Position Paper

Smart Systems for the Automated Hospital

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1 Introduction

Within the megatrend of digitising the society, all sectors will experience new concepts and approaches to respond to societal needs and to conceive products and services. The health sector will be no exception and has to rethink the role of healthcare in the society and redesign the provision of services to individuals. Digital technologies offer interesting opportunities to improve the healthcare system by providing more personalised approaches to cure diseases, by putting emphasis on preventing and predicting diseases instead of treating symptoms and by engaging with and empowering patients in a participatory approach.

In addition, digitising healthcare shall respond to crucial challenges that healthcare systems are currently undergoing and which can have dramatic consequences if they are not adequately addressed.

eHealth is often meant when speaking of digitising healthcare, but is actually only one side of the coin. Indeed in parallel to the software approaches to adapt existing or to create new tools to be applied in healthcare, digitisation does imply hardware-centric or hybrid hardware-software (smartware) solutions. Automation is one of these smartware approaches that supports digitisation of healthcare.

The European Technology Platform on Smart Systems Integration – EPoSS – aims at contributing to the societal challenge of digitising healthcare for the benefit of patients and the society by addressing the issue of automation in the hospitals, where the potential impact of smartware on the delivery of healthcare is greatest with respect to quality, accessibility and cost-reduction.
The main focus of EPoSS lies on the applications of Diagnostics and Therapy in the hospital, since these domains represent the highest potential of increased added-value through the integration of Smart Systems. However this doesn't imply that automation may not have impacts on other applications, with benefits that may even extend beyond the hospital specific setting (facility-management, automated transport).

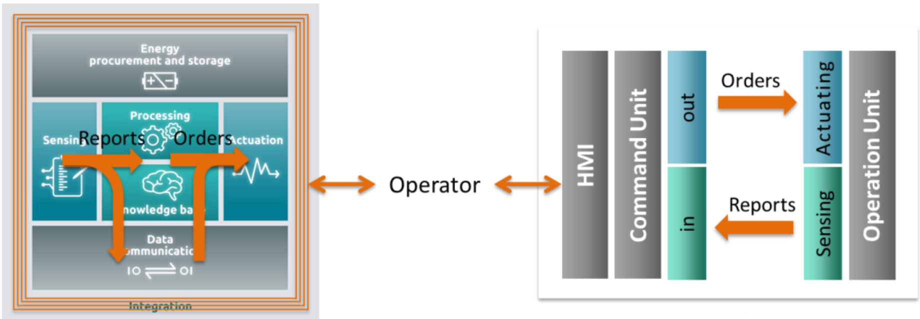
Figure 1: Targets for automation in Hospitals and EPoSS Focus for Paper

2 The Automated Hospital

Despite the broader trend towards a delocalization of healthcare[1], hospitals shall remain central elements in future healthcare systems as they provide a set of services that cannot be delocalised neither to practitioners offices nor to the „Point of Life“ of patients. Hospitals represent the centres of excellence for healthcare interventions and therefore need to constantly adapt to incorporate high-quality, up-to-date and cutting-edge medical services and equipment making use of safer, more efficient, specialised and accurate solutions for patients. : In addition to providing a high level of general services, hospitals will need to face more and more acute cases and will have to cope with increasingly restricting cost constraints.

Two of the main key performance indicators of hospitals are a reduction on (human) medical errors and a reduction revision rates for surgeries. Increased automation can lead to major improvements in these KPIs by improving clinical outcomes and by increasing the proficiency of the medical staff.

Full or partial automation in hospitals environment is an approach to tackle this challenge and to realise the link with the digitisation of healthcare.



Smart System ***Automated System***

Figure 2: Similarities between the smart and automated system

3 SSI for the Automated Hospital

3.1 Vision

- Unburden emergency care centers through automated, precise and fast check-in procedures that facilitate and speed up the first diagnosis and the transfer of patients for subsequent care.
- Increase efficiency and safety by providing doctors with crucial personalised medical information
- Decrease mortality and morbidity rates by providing tools for early detection / prediction and prevention of diseases
- Support medical innovation by providing doctors with smart simulation systems for education and training
- Increase quality of life by providing implants and prostheses with human-like functionalities offsetting the impact of impairments / loss of capabilities resulting from injuries or (chronic) diseases
- Increase efficiency and safety of surgical interventions with partial or fully automated procedures
- Develop in-silico human models to accelerate drug developments and reduce impact on animals

[1] EPoSS SRA 2017: https://www.smart-systems-integration.org/public/documents/publications/EPoSS_SRA2017.pdf/at_download/file

- Evaluate and increase proficiency of medical staff by providing functionalized surgical tools and smart concepts for real-condition trainings.
- Monitoring efficiency of hospital and sanitary procedures
- Encourage harmonisation of technical standards to allow for remote interventions across country borders

