# Smart wearable technology: enabling future prevention-based healthcare

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***Zusammenfassung***

*Tragbare Technologie, die in einem einzigen durchdachten System energieeffiziente Rechnerleistung, das Erfassen mehrerer Parameter, drahtlose Kommunikation und Energiequellen kombiniert, scheint heute eine Revolution des Gesundheitswesens einzuleiten, da sie einen allmählichen Wandel von behandelnder zu präventiver Medizin ermöglicht. Sie erscheint in zahlreichen Formen, die allesamt das Ergebnis des gewaltigen Fortschritts in der Informations- und Kommunikationstechnik sind: intelligente Schnittstellen (Smartphones und intelligente Uhren), Geräte, die am Handgelenk getragen werden, intelligente Verbindungen, intelligente Kleidungsstücke, Geräte, die auf der Haut getragen werden, drahtlose Sensorknoten etc. Doch die intelligente tragbare Technologie ist auch mit grossen Herausforderungen konfrontiert: Sie muss Lösungen für die eigentlichen Probleme der Medizin bieten, für Ärzte effizient einsetzbar sein, Datenschutz und Datensicherheit garantieren und schliesslich von den Nutzern im Hinblick auf die Verbesserung ihrer Lebensqualität angenommen werden.*

*Wir analysieren die Herausforderungen und Chancen selbständiger intelligenter Systemtechnologie unter verschiedensten Gesichtspunkten, unter anderem aus Sicht des Einzelnen, des Arztes, des Managements im Gesundheitswesen und der Gesellschaft als Ganzes. Wir liefern grundlegende Überlegungen zur zukünftigen Rolle der intelligenten tragbaren Technologie als Bestandteil des Versorgungszyklus und zu den Veränderungen, die sie auslösen kann, indem sie die Prävention von Stoffwechsel-, altersbedingten und psychischen Krankheiten erleichtert. Intelligente Sensorsysteme, die zahlreiche Parameter quasi fortlaufend über lange Zeiträume am Körper und in der Umwelt aufzeichnen, können einzigartige Zusatzinformationen für die Früherkennung von Krankheiten bieten und damit Unterstützung bei den objektiven Entscheidungen leisten, die für Präventionsansätze erforderlich sind. Sie können auch zur Schaffung einer neuen Art von komplexen und strukturierten elektronischen Karteien beitragen. Doch vor allem kann tragbare Technologie ein neues Hilfsmittel für Ärzte*

*und Patienten darstellen, das Feedback quasi in Echtzeit ermöglicht und somit unseren Lebensstil in Bezug auf physische oder geistige Tätigkeiten, Ernährung, Trinken und allgemein alle Arten von gesundheitsrelevanten Gewohnheiten beeinflussen kann.*

*Zum Schluss besprechen wir gesellschaftliche Szenarien, bei denen die Nutzung der neuen intelligenten tragbaren Geräte als neue Komponente einer nachhaltigeren Strategie in der Gesundheitsversorgung und im Versicherungswesen in Erwägung gezogen wird.*

***Résumé***

*La technologie portable, qui associe en un système intelligent unique une informatique économe en énergie, la détection multi-paramètres, les communications sans fil et les sources d'énergie forment actuellement le catalyseur d'un changement de paradigme dans le secteur de la santé, en ouvrant la voie à une migration de la santé curative vers une santé basée sur la prévention. Ses incarnations multiples dans les plateformes intelligentes (smartphones et montres), les dispositifs bracelets, les patchs intelligents, les vêtements intelligents, les nœuds de capteurs sans fil, etc. sont le fruit des énormes progrès de la technologie en matière d'information et de communication. Cependant, la technologie portable intelligente est également confrontée à de grosses difficultés en termes de résolution de problèmes concrets dans le domaine médical, de service efficace aux médecins, de garantie du respect de la vie privée et de sécurité des données, et enfin pour se faire accepter par l'utilisateur en tant qu'outil d'amélioration de la qualité de vie.*

