NANO-TERA.CH:
Electronic Technology for Health Management

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ABSTRACT

The Swiss Nano-Tera.ch program addresses – among others – issues at the crossing of engineering and medical domains. Specifically, electronic-health (or E-Health) is a broad area of engineering that leverages transducer, circuit and systems technologies for applications to health management and lifestyle. Scientific challenges relate to the acquisition of accurate medical information from various forms of sensing inside/outside the body and to the processing of this information to support or actuate medical decisions. E-health is motivated by the social and economic goals of achieving better health care at lower costs and will revolutionize medical practice in the years to come.

INTRODUCTION

Bettering health care and lowering its costs is a pressing economic and social issue, and it is part of the agenda of the governments of most countries in the world. The rapid expansion of distributed communication and computing systems, with low-cost terminals (such as smart telephones) suggests that electrical and information technology can address many health management issues. In parallel, recent discoveries in biology and medicine have made these sciences more quantitative, and thus the gap between medical and engineering sciences has narrowed.

Health has to be understood within a broad perspective. The *World Health Organization* (WHO) defines health as “a state of complex physical, mental and social well-being and not merely the absence of disease and infirmity”. For this reason, E-health can address various social and market segments with different requirements, such as: i) devices and systems for monitoring and enhancing the well-being of active people, like sportspeople; ii) monitoring devices for the weak sectors of the population, such as the elderly, the handicapped and those affected by chronic but mild pathologies; iii) therapeutic means for diagnosing, monitoring and treating peoples with infirmities. Within these three sectors, barriers to adopt new technologies vary widely, as risks, costs and projected success rates change.

Nano-Tera.ch is a Swiss federal program that supports 25 collaborative 3- and 4-year collaborative projects, uniting teams right across the country. With an average budget of about CHF 5 million, they are funded at a 45% rate by Nano-Tera.ch, the rest of the budget being provided by the participating institutions. Health-related research can be loosely arranged in three distinct thematic clusters:

SMART PROSTHETICS AND BODY REPAIR

Smart prosthetics and body repair is an integral part of the program, with projects addressing tactile prosthetics and other sensorimotor functions (in particular after spinal cord injury), smart muscles for incontinence treatment or micro surgery. More specifically, the following challenges are being addressed:

Image-guided micro surgery for hearing aid implantation. The project HearRestore is developing novel robotic technologies to drastically reduce the invasiveness and improve the outcome of cochlear implant surgery. The project specifically aims to increase the safety of the procedure through the implementation of advanced surgical planning/image analysis, non-invasive registration, modeling/prediction of bone drilling, neuromonitoring, and nanometer tracking. A recent highlight is the successful transfer of the base technology to clinical use. The project was able to achieve regulatory clearance from both the local institutional review board – ethics commission – and the regulatory body Swissmedic for a first clinical trial. Additionally, a live animal study was launched in collaboration with all four partner institutions, which will help evaluate a new nerve stimulation probe to improve the accuracy of facial nerve detection.

High-performance spinal cord neuroprosthesis for restoration of locomotion after spinal cord injury. The mission of the SpineRepair project is to develop and optimize the enabling technologies to implement a cutting-edge spinal cord neuroprosthesis, allowing victims of paraplegia to recover partial mobility. Prototypes of the novel integrated devices are evaluated in animal models. The findings pave the way towards fundamentally new technological solutions and treatment paradigms to improve functional recovery in severely paralyzed individuals in a timely manner. So far, the research team has demonstrated a chronic, wired, soft spinal cord neuroprosthesis for a rat model, developed novel stretchable wiring based on Ag nanowires, defined the layout of the implantable electronic hardware and the CMOS stimulator, and conducted the first characterization of locomotion enabled by the multielectrode array implants in spinal rats.

Use of superparamagnetic nanoparticles for the detection and treatment of cancer. Indeed, such particles are used as contrast agent for MRI, especially for the liver, and as heat sources for the treatment of tumors (magnetic hyperthermia). The goal of the project MagnetoTheranostics is to combine both application using optimized particles for imaging and heating in an alternate magnetic field. So far, the consortium has developed a synthesis method to manufacture superparamagnetic iron oxide nanoparticles; the animal model was selected and the team is building the magnetic field generator.

