et al.* (1) and its redesign for enabling soft tissue palpation in neurosurgery. The focus is on improving the mechan-ical robustness, enabling compliance, and reducing the outer diameter from 10 mm to 6.8 mm to comply with di-mensions of endoscopes used in neurosurgery.

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References:
(1) I. Susic, A. Zam, P.C. Cattin, G. Rauter, "Versatile, force range-adjustable, tri-axial force sensor with integrated micro camera for the tip of endoscopic devices". The Hamlyn Symposium, 2018.

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Development and realization of analog, high input impedance preamplifiers for NMR and MRI at low frequency (4.2 MHz)

Master Thesis of Thomas Quirin at AMT-Center.

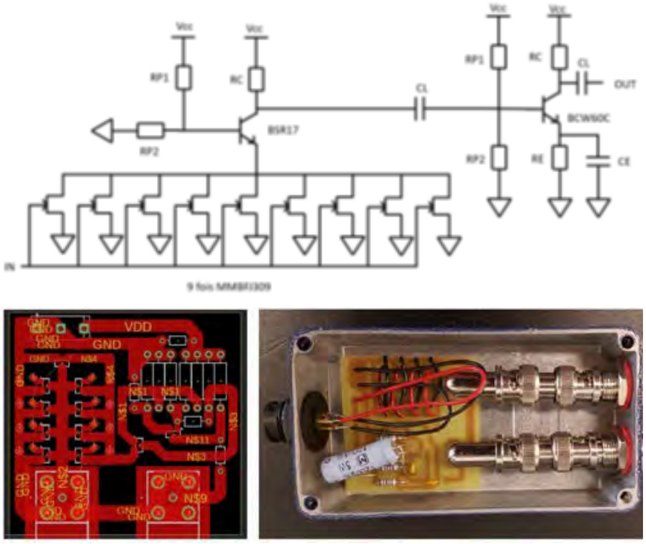

Figure 1: Above: Design and below: Construction (PCB design & integration) of the 2nd generation high-input preamplifier prototype. (Pictures: T. Quirin)

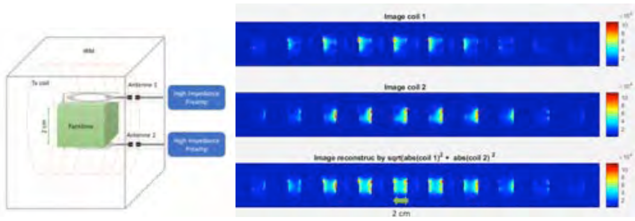

Figure 2: Decoupling performance assessed with MRI. A) Schematic showing two NMR surface coils facing each other, placed inside the MRI scanner and connected to our high-input impedance preamplifiers. B) Images obtained reveal minimal coupling between the two facing coils (image coil1&2), despite their close proximity and potential strong coupling. The combined images allow to nicely depict the imaged phantom. (Picture: T. Quirin)

At low frequency (<5MHz), the noise dominance regime in NMR transitions from sample dominated to the so-called Johnson noise dominated regime, where electromagnetic noise from the acquisition chain dominates. In this context, the noise perceived by multiple detectors can be assumed to be incoherent, and strategies that combine multiples sensors can be leveraged to increase sensitivity. NMR detectors (coils) are resonant systems that include an inductor (L), a capacitive network (C) and some intrinsic resistance (R), and whose frequency of operation is being tuned to match the Larmor frequency of Hydrogen nuclei at a particular magnetic field. Unfortunately, multiple NMR coils in close vicinity are subject to strong coupling phenomena that impact their performance, and hence cannot be used as envisioned to increase sensitivity. We proposed developing custom, analog preamplifiers with a high input impedance to attenuate the circulating current in NMR conductors, hence diminishing electromagnetic interactions (coupling) to favour sensitivity and/or coverage for MRI applications. In this context, we have designed, developed and constructed two generations of analog preamplifiers. Their gain performance was assessed, and their decoupling efficiency for imaging was successfully demonstrated in a custom-built phantom placed within the bore of a 0.1 T compact MRI scanner. This original work validates our hypothesis of employing high-input impedance to promote decoupling efficiency in NMR resonators, and opens new perspectives to boost sensitivity and hence imaging performance in low magnetic field MRI systems.