*Nous analysons les difficultés et les opportunités qui se présentent à la technologie des systèmes autonomes intelligents de différents points de vue, dont celui de l'individu, du médecin, de la gestion de la santé et de la société en général. Nous fournissons une base de raison nement sur le rôle futur de la technologie mettable intelligente en tant que composante du cycle de soins et des changements qu'elle peut induire en renforçant les stratégies de prévention en matière de maladies métaboliques, liées à l'âge et mentales. Les systèmes de détection multi-paramètres intelligents enregistrés en quasi permanence et sur de longues durées sur le corps et sur*

*l'environnement peuvent offrir des informations complémentaires uniques permettant la détection précoce de maladie et aident ainsi à prendre les décisions objectives nécessaires dans les approches préventives. Ils peuvent également contribuer à la création de nouveaux types d'enregistrements électroniques complexes et structurés. Et surtout, la technologie portable peut constituer un nouvel outil pour les médecins et les patients en les aidant à mettre en œuvre de feedback en temps réel capables d'influencer notre style de vie au plan de l'activité physique ou mentale, de la nutrition, de l'hydratation et de tout type d'habitudes liées à la santé en général.*

*Enfin, nous débattons de scénarios de société qui considèrent l'intégration de la nouvelle technologie portable intelligente comme une nouvelle composante dans le cadre de stratégies de santé et d'assurance plus durables.*

**Abstract**

Wearable technology, combining in a single smart system *energy efficient computing, multi-parameter sensing, wireless communications* and *energy sources*, appears today as the enabler of a paradigm change in healthcare, providing a migration path from curative to preventive-based healthcare. Its multiple embodiments in smart hubs (smart phones and watches), wrist devices, smart patches, smart garments, epidermal electronics, wireless esnor nodes, etc., are the result of the tremendous progress of the Information and Communication Technology. However, smart wearable technology is also facing big challenges in terms of addressing the real problems of the medical field, efficiently serving the physicians, offering privacy and security of data, and, finally having user's acceptance for improving the Quality of Life.

We analyze the challenges and the opportunities of autonomous smart system technology from many different points of view, including that of the individual, the physician, health care management, and society in general. We provide a rationale for the future role of smart wearable technology as a component of the care cycle and the changes it can induce by reinforcing preventive strategies for metabolic, age-related and mental diseases. Multi-parameter smart sensing

systems recorded quasi-continuously over long periods of time on the body and on the environment can offer unique complementary information for the early detection of diseases, supporting objective decisions needed in prevention approaches. It can also contribute to creating new type of complex and structured electronic records. More importantly, wearable technology can form a new tool for physicians and patients, supporting the implementation of real-time feedback loops capable of influencing our life style in terms or physical and mental activity, nutrition, hydration and any type of healthy habits, in general.

Finally, we discuss societal scenarios that consider including the new smart wearable technology as a new component of a more sustainable healthcare and insurance strategies.

## Wearable technology as emerging component of ICT

Information and Communication Technologies (ICT) are expected to have a transformational effect on the future society due to their capability to supporting more personalized and trusted services, covering daily activities and services for humanity.

The recent ICT advancements in terms of portable computing and communication technology together with the co-integration of computation, sensing and communication functions in a single smart system have contributed to the believe that many services can be taken out of hospitals and integrated with more user-friendly and accessible devices. Today mobile smart hubs like smart phones, tablets and smart watches are offering to people new options of undergoing parts of their medical data recording in the privacy of their own homes. However, these devices are designed to rather act as smart gateways supporting infotainment purposes and have still limited sensing capabilities for true medical applications. In the future, it will be crucial for these smart hub devices to cooperating and being in communication with other sensing functional parts capable to accurately monitor our body and its environment in a trusted way, all being foreseen as parts of a smart wearable assistant (forming body area networks of sensors, BAN), reconfigurable according to the needs.