Cutting-edge technology for the next-generation of artificial muscles. The application being targeted in SmartSphincter is smart muscles for incontinence treatment and involves hundreds of thousands of low-voltage, dielectric, electrically activated nanometer-thick polymer layers. Already, the researchers have found two promising alternatives to conventional stiff metal electrodes for the polymer actuators and shown that they are able to power them for 10 days without recharge from available lithium ion cells. The team has also successfully applied to their local ethical committee for a full pilot study involving 10 male and 10 female participants.

Wise skin for tactile prosthetics. Amputation of a hand or limb is a catastrophic event resulting in significant disability with major consequences for daily activities and quality of life. A sense of tactility is needed for providing feedback for control of prosthetic limbs and to perceive the prosthesis as a real part of the body, inducing a sense of “body ownership” and a natural sensation of touch. The idea of the WiseSkin project is to provide a non-invasive solution for restoration of a natural sensation of touch by embedding miniature tactility sensors into the cosmetic silicone coating of prostheses, which acts like a sensory “skin”. Already, a first sample of the artificial skin was developed.

HEALTH MONITORING

Nano-Tera focuses on personalized health management through the use of implanted devices, smart textiles and intelligent drug monitoring systems. Application targets are in the fields of monitoring of obesity and neonatology, among others.

Like in the initial phase of Nano-Tera, the area of health monitoring and personalized health management is well covered, with several projects addressing different research avenues, such as:

Monitoring the consequences of obesity. ObeSense is building integrated wearable body sensors networks to monitor obese patients at different stages of the disease. The physiological sensors include respiratory rate and volume, energy expenditure, blood pressure and cardiac output and are to be integrated into stand-alone comfortable systems using both low power electronics and smart textiles. Regarding the monitoring of the respiratory rate and volume, transparent flexible polymer-optical fibers have already been integrated in a smart T-shirt and have been successfully tested. Moreover, near infrared spectroscopy is being developed to measure the arterial and venous oxygen saturation, important parameters to determine energy expenditure. An application for mobile phones and tablets has been developed.

Monitoring of the healing of chronic wounds. The research consortium of FlusiTex is fabricating a sensing wound pad that can be used for non-invasive wound monitoring based on integrated fluorescence coupled biosensors, and which is likely to find broad applications in strongly growing fields such as health care and medtech.

Newborn monitoring based on multiple vision sensors. The increasing number of parameters to monitor and the sensitivity of current sensors to body movement are responsible for unacceptably high rates of false alarms in new born monitoring. NewbornCare seeks to drastically reduce the false positive alarms by using a computer vision-based approach to estimate accurately the heart and respiratory rates in a contactless fashion.

Therapeutic drug monitoring for personalized medicine. The overall benefit of this research is to develop a technological platform to improve medical practice by enabling personalized medicine via therapeutic drug monitoring, while reducing healthcare costs. This ISyPeM II project is exploring new sensor technologies, hardware and software data processing means, and drug release mechanisms based on silicon membranes. This will provide a comprehensive integrated approach to Therapeutic Drug Monitoring which combines innovative point-of-care compatible assays, prescription decision support and interoperability in a complex data-sharing scenario.

A system on a chip to make medical devices wearable. For both in- and outpatient applications, the electronic interface to typical sensors and electrodes still has a size and weight that prevents it from being used in the convenient and flexible way. Integration of the plethora of functionalities required in a wearable medical monitor, including the management of wireless connectivity, holds the key to the breakthrough required for clinical and user acceptance. This is why WearMeSoC is developing a chip that will enable very small wearable medical monitors with wireless connectivity to small phones and tablets. So far, the prototype of hardware platform is ready and has been evaluated by medical partners, the design of the SoC started and progresses well.

MEDICAL PLATFORMS

In this new phase, Nano-Tera.ch is developing several medical platforms, notably a next-generation, high-quality, mobile ultrasound imaging device and elastic, lightweight MRI detectors that patients can wear like a piece of clothing. The research covers several fields of medicine, such as oncology.

