Sensors and Systems for Obesity Care and Research

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***Abstract*— Obesity and overweight decrease the quality and length of life and increases healthcare costs. Dramatic increase of obesity, particularly childhood obesity, in developed countries requires efficient methods and systems for obesity research and monitoring of users. New generation of smart sensors and ubiquitous monitoring systems provide unprecedented opportunities to assess real-life environments, mobility, physical activity, and physiological responses. In this paper we present current trends in sensing, social networks, and systems integration. New monitoring and intervention technologies create new opportunities for remote patient monitoring and intervention.**

I. Introduction

Excess weight, especially obesity, increases risks for many conditions, including diabetes, heart disease, sleep apnea, and even cancer. Obesity decreases the quality and length of life, and increases individual, national, and global healthcare costs. During the past 20 years, there has been a dramatic increase in obesity in the United States. More than one-third of U.S. adults (35.7%) and approximately 17% of children and adolescents aged 2-19 years are obese [1]. Annual medical expenditures attributable to obesity have doubled in less than a decade, and may be as high as $147 billion per year, according to a new study by researchers at RTI International, the Agency for Healthcare Research and Quality, and the U.S. Centers for Disease Control & Prevention. Environmental factors, lifestyle preferences, and cultural environment represent the most important factors in the increase of obesity. Over-consumption of calories and reduced physical activity are the most critical contributors; however, prevention of overweight and prevention of weight regains, social networks, and electronic media are increasingly used in fighting obesity epidemics [2].

Monitoring of daily food intake and ingestive behavior is not only important for obesity monitoring, but for other conditions such as malnutrition and underweight. Traditionally, monitoring relies on self-reporting. However, self-reports tend to under-report 20% on average, and as high as 50%. Understanding ingestive behavior is also a key in diagnosis and treatment of eating disorders such as anorexia, bulimia and binge eating.

Wearable technology and ubiquitous monitoring provide new opportunities for obesity care and research. Smartphones made possible ubiquitous monitoring and connectivity, anytime, anywhere. Wireless sensors networks integrate variety of sensors to smartphones, with unprecedented capabilities [3][4]. The introduction of smart activity monitors, such as Fitbit [5], Jawbone and Nike and handheld food composition sensors like TellSpec [6], change the research and monitoring landscape. Smart sensors can automatically detect the type of activity we are engaged in, and calculate how much energy is being burnt. Some sensors provide reminders when we are idle for too long. Other sensors might provide insight into portion size and the nutritional information of our meals. Future sensors will be able to analyze nutrients directly in our bloodstream. Emerging systems integrate all this information together to facilitate obesity research and real-time monitoring.

In this paper we present sensors and systems for obesity research and daily monitoring of users. Section II presents current trends and opportunities of sensing technology; Section III overviews social networks; Section IV present examples of integrated systems; and Section V presents discussion and conclusions.

New generation of sensors will be capable of real-time monitoring of biochemistry of blood, providing direct monitoring of effective nutritional and energetic value of ingested food.

II. Sensors

Food provides the energy needed for basal metabolism and physical activity; excess energy is stored in adipose tissue for future use. Abdominal obesity, together with insulin resistance, hormonal imbalance and other physiological parameters are found to be risk factors of metabolic syndrome (MS), which has received increased attention in the past decade [7]. While some of these parameters such as body mass index and waist circumference change relatively slowly over time, other MS-related parameters such as blood pressure and blood glucose can vary significantly daily. Challenges therefore remain to develop wearable, biocompatible and integrated sensors for collecting the information at appropriate times and places.

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Wearable sensors provide new opportunities for obesity research and monitoring. We divide sensors in three categories: *a)* physical activity, *b)* physiological monitoring, and *c)* food intake sensors.

In addition to functionality, the most important factors for the acceptance of sensors are human factors influencing their wearability, such as size/weight, power consumption/battery life, obtrusiveness, and user comfort. New generations of MEMS sensors, microcontroller, and battery technologies significantly improve human factors.

At present, most of the wearable sensors are still developed from rigid printed circuit boards and integrated circuit chips. Although these developments show promising results in controlled laboratory environments, a number of practical issues must be solved before they can be widely deployed in daily applications [8]. First, most of these sensors do not conform and adhere well to the curvilinear body surface and therefore will result in huge motion artifacts in the collected signals when the subject moves. Second, most of these systems are still considerably large if they were to be used by "healthy" subjects rather than patients. In order to enhance user compliance, these systems must be completely unobtrusive.