Therefore, smart wearable personal assistants deployed in trillions, and connected to cloud via the smart hub gateway for personalized services, could have a larger societal impact than mobile communications and computing today. Figure 1 depicts the positioning of such *autonomous smart system technology* at the edge of the cloud, as compared to high performance cloud computing and the gateways (smart hubs). Autonomous smart systems that can specifically monitor our bodies can be divided into three categories: (1) *non-invasive devices*, (2) *minimally invasive* devices and (3) *invasive* devices. The non-invasive smart systems form the so-called wearable technology having the capability of multi-parameter sensing and recording, wirelessly communicated to the cloud as parts of the Internet-of-Things (IoT) and autonomously interacting with the users for very long periods of time. The wearable technology includes wearable sensors, epidermal electronics, smart patches, wrist based devices, smart clothing, etc. to provide information about individuals' physical, physiological and social behavior in every-day life. More recently, the concept has been extended to more complex smart wearable devices like the Google glasses that can include advanced support functions based on local processing of information for healthcare professionals (such as smart assistance in surgery). Minimally invasive devices include intelligent pills that can be swallowed for various monitoring purposes and / or miniature sensors that can be injected with a needle with a limited use time. Invasive devices are intended to be put in place during surgical interventions, such as the positioning of a coronary stent, cardiac surgery, etc.

In many recent technology reviews, the *wearable technology* is being cited among top ten technological advancements in healthcare that have emerged over the last ten years[1]. The wearable medical device market growth rate is of the order of 16 percent a year, according to a Transparency Market Research[2] report, being today identified with those wearable medical devices where a few sensors collect data that is stored and / or wirelessly communicated. In the context of global health expenditure reaching 6.8 trillion US$, the wearable

challenge is to push into healthcare as means of doing more that monitoring patient's activity. But the global expectations are much higher for future smart wearable technology in order to meeting long term demands from healthcare providers, payers and patients especially for reducing health expenditure and improving the Quality of Life (QoL).

[1] *http://www.beckershospitalreview.com/healthcare-information-technology/10-biggest-technological-advancements-for-healthcare-in-the-last-decade.html*
[2] *http://www.transparencymarketresearch.com/medical-devices-market-reports-6.html*

