Smart Garments in Chronic Disease Management: progress and challenges

Ajit Khosla*
[a]School of Engineering Science, Simon Fraser University, Burnaby, British Columbia, Canada, V5A1S6.

ABSTRACT

This paper presents the progress made developments in the area of Smart Garments for chronic disease management over last 10 years. A large number of health monitoring smart garments and wearable sensors have been manufactured to monitor patient's physiological parameters such as electrocardiogram, blood pressure, body temperature, heart rate, oxygen saturation, while patient is not in hospital. In last few years with the advancement in smartphones and cloud computing it is now possible to send the measure physiological data to any desired location. However there are many challenges in the development of smart garment systems. The two major challenges are development of new lightweight power sources and there is a need for global standardization and a road map for development of smart garments. In this paper we will discuss current state-of-the-art smart garments and wearable sensor systems. Also discussed will be the new emerging trends in smart garment research and development.

Keywords: Smart Garments, Nano-composites, Smart Phones, Fiber-Electronics, Screen-printing, Bio-signals, wireless, cloud network, Health Care, e-bra.

1. INTRODUCTION

In 2011, Global healthcare expenditures exceeded $6 trillion[1]. It has been estimated by World Health Organization (WHO) that up to 75% of healthcare spending is on chronic disease management[2], such as: cancer, heart disease, diabetes, obesity, arthritis, hypertension etc. In order to reduce the expenditure associated with chronic disease management, there is a need to change the way healthcare monitoring is done. This can be done by making a shift from Hospital based chronic disease management to Home based chronic disease management. By developing Smart-Garments for home based chronic disease management will result in reducing hospital visits and thus significantly reducing the cost.

To address this demand, in last 10 years, a lot of progress has been made in the development of smart garments for chronic disease management. A large number of health monitoring smart garments and wearable sensors have been manufactured to monitor patient's physiological parameters such as electrocardiogram (ECG)[3], blood pressure (BP)[4], body temperature (T)[5], heart rate (HR)[6], oxygen saturation (SpO2)[7], while patient is not in hospital. However, in last 5 years, efforts have been made to implement real-time continuous feedback data of health condition/physiological parameters, to the user via smart phone and in case of any possible health threatening condition an alert or SOS can be sent to hospital or a medical clinic[8,9,10,11,12]. Development of such smart garments requires multi-disciplinary research effort, which includes: sensory textile/threads/fabrics, bio-potential sensors, novel materials, electronics, wireless communication, information technology, energy supply, data management and integration with smart phone technology[13].

Smart garments consist of following components: (1) sensors, (2) wireless components, (3) microprocessor circuits, (4) energy supply components, and (5) data management components[14]. One of the major challenges in issue in smart garments is the use of conventional power supplies/batteries which are heavy, rigid, and a short life time and is the heaviest part of the smart garment. Much needed research needs to go in to developing batteries which are light weight, flexible, paper thin and

*ajit_khosla@sfu.ca; This paper has been submitted to Journal of Smart Nanosystems in Engineering and Medicine, for consideration.

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can be recharged easily. Few commercially available light weight, paper thin, flexible batteries which looking processing for integration in smart garments are UT Series (Blue Spark Technologies)[15] and SF Series (Solicore-Power solutions)[16]. Another area of development which will revolutionize is fabrication of fabric based organic transistors or flexible transistors fabricated directly on fibers[17]. Further work needs to be done in order to integrate low powered organic bendable microprocessor that can be stitched or printed on the garments to perform complex computing such as an 8-bit microprocessor circuit with 4000 transistors developed at IMEC [18] (Interuniversity Microelectronics Centre-Europe). Although much progress has been made in the area of smart garments, however, home based monitoring of cancer such as breast and skin cancer via smart garments has not been investigated because of technical challenges. Noninvasive cancer detection is possible by employing electrical impedance method[19], challenges lay with the development of custom made small-lightweight low frequency impedance analyzers.

It should be noted that most of the development in the area of smart garments has been carried out in European Union and United States. However, there is no roadmap defined which focus on technology development and standardization. However, European Union funded projects have defined their own roadmaps such as SIFIT- Cluster of EC co-financed projects on smart fabrics and interactive textile[20].