Recent advancements in flexible electronics can partly address the aforementioned issues. Sensors which are fabricated on flexible substrate such as polydimethylsiloxane or polyethylene naphthalate, such as those shown in Fig. 1, have the potential to be made ultra-thin and stretchable [9]. They can therefore adhere well to the irregular body surface and even when the subjects move, signals could be robustly obtained.

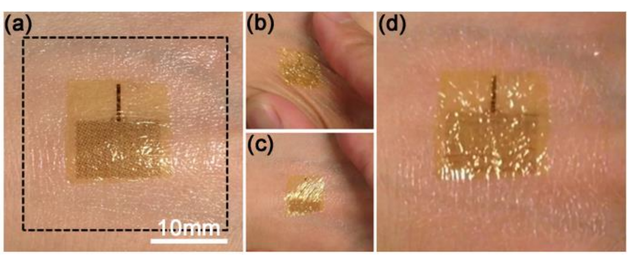

Figure 1. The fabricated serpentine-shape electrode after transferred onto the skin of the human subject (a) with PDMS as adhesive tape (black dash line pane); (b) under compressing; (c) being stretched; and (d) after stretching [9].

Similar technologies can be applied to the development of sensors that are able to perform highly-sensitive electrochemical analysis [10]. This new sensing paradigm will have a crucial role in future physiological sensing for obesity care and research.

While the next generation of flexible and stretchable electronics and epidermal electronics are emerging research areas to solve the disadvantages of rigid electronics, these fabrication technologies are mostly applied on single device integrated circuits and sensors due to the limitation of material strength and fabrication process, but not complicated electronic components such as microprocessor and instrumentation amplifier. More readily available solutions for light-weight and unobtrusive physiological sensors would be to use copper / polyamide films as flexible printed circuit boards with conventional surface mount electronic components.

II.1. Physical Activity Sensors

Advances of MEMS sensors, particularly accelerometers and gyroscopes, facilitated the development and miniaturization of the physical activity sensors. First generation of activity sensors was implemented as pedometers, to monitor physical activity as a number of steps per day. However, more sophisticated sensors based on inertial sensors were capable to assess overall level and intensity of physical activity [5], [11], [12].

Present generation of smartphones are already equipped with high quality inertial sensors [13]. That allows unobtrusive monitoring of user's activity using smartphone as a sensor device. Responding to the need of users, Apple even decided to provide a dedicated motion processor as standard device in iPhone 5S. Dedicated motion processor provides low-power background counting of steps with time stamps, which makes possible automatic monitoring of physical activity of users, whenever they carry their smartphone with them.

II.2. Physiological Sensors

With the advancement of new sensing technologies, it is anticipated that physiological parameters that are related to obesity care and research, e.g. blood glucose and blood pressure, can be better obtained at specific instances in the ambulatory environment. Wearable sensors provide unobtrusive assessment of energy expenditure through analysis of body temperature, physical activity, and galvanic skin resistance [11], or heart rate and physical activity [14].

II.3. Food Intake Detection

The balance between energy intake and energy expenditure is an essential factor for maintaining a steady body weight in humans. Miniature devices can detect ingestion events and then further characterize the ingested foods, regardless of how short or insignificant they may seem. A wearable sensor could potentially capture timing, duration, and microstructure of food intake episodes, characterize rate of ingestion, ingested mass and nutritional and energy contents of food, without creating a reporting burden for the user [15], [16].

In order to characterize food intake, the system must estimate the number and type of food items in a meal, mass and volume of ingestion, rate of ingestion of each episode, and caloric and nutritional content of a meal.

Food intake monitoring may include:

- *Monitoring of swallowing*. Swallowing of food can be detected using:
  - electrical activity of muscles (electromyography/ EMG),
  - monitoring of sounds (microphone placed over laryngopharynx or mastoid bone) [17],
  - monitoring of motion of larynx using accelerometers or magnetometers, and
  - monitoring of changes in electric impedance across the neck at larynx level (electroglottograph/EGG).