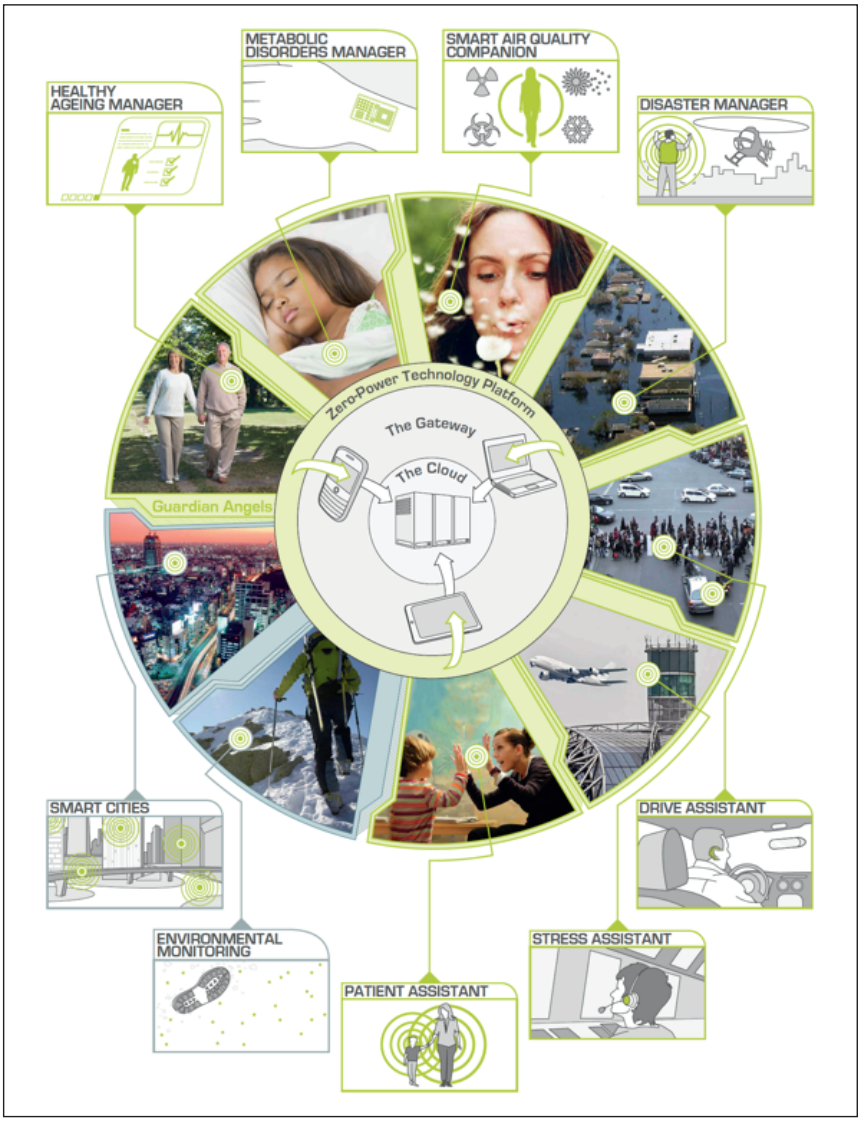


Figure 1: Positioning of *autonomous smart system technology* and applications with respect to cloud computing and gateway technologies. Many of the applications of the future autonomous smart system are envisioned in the medical field and in relation with prevention strategies.

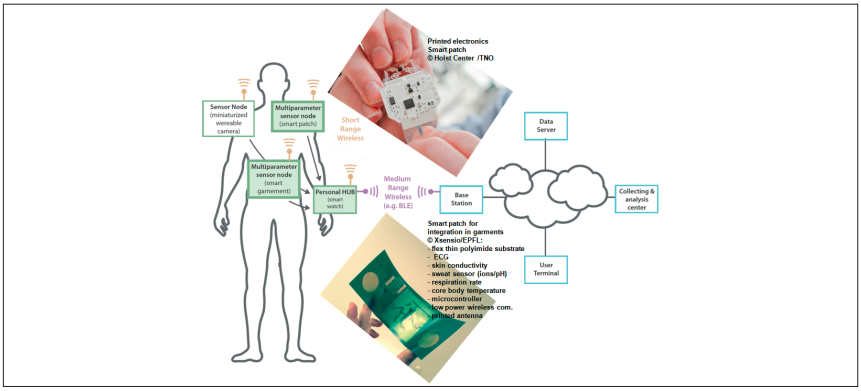


Figure 2: Wearable system architecture including various components: multi-parameter sensor nodes in smart patch and smart garments embodiment, wirelessly connected to a personal hub (here a smart watch). The role of the smart hub is to locally process part of the collected information, to communicate structured data to more complex processing in the cloud and / or for creating electronic health record, and, finally, to serve as trusted real-time feedback interface to the user.