In this paper we will discuss current state-of-the-art smart garments and wearable sensor systems for chronic disease management which have been developed various researchers since 2000. New emerging trends such as incorporation of energy source, transistors based fabrics and energy harvesting fabrics will also be discussed.

2. RESEARCH AND DEVELOPMENT IN SMART GARMENTS

In last 10 years, there have been various research efforts made and products developed for chronic disease management which monitor patient's physiological parameters such as electrocardiogram (ECG), heart rate (HR), perspiration rate (PR), breathing rate (BR), body temperature (T), blood pressure (BP), activity related data (ARD) such as posture recognition stretch and bend, bio-impedance sensors (BIS), Glucose (G), galvanic skin response (GSR), Heat Flux (HF) and ambulatory healthcare monitoring (AHM). This section summarizes research efforts made by industry and research labs in development and commercialization of smart garments. Table 1 lists the companies and research labs involved in research and development of garments.

WEALTHY-European Union

WEALTHY[21]- stands for wearable health care system were funded as a part of 5th framework program of European union from 2001 to 2005. The employed use of smart materials such as electrically conductive and pizeoresistive in fiber and yarn and were used as basic elements to implement wearable system for collecting physiological data. They developed a wearable garment covering upper body and was capable of measuring ECG, Body temperature, activity related data, blood pressure, and oxygen saturation. An analogue to digital convertor along with a wireless/Bluetooth module were integrated with the garment for partial data processing and transmission.

My Heart Project-European Union

MyHeart[22] project was funded by the European Union as part of the 6th frame work from 2003 to 2009. This project was aimed at fighting cardio-vascular (CVD) diseases by preventive lifestyle and early diagnosis. Myheart project was none of the largest E.U funded project and consisted of 40 different partners from 11 countries. They employed use of conductive wires woven in to fabric in order to develop function clothes with integrated textile sensors. The integrated textile sensors capable of measuring ECG, heart rate and activity related data such as running, sleeping, and falling down.

STELLA-European Union

The STELLA[23] project was one of the most ambitious and successful project funded by European Union. The project duration was four years, it started in 2006 and ended in 2010 and included eleven partners from industry across 4 European countries. They were successfully able to develop garments, which could do varity of physiological measurements of human body in a real time such as ECG, heart rate, heart rate variability, blood oxygen saturation, temperature, and activity related data. This work was unique in nature, as they developed flexible and stretchable robust micro-sensors of soft touch nature that were RoHS compliant. Theses new stretchable micro-sensors had a direct skin contact, which allows reliable measurements. These sensors were interfaced with electronics blue tooth or wireless capability to transfer data for further processing. Furthermore, they employed software-based corrections to remove the artifacts in the measured data.

OFSETH- European Union

Unlike any other research initiative in European Union, in 2006, OFSETH[24] project was commissioned in order to investigate used polymer optical fibers for sensing vital parameters such as heart rate, respiratory rates and pulse oxymetry while being compatible with a textile manufacturing process. This project lasted for four years and constituted of 11 partners from 5 EU countries with cross competencies in the fields of health, textile and optics. They investigated pure techniques, such as fiber Bragg gratings (FBG) sensors and near infrared spectroscopy (NIRS), for non-invasive pH or glucometry measurements.

BIOTEX- European Union

BIOTEX[25] is again a EU funded project and was a part of Sixth Framework Programme of the European Commission. This project focused on biochemical-sensing techniques compatible with integration into textile. A unique aspect about BIOTEX was that an attempt was made at coming three different sensing techniques electrical, optical and chemical. The developed textile based sensors can measure PR, salinity, glucose levels, ions (K+, Na+, Cl-, Mg+, Ca+), pH & organics, unlike any other smart garment. In fact this was the first time that an attempt was made in order to monitor body fluids by using textile sensors and performing biochemical measurements.

Ohmatex- European Union

Ohmatex[26] is an intelligent textile development company based in Denmark. They focus on development of electronic textiles and stretchable electrodes combined with IT technology in order to create smart garments along with other industrial and academic partners. Their sensors are flexible and washable, electronic textile that can be sewn easily in to garments. The developed textile based stretchable sensors can perform following physiological measurements: ECG, EMG, body temperature, and respiration.