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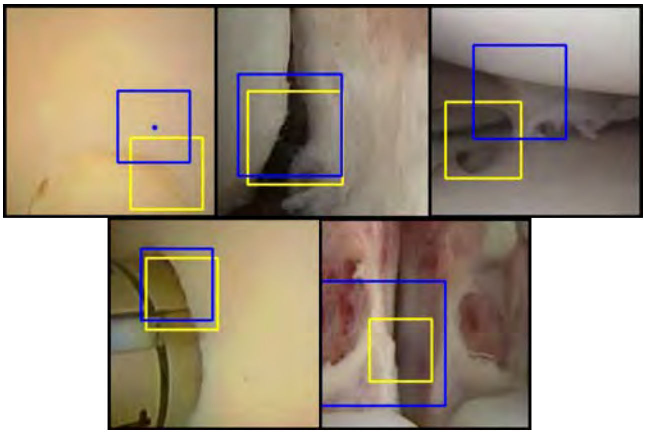
Evaluation of Tracking Algorithms for a Visually Servoed Robotic Endoscope

An endoscope prototype with an integrated miniature camera was built to track a target during arthroscopies. (Picture: Stephan Schraivogel)



Arthroscopic videos were used to compare different tracking algorithms from an existing computer vision library for robustness and precision. The yellow frame shwos the ground truth target location, the blue frame indicates where the tracking algorithm assumes the target to be. (Picture: Stephan Schraivogel)

Master Thesis by Stephan Schraivogel (Uni Freiburg) at BIROMED-Lab.

Controlling dexterous surgical instruments through small skin incisions is still a major challenge for surgeons during minimally invasive surgery. Automating the steering of the endoscope could help the surgeon to focus on the actual surgical task.

As a first application, we automated the steering of the endoscope to keep a moving target in its field of view during an arthroscopy. A miniature camera was embedded in the endoscope prototype with two degrees of freedom (pitch up and down, yaw left and right). The images of this camera were processed in real-time and the extracted information were used to control the movement of the endoscope. For image processing, we compared different tracking algorithms from an existing computer vision library. In a first step, these tracking algorithms were applied to already recorded arthroscopic videos to measure their robustness and precision. Afterwards, the most promising algorithms were used for an experiment on the real endoscope prototype in order to evaluate the entire control system.

The experiments showed that vision-based control is a promising approach to automate the steering of the endoscope and that existing algorithms can be used to track targets even in challenging scenarios like arthroscopies [1].

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References:

[1] Fasel, L., Schraivogel S., Gerig N., Friederich N.F., Zam A., Cattin P.C., Rauter G.: Visual servoing for tracking cartilage with a robotic endoscope. In: Automation in Medical Engineering. Infinite Science Publishing (2020)

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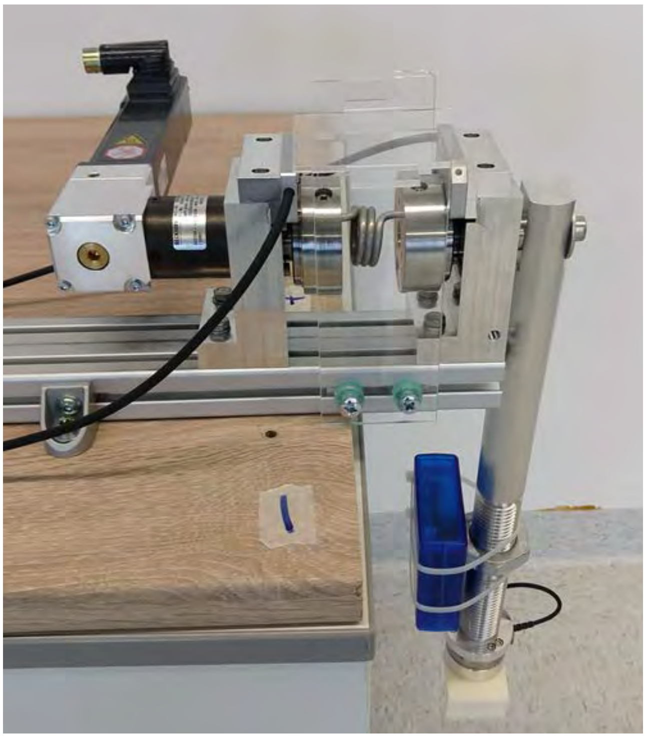
Series Elastic Actuation for a Surgical Robotic Arm



The SEA testbench developed to compare the performance of different elastic elements. (Picture: A. Shalaby)

Impact test conducted with the testbench that shows the mechanical compliance in the joint (Picture: M. Karnam)

Master Thesis by Abdelrahman Shalaby (Eidgenössische Technische Hochschule Zürich – ETHZ) at BIROMED-Lab.

An important concern in human-robot interaction is the possibility of large impacts where forces can cause serious injury to humans or damage the robot. Series elastic actuation (SEA) provides force control and passive compliance through the integrated elastic element making it a safer actuation joint than rigid joints. Nevertheless, this added compliance negatively affects force bandwidth and payload capabilities making a SEA design for a surgical robotic arm challenging.