Smart automated systems aim at benefiting primarily patients and doctors, but also further hospital staff such as nursing staff, laboratory technicians and researchers and the hospital management. While patients expect increased efficiency, better clinical outcome and increased safety of medical interventions as well as an increased quality of life during and after the hospitalisation, medical staff has sometimes different expectations, in which smart automated systems represent efficient tools for decision making support as well as an increased overall efficiency and safety of medical procedures.
From the view of hospital management, smart automated systems are necessary tools to increase productivity and quality of services by offering optimal use of space, equipment, time and staff. These aspects become crucial when considering a competitive environment, where hospitals have to prove their readiness to new requirements and constraints.

3.2 R&D&I Requirements

From this vision, the European Technology Platform on Smart Systems Integration derives several needs for research, development and innovation in five focus areas that EPoSS will advance according to the roadmap from the SRA. In all these areas, EPoSS evaluates smart systems integration as a crucial topic to achieve the aforementioned vision. For these, EPoSS evaluates smart systems integration as crucial regarding the realisation of the aforementioned vision:

1. **In-vitro diagnostics**
2. **In-vivo diagnostics and imaging**
3. **Surgery**
4. **Therapeutics**
5. **Prosthetics**
6. **Rehabilitation**

The demand shown is grouped together into important functionalities for automation, such as autonomy (incl. localisation tracking), personalisation (incl. monitoring and sensing), efficiency and effectiveness (incl. energy harvesting, storage and efficiency), real-time operation (incl. the communication network and precision), safety and reliability, as well as integration and cognitive operation (incl. HMI and organic/inorganic interface).

In-vitro diagnostics

In the context of 4P-medicine (Predictive, Preventive, Personalised, and Participatory)[2], in-vitro diagnostics is becoming increasingly important as the main instrument to characterise each individual and detect any disorders or diseases before they even become symptomatic, increasing thus the chance of curing without hindering normal life. However, the increasing variety of different types of tests together with the increased number of individuals to be tested requires a disproportional increase in the size and availability of biobanks. The development of advanced sampling, testing, and analysis techniques as well as storage logistics is crucial to realizing this vision.

[2] Hood L, Balling R, Auffray C. Revolutionizing medicine in the 21st century through systems approaches. Biotechnol J. 2012;7(8):992–1001. Provides an overview of the science and technological foundations of predictive, preventive, personalized and participatory healthcare.

Integrating advanced fluidics with multiplex, combinational and sensitive sensing on hybrid substrates at the micro and nanoscales, smart automated systems contribute to reducing the required volume of sampling (blood, tissue …) while increasing the number of tests done in parallel, thus supporting the optimisation of biobanks volume and output. Automatic and immediate recognitions of epidemiologic patterns throughout biobanks and the access to knowledge resources in the cloud (BigData) along with advanced data analysis algorithms to make use of the available information are further features that smart automated systems can contribute to the area of in-vitro diagnostics. Advanced localisation technologies (RFID, NFC) increase the optimisation and security of tracking and the management of samples.

Furthermore, the development of miniaturised automated systems and of wearable devices paves the way for continuous and non-invasive, or minimally invasive, sampling techniques at the Point of Need, thus reducing pain and inconvenience for the patient and increasing flexibility for medical staff.

Furthermore, bio-hybrid smart systems inspired by biophysiological mechanisms and processes (biomimicry) provide new ways to increase biocompatibility and to address challenges of growing relevance such as the detection and elimination of multi-resistant bacteria, parasites, viruses and fungi.

Smart Systems Integration is moreover a key component in realising functional organ-on-chip systems with the objective notably to model living organisms and mechanisms in order to simulate and optimise new treatments, new pathways and to better understand and control pathologic or therapeutic approaches. Smart and advanced organ-on-chip systems or combinations of those have the potential to replace tests on living animals and to increase ethical acceptance of pharmaceutical clinical developments.

In-vivo diagnostics and imaging

The precise and real-time knowledge of biological or physiological events or of their current state is a key success factor in medicine. The monitoring of such parameters for all patients in a continuous manner is crucial for hospitals as it allows for better outcomes of medical procedures and better efficacy and management of individual cases.

Active implanted devices (temporary or permanently) or devices autonomously circulating in the body (ingestible, injectable) per se require a higher level of automation, even if they remain remote controlled from the outside. Wireless endoscopes, smart pills, implantable devices and by extension wearable devices require smart systems for an efficient energy generation and management. Taking advantage of different sources (mechanical, chemical, physical) to harvest the required energy and fulfil its task is one characteristic of smart automated systems besides assuring safe and secure wireless communications with the external control unit and/or the operator and providing relevant multi-parametric information at precise localisations in the bodyMedical treatments require regular control to check efficacy and potential adverse reactions. Companion diagnostic systems are able to provide this monitoring and to automatically alert medical staff in case of unforeseen event. Such systems shall also monitor compliance to treatment and detect if the patient is not correctly following prescriptions.