Phillips- The Heart Cycle -European Union-China

Heart Cycle[27] project which is led by Phillips, is one of the largest research program ever funded for development of smart garments, with a budget of EUR 21 million out of which EUR 14 million will be funded by the European Union as part of the EU 7th Framework Program. The main objectives of this research project are to develop smart garments and wearable sensors chronic heart disease and heart failures. Just like many other Smart garment projects Phillips also aims to interface the developed smart garments with electronics blue tooth or wireless capability to transfer data for further processing. This project involves collaboration of over 18 public and private partners , research, academic, industrial and medical organizations from nine different European countries and China. One of the may collaborates of Heart Cycle project is Clothing+, and have developed textile based sensors which are not only stretchable but also can be washed. These textile-based sensors are capable of measuring ECG, GSR-, EMG- and EEG-sensors, thermometers, stretch and bend sensors, and bio-impedance sensors.

Khosla, Gray-Canada

Since 2007, Khosla[28] along with Prof. B. L Gray from Simon Fraser University, Canada; have been working on developing multifunctional, highly flexible, silicone based polymers which can be nano-micropatterened. These polymers are prepared by doping nanoparticles such as graphene, silver, magnetic nanoparticles in silicone based polymers. These polymeric nanocomposites can be electrically conductive, magnetic, or both in nature. Recently, they have developed a shape conformable, highly flexible, stretchable Silver-Silver Chloride nano-micropatternable nanocomposite which can be micromolded and/or screen printed using conventional techniques. This novel nanocomposite is currnely being employed to develop an e-bra, which is capable of monitoring breast cancer, by employing electrical impedance techniques.

Smart Life Tech-United Kingdom

Smart Life Tech[29] is a UK based Technology Company, and has developed smart garment system known as Smart Life Vest, which is capable of performing physiological measurements. Their garments employ knitted e textile based soft sensors with specific electrical properties. Data collected by the Smart Life Vest can be transmitted in real time via bluetooth to a remote computer, or smart phone. Smart Life Vest can monitor subject's ECG, heart rate, EMG, respiration, and body temperature. They also make use Advanced Digital Signal Processing and other software based corrections in order to remove the artifacts obtained while acquiring the ECG signal.

Peratech-United Kingdom

Eleksen, which is a part of Peratech[30], United Kingdom, has developed highly flexible and durable touch fabric based touchpads and has no mechanical moving parts. The fabric based touchpads also known as "ElekTex" are less than 1mm thick, consists of a special arrangement of multiple layers of resistive fabric to form a touchpad. These touchpads response and distinguish between, touch, swipe, scrolling, stroke, and gestures. Moreover they can be simply stitched on garments, interfaced with cell phones for data input and more importantly are washing and dry cleaning safe. The touchpad technology developed by Eleksen, can be utilised by the scientists in order to interface the sensors on smart garments and smart phones.

Dongseo University- South Korea

In 2011, Young-Dong Lee and Wan-Young Chung from Dongseo University[31], Busan, South Korea, developed a wireless sensor network based wearable smart shirt for health and activity monitoring. The developed smart shirt prototype was capable of accurately measuring electrocardiogram (ECG) and activity related data in real time. They employed electrically conductive fabrics/threads as sensors and/or electrode material. The measured physiological data and activity related data is transmitted using wireless and or low power Bluetooth to a server for remote monitoring. They also employed adaptive filtering software-correction tools in order to remove the artifact in data such as noise.

Vijay Vardan's Group- U.S.A

Vijay Vardan's Group[32] at University of Arkansas has developed an e-bra system which consists of a bra with nano-enabled-sensors and textile electrodes for measuring Electrocardiography. The developed sensors are coupled with a wireless module called the e-nanoflex and can be trasmeitted to any desired location such as a server, a cloud network or to a medical clinic. Furthermore, e-bra is capable of capable of monitoring blood pressure, body temperature, respiratory rate and oxygen consumption. Its connectivity to cloud server can potentially help in initiating emergency medical response and prompt communication with the medical doctor for an e-prescription. Prof. Varadan's group has also developed a vest which can perform similar functions as e-bra.