This project focusses on the design and control of a safe and compliant actuation joint for a surgical robotic arm. Different elastic elements were evaluated for the application requirements to study the use of SEA for a surgical robotic arm. Experimental tests were formulated to evaluate and compare the performance of the different SEA joints. A SEA test bench that allows for the exchange of different elastic elements and actuator components was designed and manufactured. A real-time controller was developed to characterize the compliant actuator and improve its performance. Finally, a compact and modular SEA joint that can be integrated into a robotic arm was designed.

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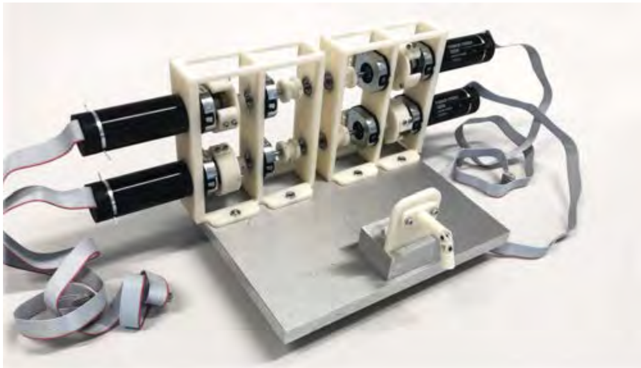
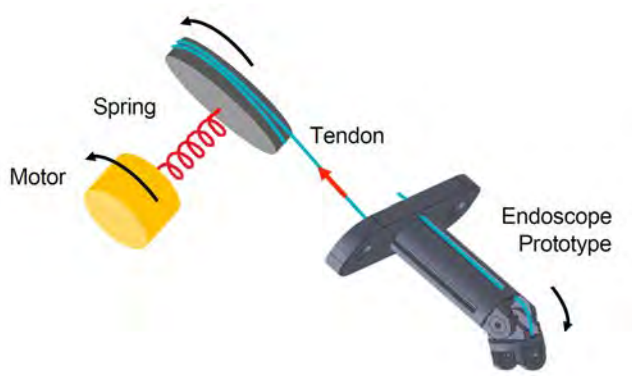
Design of Series Elastic Actuation for a Cable-Driven Articulated Endoscope



A proof-of-concept endoscope prototype with series elastic actuation was built. (Picture: S. Pensotti)



Series elastic actuation is a concept where a spring is placed in a mechanical system between the motor and the moving part, in this case the tendon-driven endoscope. (Picture: S. Pensotti)

Semester Thesis by Sara Pensotti (Eidgenössische Technische Hochschule Zürich – ETHZ) at BIROMED-Lab.

Robots have been more and more present in surgeries in the past years. Often, the surgical robots are tele-manipulated by the surgeon, i.e., the surgeon is controlling the robot from a mechanically decoupled console. As a result, the surgeon does not feel the interaction between the surgical tools and the tissue. This can be unintuitive and even dangerous in some situations. To counteract this, placing a spring in the robot's motion transmission could lower the contact forces. Furthermore, information of the contact force between the endoscope and its surrounding tissue could be obtained by measuring the spring's deflection. This actuation concept is known from other fields of robotics as "series elastic actuation".

In this semester thesis, a proof-of-concept endoscope prototype with series elastic actuation was built. After an initial concept phase, the spring's stiffness was chosen based on surgical requirements, and the prototype was designed, manufactured and assembled. A control algorithm was implemented that consisted of combined force and position control.

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THORLABS

Spin-Offs

By the end of 2019, the DBE has given birth to 11 spin-off companies. They bring research results to the market and to patients and are one of the core elements of the DBE's mission.

ACTHERA is a Swiss biotech company which provides a therapeutic platform based on Hard-Shelled Liposomes (HSLs) that can contain a broad variety of therapeutically active ingredients. ACTHERA's unique and highly innovative release mechanism will allow the release of active ingredients at therapeutic sites, thus revealing an extraordinarily wide field of applications to transform numerous therapeutic areas.

AD MIRABILES AG develops and sells patient specific implants for all kinds of indications, in particular we focus on CMF applications. Besides our current product offering, namely customized PEEK implants, we are committed to continuously develop our product and service portfolio further, in order to improve the quality of life of the patients.

For thousands of years, man has cut bone with saws of all kinds. But today we have the technology to finally reinvent bone surgery. That's why we founded AOT, the first company to cut bone and hard tissue with laser, more specifically with robot-assisted cold photoablation.

The Bottmedical AG develops two systems: NaturAligner®, a bio-based plastic splint for the correction of malpositioned teeth, and TOFI, a unique ultra-thin nano-sensor that works as a tactile interface between the tongue and a smartphone app. This system will enable interactive and fun training of myofunctional tongue motor skills to improve tongue tension and subconscious control during the night, thus preventing chronic snoring and mild sleep apnea.