In- and on-vivo devices highly benefit from flexible electronic substrates to adapt to body requirements without hindering patient’s activities. The development of fully biodegradable devices shall furthermore simplify medical procedures and prevent from unnecessary surgery to remove smart implants.

Furthermore, the fusion in real-time and visualisation in 4D of information from a multitude of biosensors and multimodal imaging techniques provide doctors with enhanced and multi-perspectival tools for decision-making support during medical consultations or interventions.

In addition, intelligent data and image analysis algorithms are required to allow for semi- or fully autonomous operation of active implanted devices and to support the diagnostic process on-site but also to increase dissemination of diagnostic services through telemedicine.

Surgery

Automation has the potential to improve performances and outcome of medical procedures, and in particular surgical procedures, considering that these are a significant source of medical errors occurring in hospitals resulting thereby in disabilities and fatalities[3].

The support to surgeons provided by smart automated systems can be divided into two main areas, the first one being the training of doctors which requires integrated systems for real condition simulation of surgery, including and combining wearable motion recording devices, smart instruments providing haptic feedback and precise localisation, analysis of video content, and image-guided procedures. The goal for the surgeon is to improve proficiency by training dexterity and precision, by rehearsing complex surgeries, by improving reaction time in critical situations and by better apprehending new cases.

The second area of surgery impacted by smart automated systems is the operating theatre itself, in which surgeons can benefit from companion devices to improve medical outcome. The use of robotic arms guided by surgeons allows for less invasive surgery because of the miniaturisation of the systems and a gain in the precision, control, celerity, and reproducibility of movements as well as additional degrees of freedom to proceed to tasks such as cutting, analysing and removing tissues. The adjunction of automated tissue analysis features would allow surgeons to better differentiate tissues and avoid medical errors while the combination with 3D-printing features could also allow for reconstructing tissues and bones directly on site. The interface between robot and doctor is an important issue as it shall guarantee the continuity and integrity of the surgeon's intention into gestures. The use of smart systems integrating cognitive functionalities, gestures recognition and 3D visualisation techniques such as image-guided surgery and augmented reality provides surgeons with an immersive environment to fully control the intervention on site or in a remote location (telesurgery). However, significant efforts towards a standardisation in medical guidelines and regulatory documents between countries has to be done in order to improve cross-bordes remote operations. At the same time, the integration of wireless communication are an opportunity for reducing the physical limits of wiring in operating rooms.

Considering lower degrees of autonomy, surgeons would also benefit from adaptable ergonomic instruments such as exoskeletons reproducing all gestures while providing an increased stability of movements and avoiding involuntary moves due to stress, strain and fatigue. Decisions remain thus under the entire responsibility of the operating surgeon. In addition, adaptable and flexible monitoring devices during the operations remains an area for research and innovation and that will contribute to the overall knowledge needed by the automated systems.

On the other side, increased automation is required to developed advanced intracorporeal surgical robots, incl. soft robots, for minimally invasive surgery using digestive or blood systems.

Finally the introduction of further smart automated systems into the operating theatre such as automated sterilisation of surgical tools or the automated inventory of tools before / during / after procedure aims at discharging medical staff from this peripheral but crucial task and highly contributes to safety issues during surgical procedures.

Therapeutics

The therapeutics area can benefit from three main functionalities offered by the integration of smart automated systems: fusion of therapeutics & diagnostics, automated 3D-printing and targeted delivery of therapeutics (drugs, cells, tissues) and extracorporeal management of body fluids.

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[3] G. Shorten, UCC, P. Galvin, Tyndall - Machine learning and human performance in medical / surgical procedures

The success of a treatment depends on many different parameters. Evaluating drug efficacy and potential adverse reactions for a particular patient is one of these parameters. Smart systems relying on compliance & companion diagnostics to automatically adapt the treatment (mix of active ingredients, doses, frequency) are solutions for personalised theranostics. With a core loop based on advanced multiple sensing and actuating, the smartness of such solutions would reside in the integration of further patterns and knowledge to optimise the automation process.

Miniaturisation and new substrates for devices allow the use of new routes for targeted drug delivery. While smart patches allow to continuously adapt administration of drugs to individual parameters, smart pills or extracorporeal robots (soft, origami, biological…) can be guided individually or as a swarm to reach a particular target (organ, tissue) in the body. In addition, smart needles providing feedback on the nature of tissues passed through would allow to inject drugs or anaesthetics at the right place and to prevent a major source of medical errors. Automated 3D-printing production of drugs, tissues or even organs directly at the site of use simplifies logistics and spares crucial time for patients to receive much personalised treatment in critical situations.