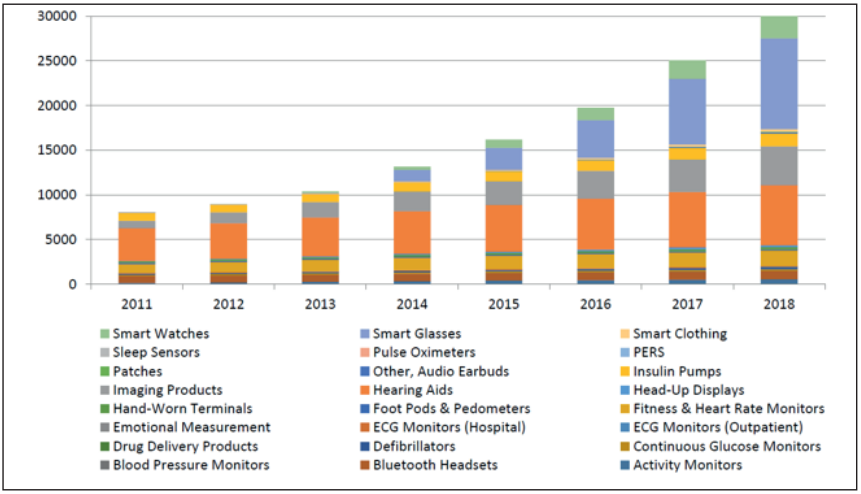


Figure 3: Market projected evolution for wearable technology[3] categories relevant for healthcare and wellness applications (in Million units).

[3] *Shane Walker, Market Trends for Mobile and Wearable Technology –HIS, Beyond Fusion Conference, San Francisco, June 23, 2014.*

Today, the majority of the wearable devices on the market (smart phones and watches, wristbands, sensors, headsets, patches, smart clothes, etc – see Figure 3) do not solve major problems of health but are rather perceived as exotic technology gifts that can serve as smart trainers because of their capability of activity monitoring (and its conversion into calories). In many cases the user's expectations are not met and, surprisingly, their adoption seems limited just to few months. One reason could be that technology developers have their own limited view about the expectations of the users on wearable technology capability and, in the majority of cases, the end users (health professionals and patients) are very lately involved in the product design and development.

The smart wearable technology of today can certainly collect, store, process and transmit huge amounts of physical and physiological data but there is a lack of objective evidence that those wearing them overcome any chronic condition like diabetes, cardiac disorders, obesity, etc. On the other hand, it is true that many of existing wearables can provide some alerts and reminders but their impact remains limited. Moreover, recent reports show that physicians are reluctant to consider and use huge amounts of non-structured collected data, as they cannot be easily used to make a true clinical difference.

**The real challenge for the wearable technology is to become 'smart'** enough in order to constitute a future tool that physicians can adapt, reconfigure, personalize and recommend to patients in order to objectively manage their lifestyle and finally prevent the onset of lifestyle-related diseases and / or to evaluate the effect of a lifestyle change and treatment. By their smartness such new technology is expected to enable personalized advice and assistance, concerning health and interaction with the environment, far beyond what today's smart phones and smart watches can offer. Such smartness can be achieved by non-invasive, multi-parameter, quasi-continuous sensing capability embedded in reconfigurable systems exploiting energy efficient computation and communication technologies (enabling autonomous operation for weeks or months), all combined with advanced data analytics. Today, many of the

needed sensing technologies already exist or, in some cases, could require less than five years research and development cycles for already existing proof-of-concepts. We do have available different kinds of heterogenous integration techniques (3D stacking, dies on flexible substrates, printing, stenciling, etc) that can bring together a variety of individual sensors, communications interfaces, computation and energy blocks.

## Lifestyle-related diseases: challenges for smart wearable technology to support prevention based strategies

The past two decades have seen significant progress in the field of biology, such as the sequencing of the human genome and the resolution of membrane proteins at the molecular level. In parallel, technical developments in medical imaging have allowed non-invasive visualization of the brain and its activity. These major accomplishments bring us to the verge of personalized medicine. However, in spite of the large efforts and progress in research and targeted drug design, little progress has been made in improving the treatment of *lifestyle-related chronic diseases*. Or may be the right way to address these categories of diseases is not exclusively by treatment but also by including prevention strategies based on data collected and processed by smart wearable technology in the care cycle?

Due to the prevalence of chronic diseases in Europe, and the associated economic and societal burden, it is now recognized that the prevention of chronic diseases and closer follow-up of patients are two key components for improving the Quality of Life (QoL). The efficacy of prevention as opposed to treatment could be reflected by the reduction in the number of cases of lung cancer and heart attacks obtained by adopting a healthy life style (exercising, stopping smoking). The importance of a closer follow-up is shown for chronic diseases that are already diagnosed, such as diabetes, where self-management is the most efficient way to improve QoL and prevent unnecessary hospitalization.