The system must resolve the difference between swallowing during food intake and spontaneous automatic swallowing that happens 1-2 times per minute.

- *Monitoring of chewing*. Chewing precedes swallowing of food and can be detected by monitoring:
  - electrical activity of jaw muscles (electromyography/ EMG),
  - sounds generated during the movements using a microphone that is placed over laryngopharynx or mastoid bone,
  - changes of jaw shape using strain gauges/piezoelectric film that generates voltage when flexed.
- *Monitoring of hand gestures*. Food intake can be also monitored by monitoring hand-to-mouth gesture. Standard inertial sensor (e.g. gyroscope) can be used to detect motion of the wrist. New generation of activity monitors can be implemented as a watch or hand band device that can be used to detect hand gestures.
- *Monitoring of gastric activity and physiological response to food intake.* The processes of food digestion manifest as physiological indicators such as changes in blood glucose, body temperature and other indicators that can be monitored by on-body and in-body (e.g. attached to gastric tract) sensors.
- *Monitoring of quantity and type of food*. Image processing methods have been used in controlled settings to monitor the quantity, number of foods in a meal, or limited number of foods in a meal [18].
- *Monitoring of chemical food composition*. New generation of sensors uses spectroscopy to analyze the chemical composition of food in a couple of seconds (e.g. TellsSpec [6]). The TellSpec handheld scanner beams a light at the food, measures the reflected light with its spectrometer, and sends the data via smartphone or computer to the servers to analyze food. The results are displayed on user's smartphone or computer to inform the user.

III. Social Networks, Social Media, and Related Technologies

Generic approaches to prevention and treatment of obesity have limited success due to the disparities by race/ethnicity, neighborhood, socioeconomic status, and access to health care. Therefore, most successful approaches take into account the physical and social environment to influence behaviors and sustain changes in behavior of participants and their families. Social networks supported by social media (Web-based and mobile technologies) are commonly used for interaction and communication within the network. Social-media based interventions have been frequently used in social networks for health and obesity applications [2]. Interventions include internet-based interactive methods, purposefully developed social networks to address obesity, e-mail and texting, and active video games.

IV. Systems and Applications

Innovative technologies provide new and exciting opportunities for obesity research and monitoring. However, full potential of these technologies can be used through synergy of information from multiple sensors. For example, synchronized monitoring of heart activity and inertial sensors may provide personalized physiological response to specific physical activity [13].

Combined monitoring of chewing and swallowing can provide better assessment of food intake and ingestive behavior.

Typical example of the research multisensory system is presented in Fig. 2.

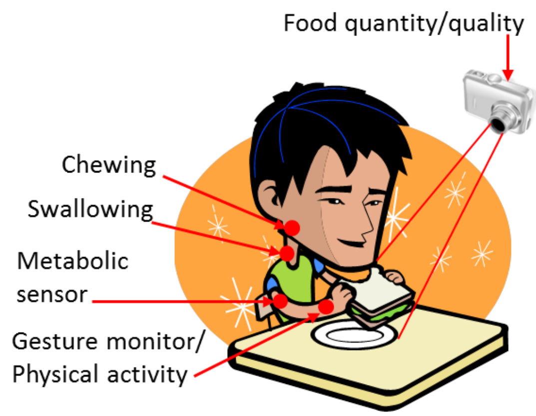

Figure 2. Multisensory monitoring for obesity research

V. Discussion and Conclusion

Some of the first applications for smartphones included electronic food diaries. Recent development of wireless sensors and integration of sensors in smartphones opens unprecedented opportunities for monitoring of users. We presented recent trends in sensor development and typical applications of monitoring users in laboratory settings and during activities of daily living. New miniature sensors provide unobtrusive monitoring with minimum or no interference with user's activity.

Ongoing research is addressing the need for innovative methodologies for dietary assessment and physical activity of users. The development of wearable devices that integrate different non-invasive sensor modalities seems to be the most promising approach to ambulatory monitoring. A successful implementation of such devices and methodologies would have tremendous impact on obesity research and monitoring applications.

Exponential increase of the number of users and collected data sets will facilitate better understanding of underlying problems. Huge datasets collected from continuous monitoring of users will facilitate data mining and new discoveries. Self-tracking tools and methods will allow users to gain more insights about themselves, others and the world around them [19].

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