Wearable ICT for zero power medical applications. Keep your friends close, but keep your medical sensors closer: such could be the motto of the BodyPoweredSenSE project, which aims to demonstrate that smart medical diagnostics can be performed using ergonomic, efficient, energy harvesting based sensors. Specifically, the scientists are developing smart, energy aware, user friendly wearable sensors and associated medical algorithms for the early diagnosis of Alzheimer's disease and childhood epilepsy, where the sensors derive power from the user's body energy (heat and motion) as well as from ambient light. The energy harvesting work has resulted in several prototypes being tested in the laboratory. Thermoelectric generators have been integrated into headwear and the stretching piezo composite materials are being evaluated. Design of the embedded clinical applications for ECG and EEG has begun as well as the design of a test hardware platform so that real time energy consumption can be evaluated. At the clinical level, the set of epilepsy detection algorithms are being finalized and EEG algorithms are being tested. Finally, the team is working on system level networks and potential means to save energy through collaborative system behaviors.

Novel semiconductor disk lasers for biomedical and metrology applications. In a follow-up to the original MIXSEL project, MIXSEL II is consolidating its high-power ultrafast semiconductor laser technology. The goal is to develop prototype demonstrators for end-user demonstration in biomedical imaging, compact efficient white light generation for general high brightness illumination and frequency metrology applications. So far, the project has achieved the first demonstration of a femtosecond MIXSEL generating 620 fs pulses at 4.8 GHz repetition rate and 101 mW average output power.

Rapid sensing of cancer. PATLiSci II is developing rapid diagnostic tools for cancer by paralleled mechanical cantilever sensors to investigate the elastic properties of biopsy samples in a fast and reliable way. Such a cantilever array approach reduces diagnosis times from 3 hours to minutes, allowing faster decision on the appropriate therapy. Rapid biomarker tests based on cantilever sensors complement information on the status of the tumor. The project is benefitting from its predecessor, where basic concepts of parallel force spectroscopy and nanomechanical biomarker sensing were validated. The approach here is to combine two complementary methods (force spectroscopy mapping for cell stiffness and nanomechanical cantilever sensing for biomarker detection) into a single instrumental platform, which can be handled easily. First conclusive results on discrimination of breast cancer cells from unaffected cells in tissue using a single cantilever have already been demonstrated. Investigation of RNA in melanoma and wild type cells shows clear difference in nanomechanical bending response of functionalized cantilevers, in particular the BRAF mutation that is essential for selection of appropriate treatment measures.

High performance portable 3D ultrasound platform. While ultrasound imaging is ubiquitous in medicine due to its low cost compared to other imaging techniques such as MRI – whose own challenges are addressed below – its image quality is usually poorer, and the high-quality devices that exist are expensive and aimed at hospital operation only. This is the reason why UltraSoundToGo is developing a prototype of next-generation, high- quality, mobile ultrasound imaging device, while operating at a level of power consumption compatible with battery-powered operation on the field. So far, an early version of compressive sensing applied to ultrasonic imaging was developed, as well as a novel image reconstruction technique that reduces pressure on the hardware memory interface. Regarding software implementation, a QoS-aware flow and a parallel beamforming algorithm were prototyped.

Wearable MRI detector and sensor arrays. Magnetic resonance imaging (MRI) is another widely used imaging technique in medical diagnostics and basic research. The project WearableMRI seeks to advance the technique by introducing flexible, lightweight signal detectors that patients can wear like a piece of clothing. What renders this project unique in this field is the radical step from rigid, cage-like detectors to wearable assemblies that conform to the patient. To master this transition, the project is tackling unique challenges of mechanical and electronic adaptability along with those of miniaturization. At this point, the system design for a demonstrator has been completed. The evaluation platform is essentially completed and has already been demonstrated in practice, receiving high-fidelity MR signals from conventional detectors with non-integrated in-magnet digitization and optical transmission.

CONCLUSIONS

This survey is covering several activities within the Nano-Tera.ch program. The topics are highly important to the improvement of medicine from both a quantitative and a qualitative aspect. Indeed, e-health is going to revolutionize health care as much as information technology as changed our way of interacting. Thus it represents a broad area of research as well as a wide potential market for applications for well-being and health management. This review has just scratched the surface of a wide body of activities that give a new meaning to the words 'electronic' and 'health' combined together, as enablers for a better society.

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