Zypher Technology

Zypher Technology[33], in Unites states has developed sensers in strap or clothing for known as The BioHarness™ which are capable of measuring critical physiological parameters such as ECG, heart rate, breathing rate, skin temperature and activity related data. The physiological data measure is transferred via a Bluetooth named as "BioHarness™ BT" to a smart phone, cloud network and fixed data networks which enables remote monitoring of health of a patent or athlete in the real time.

3. NEW EMERGING TRENDS

New emerging trends such as incorporation of new energy harvesting fabrics, lightweight energy sources, and transistors based fabrics will be discussed in this section.

In 2012, *Xi Chen* et al[34] from Stevens Institute of Technology and Princeton University reported a piezoelectric nanogenerator based on PZT nanofibers wich is able to generate 1.6 volts. The developed PZT nanofibers had a diameter 60 nm and length of 500 µm. Fabricated PZT nanofibers were aligned on inter-digitated electrodes of platinum. This assembly was then further packaged using silicone. On applying stree the packaged device was able to generate a voltage of 1.63 V and power of 0.03 µW. *Weiwei Wu* et al[35] from Lanzhou University China, in a collaboration with Georgia Institute of Technology, in 2012, have developed wearable, Nano-generators which give and output voltage of 6 V and output current of 45 nA and were successfully able to power liquid crystal display and a UV sensor.

Piezotex[36] is an ongoing European union research project focused on development of Piezoelectric textile based self powered sensors for vital body signals fibers, energy harvesting, and charging batteries. They are using PVDF, which is a polymorphic polymer and exhibits piezo and pyroelectric properties. In recent years, PVDF has found its way towards intelligent textile. The foucus of this project is to develop highly flexible, light weight, melt spun piezoelectric PVDF-based fibers/yarns which can be integrated with batteries, electronic devices and sensors on smart garments.

Centexbe[37], the Belgian Textile Research Centre, has started a for year project started in 2011, called as *"The Power Weave"* in order to develop a fabric to harvest and store electrical energy. The focus of "The Power Weave" project is to fabricate photo volatic fibres which can be integrated with control electronics into a textile. This is a unique approach, which will address to the challenges faced in developing smart garments and can be used to charge batteries.

Hyunjin Kim [38] et al in 2012, from Samsung Advanced Institute of Technology , Republic of Korea have developed hybrid nanogenerator on a textile substrate. This was achieved by sandwiching a charged dielectric layer and piezoelectric Zinc Oxide nanowires in between textile fabrics. This hybrid nanogenerator had a maximum output peak voltage of 8 volts and current of 2.5 µA. The fabricated textile based hybrid nanogenerator, by Hyunjin, which has an excellent current and voltage rating was tested successfully to drive OLED and LCD panels. This textile hybrid nanogenerator is an attractive power source for charging batteries, powering sensors, wireless and other electronics which are currently being used in smart garment technology.

In 2007, *Tom Torfes* [39] et al from IMEC, have developed a wireless watch style pulse and blood oxygen saturation meter which is powered by human body heat. This was achieved by employing commercial BiTe thermopiles/Thermoelectric generators(TEGs). It is believed that about 30µW of energy is produces per square centimeter of human skin. The developed thermoelectric generator produces more than 100µW at 22°C ambient temperature, and is a fully energy-autonomous system. They have also developed a 2-channel wireless EEG (electroencephalography or monitoring of brain waves) system powered by body heat by employing thermoelectric generators. The wearable EEG system does not require any battery and is maintenance free.

Giuseppe Tarabella[40] et al from IMEM CNR Parco Area delle Scienze, Italy, in July 2012, reported Single Cotton Fiber Organic Electrochemical Transistor. They used a simple single natural cotton fiber which was functionalized with PEDOT:PSS conductive polymer, by soaking process and used as channel of an organic electrochemical transistor (OECT). This was directly interfaced with a liquid electrolyte in contact with an Ag wire gate. The device shows stable and reproducible current modulation. Giuseppe et al suggest that The developed single wire cotton fiber is a simple, low cost device, and is very attractive for wearable electronics in fitness and healthcare.