Life-style related diseases form real problems where the emerging smart wearable technology can make a significant difference, as a part of the care

cycle where multi-parameter monitoring for long time and real-time feedback loops can make a true difference. For instance, frailty during ageing is a multi-system functional impairment[4] including dysfunctions of pulmonary and cardiovascular systems, systemic circulation, peripheral circulation, blood, neuromuscular units, muscle metabolism, cognitive impairments. Understanding and monitoring the multiple-phenotypes character of frailty requires multiple-parameters assessment by non-invasive wearable technology (Figure 4). Beyond continuous monitoring of the activity with smart wearable technology, including interfaces with users and local information processing, one can also generate a set of feedback actions such as a list of healthy habits in terms of physical activities, mental/social activities, nutrition and hydration. Further research will be needed to objectively evaluate the

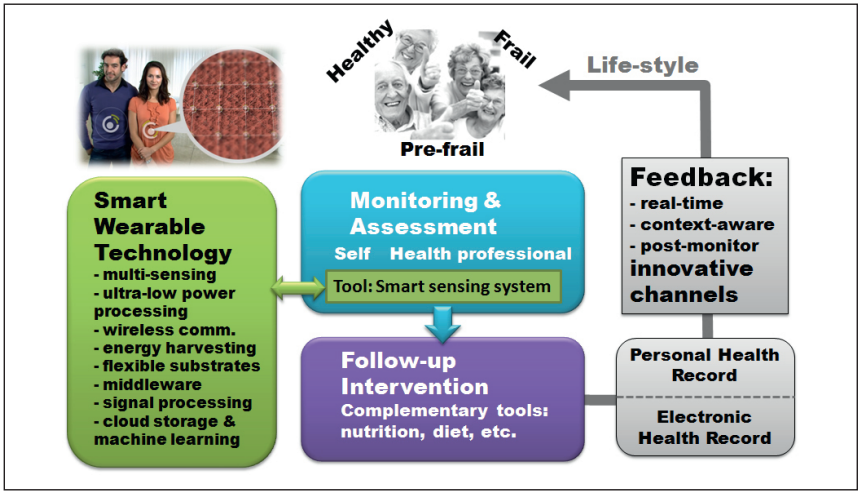


Figure 4: Depiction of a future Care Cycle including the interaction with the low power Wearable Technology and the three main innovation levels: (i) *technological*, (ii) *monitoring, assessment and intervention tools*, (iii) *feedback channels*.

[4] *Karnik, Kavita, and Dawn J. Mazzatti. "Review of Tools and Technologies to Assess Multi-System Functional Impairment and Frailty." Clinical Medicine: Geriatrics 3 (2009).*

effect of the proposed feedback on the patient via the parameters measured by the smart wearable system and to devise and optimize strategies for prevention. Therefore, there are many levels of expected innovations in the field expected, including the monitoring, assessment and intervention tools and the feedback channels used by patients and recommended by the physicians.

Multi-parameter smart wearables for long term recording applications could then naturally support prevention based strategies creating multi-level benefits for individuals, physicians and society. This is not only about the clinical prevention concerning focused behavioral counseling and testing for early detection of some conditions by clinicians but is a community level prevention, altering the lifestyle and reducing the risks for disease at the population level. Because, eventually, what physicians would like to have is a smart tool that they can use to influence the patient's behaviors once they leave the doctor's office; this is one real problem that smart wearable technology can address. The benefits could be multiple and at many levels.

*From the individual's point of view* – long term, non-invasive recordings of physiological and physiopathological conditions complement the symptom description for the physician, optimizing evaluation of the database of health status. Data sets provided by such future wearable systems will help in reducing diagnostic time and therapy, which can be optimized as a function of the personal recordings and taking advantage of electronic records forming vast amounts of data (also called Big Data). The new wearable technology will provide early warning signs, and automatic follow-up, that can help patients feel more in control of their own health and able to make informed decisions about how to improve their QoL.

