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RECENT ADVANCES IN WEARABLE SENSORS FOR HEALTH MONITORING

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ABSTRACT

Wearable sensor technology continues to advance and provide significant opportunities for improving personalized healthcare. In recent years, advances in flexible electronics, smart materials, and low-power computing and networking have reduced barriers to technology accessibility, integration, and cost, unleashing the potential for ubiquitous monitoring. This paper discusses recent advances in wearable sensors and systems that monitor movement, physiology, and environment, with a focus on applications for Parkinson's disease, stroke, and head and neck injuries.

1. INTRODUCTION

According to a May 2013 report on disruptive technologies by McKinsey Global Institute [1], the top four technologies likely to have a significant potential economic impact by 2025 are: 1) mobile internet, 2) automation of knowledge work, 3) the internet of things and 4) cloud computing. These disruptive Ubiquitous healthcare (UHC) is currently understood to encompass healthcare services that are available to everyone, independent of time and location. Systems that can fulfill the promise of delivering healthcare services at any time and any location will have significant implications for the treatment of chronic disease conditions as well as maintaining and encouraging healthy and independent living.

a) the sensors user and b) the decision-maker regarding the health and wellness personnel with whom she is willing to share the data obtained by these sensors .1.available services from an healthcare provider, 2) be flexible, 3) provide security in information exchange, 4) enable remote health data acquisition, 5) provide personalized service, and 6) develop automatic decision making and response for dis-eased or healthy situations. Figure 1 illustrates that a systems approach is needed to integrate sensors with safe, secure and timely collection, dissemination and interpretation of data related to health status. It also highlights that the role of user and decision-maker may or may not overlap.

Technologies also form the basis for ubiquitous healthcare.

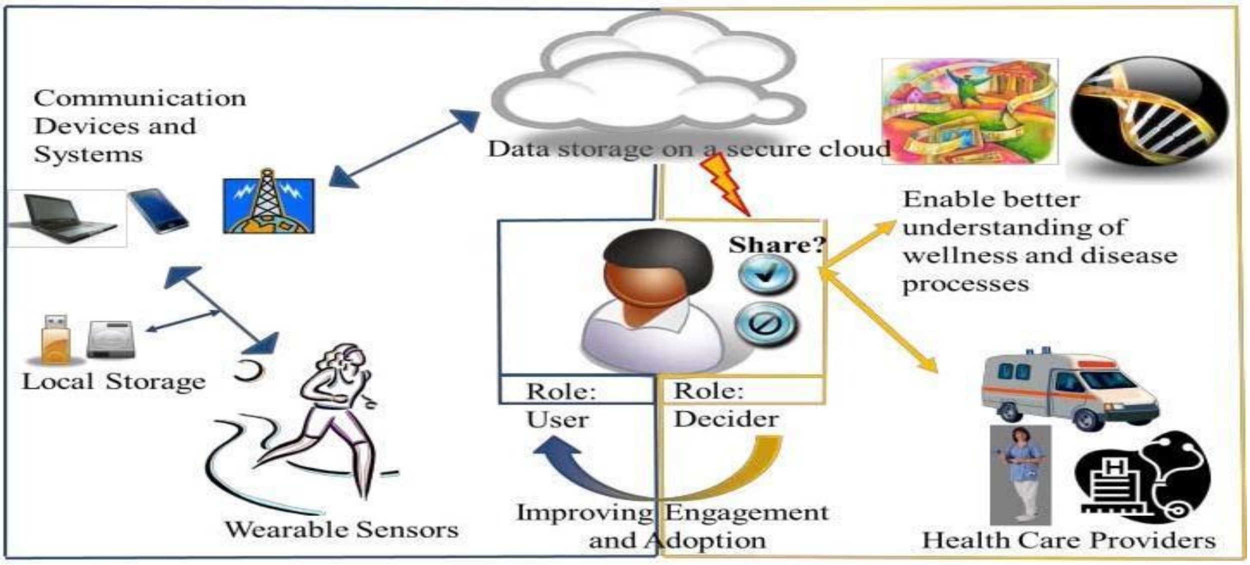

Fig.1. The "big picture" view of wearable sensors and their role in improving healthcare. Note the dual role of the patient:

b) Wearable sensors should be physically and technologically flexible to enable the monitoring of subjects in their natural environment. They have the potential to provide a rich stream of information that can transform the practice of medicine. Personal monitoring technologies have exploded over the past five years, with Google GlassTM, FitBitTM and The Nike+ FuelBandTM representative of the movement, and part of the bigger move towards an "internet of things". As sen-sors become smarter and more ubiquitous, they will enable more comprehensive monitoring. The richness of the collected datasets should lead to better understanding of wellness and disease processes, ultimately resulting in better treatments and health outcomes.