Table 1 Companies and research labs involved in research and development of garments ECG- electrocardiogram, HR-heart rate, PR -perspiration rate, BR-breathing rate T-temperature, BP-blood pressure, ARD-activity related data such as posture recognition stretch and bend, BIS- bio-impedance sensors, G-Glucose, GSR-galvanic skin response, HF- Heat Flux, AHM-ambulatory healthcare monitoring.

Project	Country	Measured signals
My heart	EU	ECG, HR, A
Wealthy	EU	ECG, BP, SpO2
Stella	EU-Germany	ECG, HR, SpO2, T, HR, ARD
MERMOTH	E.U	ECG, T, HR
AMON-WMD	E.U	ECG, BP, T, SpO2,G
MagicIC	E.U	ECG, HR
Human++	E.U	ECG, EEG
ProeTEX	E.U-Italy	EGG, BP, HR, SpO2, T
OFSETH	E.U	T, HR, SpO2, AHM
BIOTEX	EU- Switzerland	PR, salinity, ions (K+, Na+, Cl-, Mg+, Ca+), pH & organics
VTAMN	E.U	ECG, T, BR, ARD
SMASH	E.U	ARD
Ohmatex	EU-Denmark	ECG, EMG and respiration temperature, moisture, stretch
Phillips- HeartCycle	EU-Holland	HR, ECG, GSR, Cuff-less BP, EMG- and EEG, T, ARD, BIS, Contact-less ECG, Motion-compensation- ECG.
Clothing Plus	EU-Finland	HR, ECG, GSR, EMG- and EEG, T, ARD, BIS
DEPIC	E.U-France	Tele-monitoring of dialysis at home
Khosla, Gray	Canada	Not available
Smart Life Tech	U.K	HR, ECG, T
Peratech	U.K	Touch pads, electronics
Dongseo University	Korea	ECG, BP, SpO2, T
Prof. Vijay Varadan's Group		EGG, BP, HR, SpO2, T, RR, ARD
Nike and Apple	U.S.A	Not Disclosed
LifeGuard- NASA	U.S.A	EGG, BP, HR, SpO2, T
Genevieve Dion and Shima Seiki USA	U.S.A	Not available
Code Blue- Howard	U.S.A	ECG, SpO2
Heart to go	U.S.A	ECG
Health Gear-Microsoft	U.S.A	HR, SpO2
Zypher Technology	U.S.A	ECG, HR, BR, T, ARD
Polar-Wearlink+	U.S.A	HR
RAE Syatems-Bio-Harness	U.S.A	HR, BR, ARD, T
Body Media	U.S.A	T, GSR, HF

DISCUSSION AND CONCLUSION

Smart garments and wearable sensors have a great potential to revolutionize quality of healthcare and offer a new lifestyle to patients suffering from chronic diseases and might help in prevention and early intervention. Smart-Garments for home based chronic disease management will result in reducing hospital visits and thus significantly reducing the cost of care delivery. As we have seen that in last 10 years, advancements have been made in development, however, many potential problems need to be overcome, before it gets integrated healthcare practice, such as:

- Roadmap: There is no roadmap defined for Smart garments in chronic disease management. There is a need to define a global roadmap similar to one defined by semiconductor industry (ITRS). This will help with target and goal setting for next generation smart garments and identifying technological bottleneck problems. This will also bring experts and industry from all over the world under one roof and lead to global effort in research and development.
- Global Usability and Infrastructure: There is no standardization in the area of smart garments for smart garment's for chronic disease management. Develop and allocate infrastructural assets, such as allocation of bands for secure communication, centralized data storage and cloud networks, billing systems, customer care systems, and importantly simple and easy to use technology for senior citizens.
- Early Cancer diagnostics and management: There has been little or no development in order to develop smart garments for cancer monitoring such as breast or skin cancer. Development of e-bras and wireless patch sensors has to potential to detect breast and skin cancer by electrical impedance methods.

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