BioInitials, founded in April 2019, develops non-invasive medical devices to monitor the health-state of the oral cavity. Based on biochemical sensors we will evaluate saliva biomarkers to identify risk factors related to periodontitis.

DBI aims to uncover the full potential of Molecular Breath Analysis to advance precision medicine and make it available for general health care. We implement Molecular Breath Analysis by combining mass-spectrometry with advanced Artificial Intelligence to turn it into a powerful tool for medical research and daily clinical practice.

Di Meliora AG is a spin-off of the University of Basel. Its BOTTICELLI implant system helps young dentists, who want to start placing dental implants by reducing complexity and increasing treatability. The company successfully rose funds early 2018 and is prototyping its first products. Through its patents it has also received a grant from the Swiss Federal Government for a CTI project to develop a ceramic implant.

Diffuse with its software tool _Specto_ is dedicated on advanced visualisation of three-dimensional medical data. The proprietary Specto visualisation software implement state of the art photorealistic raytracing but still scalable enough to drive Virtual Reality goggles in real-time i.e. 180 frames per second. Specto has already been successfully applied in dozens of surgical interventions.

We provide patient-specific implant designs that consider given anatomical guidelines. Having this design, we produce and deliver personalized implants within few working days using highly flexible production processes such as "3D Printing".

GPS for dentists. Mininavident has developed a mobile 3-D navigation system that allows dentists to see exactly and in real time where and how they drill into the jaw during implantation. This makes the treatments shorter, easier and cheaper. The company, a spin-off of the University Hospital Basel and the University of Applied Sciences Northwestern Switzerland, has moved from the Innovation Center in Allschwil to Liestal for the launch of the product.

In cooperation with the Hightech-Research-Center (HFZ) at the Department of Biomedical Engineering (DBE) of University of Basel, University Hospital Basel and other clinics in Switzerland and abroad we develop innovative solutions in the area of Computer Assisted Surgery and Medical Additive Manufacturing and thus take the future to the clinic.

University of Basel

Department of Biomedical Engineering

Partners and Funding Agencies

The DBE is a joint venture of the University of Basel, the University Hospital Basel and the University Children's Hospital Basel and is associated with researchers of the University Center for Dental Medicine Basel. It receives funding of a number of major institutions listed here.

Universität Basel

The University of Basel was founded in 1459, educates almost 13000 students and is among the best universities in the world in the field of life sciences. Within the University of Basel, the DBE is part of the Medical Faculty complementing its research portfolio in terms of engineering approaches.

Universitätsspital Basel

The University Hospital Basel, founded in 1842, works closely with the Medical Faculty of the University of Basel. The most important joint tasks are the training and further education of physicians and research. Good coordination between the faculty and the hospital leads to innovations and improvements in the diagnosis and treatment of many diseases. Patients in the region thus benefit from the constant progress in medicine.

UKBB kompetent & menschlich

The University Children's Hospital Basel, created in 1999 from the merging of the Basel Children's Hospital and the Bruderholz Children's Clinic, is committed to pediatric research in the prevention of disease and the improvement of disease diagnosis and treatment in healthcare. UKBB's goal is to foster clinical, basic and translational research in our main research areas of human biology – the lung, the brain, the musculoskeletal system and the immune system.

FNSNF
Fonds National Suisse
Schweizerischer Nationalfonds
Fondo Nazionale Svizzero
Swiss National Science Foundation

In 2019, the Swiss National Science Foundation approved funding of about 1 billion CHF. It supports a large number of research projects at our institution, while in turn, many researchers of the DBE appear as reviewers for the SNSF.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Innosuisse – Schweizerische Agentur für Innovationsförderung

Innosuisse promotes science-based innovation in the interests of industry and society in Switzerland. It provides funding of about 200 million CHF each year, among them numerous research projects at the DBE. Together we work on translating research into innovations.

WSS
WERNER SIEMENS-STIFTUNG

The Werner Siemens Foundation provides funding to ground-breaking research projects in the natural sciences and technical fields that tackle key problems of our time. The WSS has been funding the Flagship Project MIRACLE at DBE since 2016 and will continue to do so beyond 2022, as will be reported in the Annual Report of 2020.

NOVARTIS FOUNDATION

The Novartis Foundation strives for a transformational and sustainable impact on the health of low-income communities. At the DBE it mainly supports projects of young researchers.

UZB
University Center for Dental Medicine Basel

A growing number of research projects at the Department of Biomedical Engineering are conducted in cooperation with researchers of the UZB, for example within DBE's Biomaterials Science Center or the Biological Calorimetry Lab.

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