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Smart Underwear for Diabetic Patients

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ABSTRACT

In recent years, as the demand for health care and proper diet increases, smart clothing with a built-in health care monitoring system is likely to have a high demand rate in the market. As diabetes is increasing, the smart wear for diabetic patients is necessary. Therefore, this study suggested the design of the smart underwear for diabetic patients. This smart underwear is able to monitor diabetic patients' health condition and glucose levels through the glucose sensor and biosensors. Sensed vital signs are transmitted to a dedicated operating transmitter, PC, PDA, or mobile phone. Patients are able to have real time information about their health condition, including ***blood sugar levels****. It allows patients to determine their blood sugar level and manage their diet and/or medication. As the market's demand for medical information increases, this smart underwear will provide a significant part of the answer for patients.*

Keywords: smart wear, underwear, diabetic, healthcare, biosensor

1. Introduction

Diabetes is increasing in every year, according to data released by the Centers for Disease Control and Prevention (Department of Health and Human Services, 2005). Since the population susceptible to diabetes (obesity, advancing age, poor diet and lack of exercise) will also increase, the demand for diabetes healthcare products will grow proportionally. The management of healthcare and the advantages provided by early diagnosis are extremely beneficial to patients (Lymbris & Gatzzoulis, 2006).

Therefore, the development of smart underwear which is able to monitor the health condition of diabetic patients is likely to have a high demand rate in the industry. Because diabetes is a difficult disease to control, any system allowing the monitoring of relevant parameters and supporting prompt decisions would raise an enormous interest. Diabetes can be measured by some methods; blood glucose monitoring, glucose sensing bio-implants, and noninvasive glucose monitoring.

In this study, glucose sensor and biosensors added to underwear will enable patients to gain real time information about their vital signs, glucose levels and other data bearing upon their health condition. Because diabetic patients need to determine their blood sugar levels and manage their diet and medication accordingly. This study suggested the design of the smart underwear for diabetic patients. This smart underwear is able to monitor diabetic patients' health condition and glucose levels through the glucose sensor and biosensors.

2. Smart Wear

2.1. The History of Smart Wear

Smart clothing was researched by MIT (Massachusetts Institute of Technology) for military use in the early 1990s. During the International Symposium of Wearable Computers (1997), MIT introduced many of those garments. They were more like clothing than computers (Scawartz & Pentland, 2000). At Georgia Tech, Lind and his team developed a T-shirt for use by soldiers in combat which was able to measure the extent of injuries incurred by the soldier and would help medics in the process of triage (Lind et al., 1997). MIT developed a functional, comfortable, wearable computer (Figure 1). The structure is composed of a lightweight mesh and provides a medium for integrating electrical units with flexible interconnections (Scawartz & Pentland, 2000).

Figure 1. Smart Vest of MIT Media Lab (Scawartz & Pentland, 2000)

Langenhove, Hertleer, Catrysse, Puers, Egmond, and Matthus described the smart suit was a result of collaboration between specialists in textiles, electrical engineering and pediatrics. It was considered comfortable, non-obtrusive, safe, wearable and washable. Textiles provide the sensing material and sensors have been designed to monitor heart rate, electrocardiogram (ECG) and respiration. The textile sensors are knitted structures incorporating stainless steel fibers (Langenhove et al., 2004).

Phillips (Farringdon et al., 1999) designed a jacket which includes several sensors that do not detract from wearability despite their functional attributes and are very textile-like. This technology may result in a wearable laptop computer, cellular phone or personal digital assistant. Philips Research together with Levi Strauss (Joe O'Halloran Technology, 2003) has also introduced the Industrial Clothing Design (ICD+) with an integrated MP3 player, collar earphone and microphone, telephone, and washable wiring.

Levi Strauss (Baker. 2006) is joining the mobile technology clothing trend with a new iPod ready jeans line which offers built-in headphones, a joystick, and a docking cradle. The Levis RedWire DLX jeans (Figure 2) feature a special pocket with a white leather patch that stores an iPod. The jeans also offer a joystick in the watch pocket which lets Levis RedWire DLX jeans wearers control their iPod without having to take it out of their pants or look at it. Levi Strauss has reported that the sale of the jeans is successful and has added US$5 billion of brand equity to Levis (*Talk2myshirt, 2007).*

Figure 2. Levis RedWire DLX Jeans (Levis, 2006)

Electro Textiles Company Incorporated (Eleksen, 2006) has developed and marketed a new fabric which, while retaining the characteristics of traditional fabrics, also allows for electronic interconnectivity. This new textile serves as conductor, transmitter and receiver. The goal is to produce textile material that is suitable for the attachment to traditional electronic components. The textile would serve as a signal and power carrier. Electro Textiles is already marketing a textile keyboard that can be used with a personal digital assistant and folded away after use (Figure 3). This textile keyboard is an interface easily included in clothing which provides for connectivity with Blue Tooth. This enables portable computing and provides the gateway to myriad consumer electronic devices.

Figure 3. Eleksen Fabric Keyboards (Ubergizmo, 2006)

Nike+ (Newitz, 2006) has developed smart shoes and clothing (Figure 4). Customers can track their pace, time, distance and calories burned. A sensor included in the shoes and connected with an iPod keeps track of every step and summarizes running data to motivate, track progress, set goals, win awards and challenge friends to run longer, faster or more often. During a run, the athlete can also listen to music through the same iPod that provides their data.