2. WEARABLE SENSORS

There have been several successful cases where technologies have moved out of the clinic to monitor patients going about their day-to-day life over extended periods. Perhaps the most notable of these is the ECG Holter monitor for detecting arrhythmias [3]. Wearable sensor systems are progressively becoming less obtrusive and more powerful, permitting mon-itoring of patients for longer periods of time in their nor-mal environment. Current commercially available systems are compact, enclosed in durable packaging, and utilize either portable local storage or low-power radios to transmit data to remote servers [3], [4]. The development and refinement of novel fabrication techniques, sustainable power sources, inex-pensive storage capacity and more efficient communication strategies are critical to continue this trend towards "wear and forget". Flexible sensors, no longer constrained to planar geometries, have the potential to be one of the key technologies in helping to realize ubiquitous healthcare. The development of elastomeric and electrically-conductive polymers, ultra-thin inorganics and organic semiconductors have enabled.

A. ACTIVITY MONITORS

The analysis of movement can provide many insights into well-being, rehabilitation and fitness. Non-contact devices such as pedometers have been widely available for many decades. The concept of 10,000 steps representing the activity energy expenditure to balance the average calorific intake has been developed and refined over the past three decades and embraced by several public health campaigns. However, it has been the development of low-cost inertial sensors utilizing micro-electromechanical systems (MEMS), and sophisticated software for accurately detecting steps that has resulted in a dramatic rise in the availability and use of the personal activity monitors. For instance, many personal electronic devices, including some smartphones, music players and electronic pedometers can track movement with some degree of sensi- tivity. The most accurate sensors under ideal circumstances, and calibrated for healthy adults, are typically accurate to +/−3% [21].

B. PHYSIOLOGICAL MONITORS

For many healthcare use cases, it is highly desirable to have sensors capable of directly monitoring the physiology of the wearer in real-time. These sensors can measure biological, chemical or physical phenomena to assess physiology when in contact with the skin. The technology challenge is how to maintain consistent contact for extended periods and under different conditions, while the healthcare challenges are how to achieve a high sensitivity and specificity for detecting abnormal events in real-time.

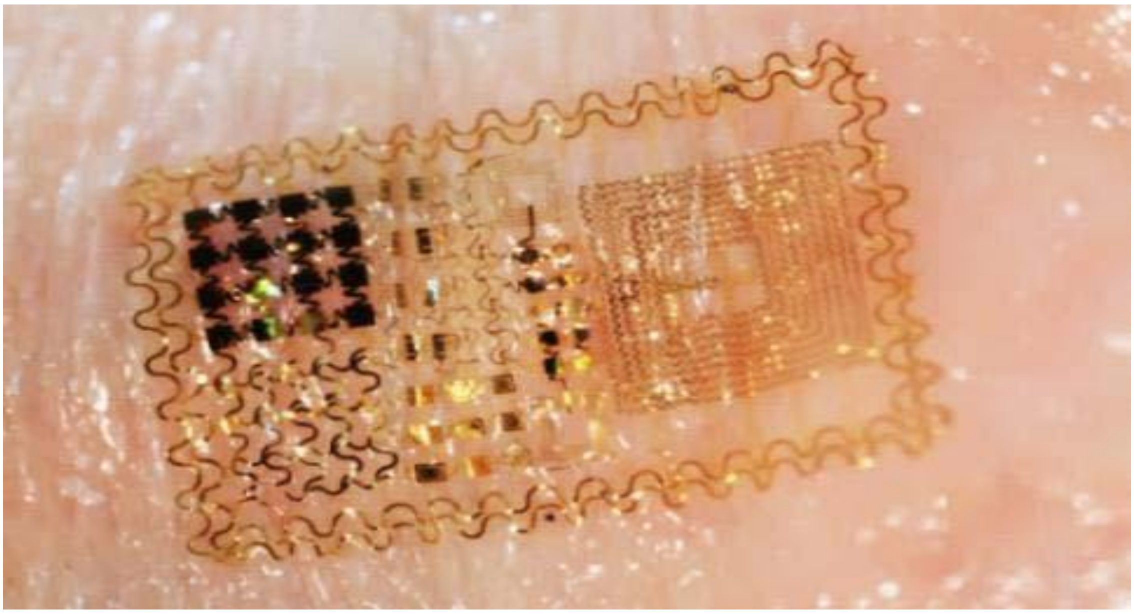

Fig.2. Skin-adhering wearable sensor. Photo shows components of a 1 × 2 cm2 array include transistors, an antenna, power coils, and tem-perature sensors.