A further field of application is automated equipment for respiratory aid and the extracorporeal management and purification of body fluids on a regular (dialysis) or one-time (during intervention) basis. Smart filters and purification technologies as well as miniaturisation of equipment are particularly needed, especially to shorten or simplify dialysis procedures, which are a real burden for patients suffering from renal insufficiencies.

Prosthetics

As a consequence of deformity, injury or disease, physiological, psychological or anatomical structures or functions may be permanently affected or lost, leading to impairment. Prosthetics, implants and artificial organs aim at avoiding damaging impact for the concerned person by providing implanted or external artificial solutions mostly based on a combination of electronic / biological / mechatronic technologies to replace limbs, organs or tissues.

A generic need in the prosthetics field is to provide advanced sensing technologies, reaching a level of resolution similar to natural human performances. While the recent advances in smart skins for instance improve the sense of touch for limb prosthetics, further developments to improve haptic and coordination of movements in a cognitive approach as well as smart control through the interface to the brain are required.

In the field of in-vivo implants, increasing biocompatibility by providing smart surfaces, miniaturised and lighter devices is definitely a focus. In addition, working on a next generation of smart implants integrating advanced sensing functionalities and based on biomimicry strategies including the full integration of biological mechanisms and an increasing bio-hybridisation of implants would allow providing patients with permanent solutions. A smart energy management for instance, combining energy harvesting from different body sources (mechanical, chemical, physical) with metabolic energy storage and low-consumption devices would for instance eliminate dispensable surgery to replace batteries.

Recent cybersecurity vulnerabilities for pacemakers[4] show how crucial it is for technology developers to integrate safety issues in the design of products and to develop secured communication hard- and software for implanted devices and prosthetics.

[4] Safety Alert issues by FDA on 29.08.2017: https://www.fda.gov/safety/medwatch/safetyinformation/safetyalertsforhumanmedicalproducts/ucm573854.htm

Rehabilitation

In the field of rehabilitation, smart automated systems provide solutions to monitor patients' condition continuously and potentially remotely. In this regard, multiplex-sensing as well as the fusion of soul (mental state), body and environment sensor networks are required in order to be able to return the person under rehabilitation to his/her living/working environment and to assess the impact of rehabilitation measures.
Furthermore and as far as the patient does not recover after an intervention to normal physiological or anatomical functions, smart automated system are deemed to train the patient to recover these functions and to provide temporary substitutions to avoid impairments. Advanced actuation features (exoskeleton, smart&soft robotics, prosthetics) as well as convenient interfaces to the patient (neurointerface, cognitive operations) shall be developed.
Similarly to the other sub-areas, safe and secure (wireless) communication technologies (NFC, Bluetooth, 5G …) are a pre-requisite for successful implementation of smart automated systems in the rehabilitation area.

3.3 Building value chains

Smart Systems Integration is considered a generic Key Enabling Technology (KET) providing very diverse activity sectors with smart solutions. Europe can rely both on a dynamic and well-functioning SSI ecosystem composed of global industrial players and a multitude of smaller actors as well as on major actors in the fields of medical technologies and hospital equipment supplies.
Starting by defining an interface between SSI professionals and the hospital world shall be a short term priority to exploit the potentials of the Automated Hospital. Beyond this, EPoSS is also striving for the upgrade of this interface into a full-fledge ecosystem, where stakeholders with different outlooks can build operational value chains leading to innovative products.

4 Conclusions & Policy Recommendations

The integration of Smart Systems into fully or partially automated hospital procedures is a cornerstone for the smart hospital of the future. It contributes to the digitisation of healthcare and to better clinical outcomes, while enabling hospitals to endorse their role as centres for medical excellence in the future healthcare systems. Smart automated systems provide smooth, secure, reliable and optimised logistics for medical procedures, powerful tools to detect and follow up patients' conditions and allow allying diagnostic, imaging and therapeutic modalities into a global theranostic approach. Patients are meant to benefit from most of the advances in this field as hospitals would offer them tailored and more efficient medical services with shorter and zero-medical errors procedures, higher hospitalisation capacities and higher quality of stay. Doctors are also substantially benefiting from smart automated approaches as they take advantage of potent tools to increase proficiency and safety of patients, guaranteeing high level of healthcare. Nevertheless automation in hospital introduces new instruments contributing to reduce both drudgery of work for medical and non-medical hospital staff and operational costs, making hospitals more responsive to future challenges and constraints affecting healthcare systems.

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