*From the physician's point of view* – smart wearable technology is expected to provide more trusted diagnostics, reduce the medical errors, through patient records and the monitoring of physiological conditions, and better information concerning the treatment with follow-up and improvement of patients' compliance. In addition, such systems can provide a direct connection through dedicated networks to optimize emergency response.

*From a societal point of view* – smart wearable technology is expected to delay disease onset through better prevention and self-management of persons at risk. Consequently, reducing treatment and hospitalisation will minimize individual and societal health care costs. There are many specific health conditions with which smart wearable technology would be particularly suited to help, but here we go into detail about only two of those, both widespread conditions in Europe today: *ageing of the population, and metabolic disorders*.

## Beyond activity monitoring: smart wearables for personalized treatment and prevention of brain and mood disorders

More sophisticated embodiment of smart wearable technology will allow for long-term, continuous monitoring of the user's both physical and mental states, in an unobtrusive manner.. Furthermore, long-term simultaneous recording of user activity at the neural, muscular, metabolic, and behavioral levels will constitute an important asset to improve our understanding of the day-to-day interactions between brain and body. This may open whole new research avenues in fields like cognitive sciences, psychology, psychiatry and neurosciences, which are traditionally confined to studying the brain using simplified, sometime unrealistic experimental setups or limited models for complex simulations, rarely truly calibrated on experimental data.

Particularly relevant are the potential implications for the development of new forms of personalized treatment and eventual prevention of brain and mood disorders. For instance, stroke is the most prevalent neurological condition worldwide. Intensive exercise and training are the basis of the motor rehabilitation therapy, but its success is limited for two main reasons. First, conventional and modern rehabilitation solutions have high cost and require therapist supervision, restricting their use. Second, there is no principled approach to promote brain plasticity. The development of easy-to-use and low-power wearable sensors, particularly monitoring EEG, will enable independent and continuous use of portable rehabilitation systems by patients. Also, wearable technology will record behavioral, contextual and brain correlates of cortical plasticity, at-

tention, engagement, and performance to monitor and tune the rehabilitation therapy.

### Who will pay for it?

It is recognized that US and Europe are on the edge of a healthcare crisis form the point of view of long term cost sustainability. In this context, it is clear that any credible initiatives directly addressing this crisis based on new technologies are of high interest. Adoption of new technologies and innovative products like wearable technology depends on the way they are monetized. If the wearable technology could indeed become a part of the care cycle and be used as a prevention tool offering added value to the society the question is *who will pay for it?* As recently pointed out by Robert Pearle[5], patients, physicians, hospitals, insurance companies, each of them thinks that someone else should pay for any new technology; this is even more critical if the disruptive technology could potentially require changes of the payment model. Critical aspects are related to the fact that current payment models dominantly rewards volume and cost of the offered medical services (treatments) and a prevention based system would potentially require a change of this. The question is also if the healthcare system is ready to quickly adopt a technology that can lower the healthcare costs or reduce patient visits. Future cost models where "pay-for-service" will be replaced by "pay-for-value" models and having specific incentives (rewards reflected in insurance cost reduction) offered by insurance companies to the patients that accept to actively used prevention technologies and donated their medical data for advancement in the medical research could be solutions to be considered. Additionally, barriers related to the privacy and security of the security of the huge amounts medical generated by wearable technology cannot be neglected in the adoption process. On the other hand, the potentially benefits for the society of smart wearable are too high as well as the potential positive impact on more sustainable healthcare expenditure through prevention strategies, to allow to neglect considering it very seriously in the coming future. Last but not least, prevention-based strategies in healthcare supported by smart wearable technology

[5] *http://www.forbes.com/sites/robertpearl/*

should be not regarded as a full replacement solution for existing health care infrastructure and coverage, but, rather, as a useful emerging complement, as a way of taking advantage of technology progress to offering to everyone the right balance between curative and preventive strategies.

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