The commercial availability of patch-based wearable sen-sors represents a significant advancement in personal moni-toring device design, functionality and wear time. Examples include HealthPatchTM and MetriaTM, which are patch-based wearable biometric sensors that adhere to the user's skin and continuously gather physiological, lifestyle information, and other indicators for up to seven days. The devices contain multiple sensors that enable monitoring of key health indi-cators such as heart rate, breathing rate, skin temperature, posture, steps taken, activity and sleep patterns.

Flexible, temporary transfer tattoo-based sensors, or "elec-tronic skin" or "epidermal electronics", show great promise for analyzing metabolites and many other potential appli-cations [38] (figure 2). The direct printing of multifunctional devices onto the skin to increase durability and mitigate some surface interface issues is very attractive though the natural skin exfoliation process still limits the lifetime of these devices to a couple of weeks.

C. ENVIRONMENTAL MONITORS

Environmental monitoring is critical both for adding con-text to activity and physiological measurements, as well as monitoring hazards. Wearable sensors that are able to detect exposure to contaminants such as explosives, viral DNA, radioactivity or high concentrations of toxic gases like carbon monoxide, and monitoring of pollutants such as heavy met-als, allergens such as pollen, and environmental conditions such as intense ultraviolet light could significantly improve health and safety. Sensors can also be used to monitor and augment senses, such as tracking eye movements, enhancing somatosensory feedback, and filtering background noise. Environmental safety monitoring, particularly for personnel involved in high risk activities, has been actively pursued for several decades, though the advent of flexible and integrated electronic devices has dramatically expanded their capabilities.

3. MEDICAL USE CASES

There are a number of medical uses for wearable sensors that can significantly impact the management of chronic dis-ease and health hazards. The following use cases demonstrate the potential power of wearable sensors for the management of Parkinson's disease, post-stroke rehabilitation, and the detec-tion/tracking of head and neck injuries.

A. PARKINSON'S DISEASE

While a number of wearable sensors are being used for patients with Parkinson's disease (PD), the most significant challenge is combining the data from these sensors to gen-erate useful knowledge and actionable information. Machine learning algorithms are typically used to analyze the complex and unpredictable characteristics of wearable sensor data in order to study tracking of movement disorders in PD patients. The overlap of voluntary activities of daily life with the variety of motions corresponding to movement disorders can make it difficult to resolve and monitor the motor func-tion in PD and is driving the need for better algorithms. Keijsers et al. [52] have utilized static neural networks to detect dyskinesia from accelerometer sensors worn by patients. Recently, Cancela, et al. [58] have evaluated the feasibility of a wearable system based on a wireless body area network to assess the gait in PD patients. For this purpose, they used the PERFORM platform, a telematic platform for remote PD monitoring developed by a European academic-industrial consortium over the last few years.

B. STROKE MANAGEMENT

Uswatte, have shown that accelerometer data can provide objective information about real-world arm activity in stroke survivors. In their study, 169 stroke survivors undergoing constraint-induced movement therapy wore an accelerometer on both wrists for a period of three days. The results indicated good patient compliance and showed that the ratio of activity recorded on impaired and unimpaired arm using accelerometers could be used to gather clinically-relevant information about upper extremity motor status. concussion, particularly in young athletes and adults in professions associated with frequent head injury, such as the military or contact sports.

4. CONCLUSION AND FUTURE DIRECTIONS

Recent advances in flexible electronics show great promise for healthcare monitoring. A great deal of work has been accomplished toward the integration of wearable technologies and communication [76] as well as data analysis technologies so that the goal of remote monitoring individuals in the home and community settings can be achieved. When monitoring has been performed in the home, researchers and clinicians have integrated ambient sensors in the remote monitoring systems. However some challenges remain, including efficient energy harvesting, human-device interfacing and improving the quality and range of measurements. The integration of dif-ferent power sources, sensors and processing and testing in a non-controlled human environment is essential to establishing confidence in the diagnostic capabilities of these systems and their ability to change outcomes. Research toward achieving remote monitoring of older adults and subjects undergoing clinical interventions will soon face the need for establishing business models to cover the costs and identify reimbursement mechanisms for the technol-ogy and its management. Building a solid evidence base for the effectiveness of these sensor systems and addressing costs and reimbursement problems will be essential to assure that wearable sensor systems deliver on their promise of improving the quality of care for older adults and subjects affected by chronic conditions.

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