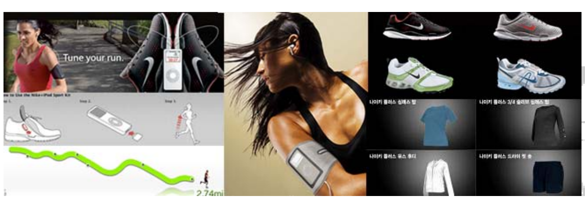

Figure 4. Nike+ Smart Wear (Nike, 2008)

Adidas (Polar Dealer, 2006) has developed smart clothing including sports shoes, sportswear, an arm band which measures and transmits the heart rate and the intensity of the workout (Figure 5). By transmitting vital signals measured in the clothes and shoes to a screen on a wristwatch-type monitor, it allows users to be able to access real-time monitoring.

Figure 5. Adidas Smart Wear (Adidas, 2007)

Scottevest Inc. (Bob, 2006) developed TWIT 4.0 Personal Area Network Fleece jacket which has 12 pockets and compartments to stow and organize gear and allows customers to carry a cell phone, an MP3 player and other personal electronic devices. The jacket has a multitude of features including an attached, extendible key holder, magnetic pocket closures, no bulge bucket pockets, special sunglass pocket, pen/stylus pocket bottle holder and more (Figure 6).

Figure 6. Scottevest TWIT 4.0 Jacket (Bob, 2006)

Burton (GizmoGuy, 2008) teamed up with the tech gurus at Motorola® to create the world's first Pinnacle wearable communication and entertainment system. They developed the Burton Audex Jacket (Figure 7). This breakthrough in Bluetooth Stereo technology creates a seamless communication link with Bluetooth-compatible mobile phones. As a result, customers can listen to music through Bluetooth Stereo connected with iPod Nano, mobile phones through Motorola RAZR. The hood contains built-in DJ-style speakers and a control button is attached to the sleeve. They allow the user to crank up the music and pick up phone calls without ever removing gloves or unzipping any pockets.

Figure 7. Burton Audex Jacket (GizmoGuy, 2008)

2.2. Smart Underwear

Mann (1996) developed smart underwear prototype that allows the wearer to control the temperature in a room (Figure 8). The sensors are sewn into waistband and the transmitter has two cables which are connected to the sensor and the transmitting antenna. The recorded data is sent to the receiver connected to the heater and temperature in a room is controlled through this system.

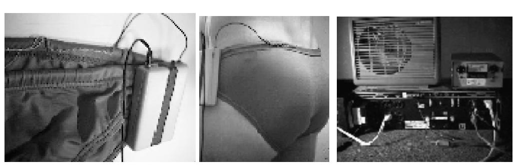

Figure 8. Smart underwear prototype (Mann, 1996)

Liu and Sun (2006) discussed the smart sport underwear included wearable sensors and communicating system. Figure 9 shows the architectural level of a smart sport underwear system which is developed as the integration of several function modules. The system consists of functional textiles, embedded microsystem, transmission units, central monitoring system**,** and database.

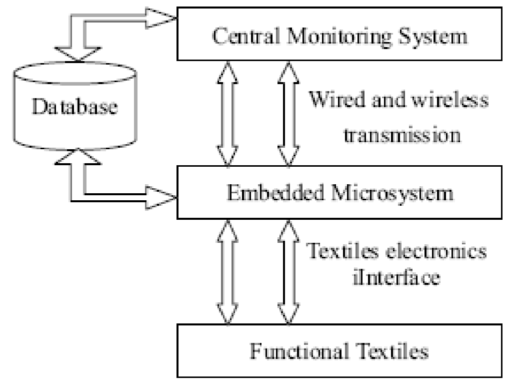

Figure 9. The architectural level of a smart sport underwear system (Liu & Sun, 2006)

Functional textiles which are the implementation of sensing elements achieve monitoring of body. These are able to monitor the body motion and measure the textile pressure of underwear. The sensors, the embedded Microsystems, identify several biomedical signals such as ECG, blood pressure, respiration, temperature, and motion of the wearer continuously.

The measured data is transmitted through Bluetooth and communication system by wireless. The central monitoring system is organized in the modules including web server, database server, client application module, central control module, and display devices.

2.3 Healthcare Smart Wear

Dittmar, Axisa, Delhomme, and Gehin (2004) described the new concepts for home care and ambulatory monitoring provided by four factors including microsensors, wrist devices, health smart clothes, and health smart homes.

Figure 10 shows Enhanced Personal, Intelligent and Mobile System for Early Detection and Interpretation of Cardiological Syndromes (EPI-MEDICS) that is able to report the health condition of a heart disease patient. The purpose of the EPI-MEDICS project is to develop a intelligent 'Personal ECG Monitor (PEM)' for early detection and management of cardiac events. The concept of this model that the ECGs record the patient's health data and the alarm messages with the patient's electronic health record signals through means of wireless communication techniques such as bluetooth and GSM (Global System for Mobile communications). The transmitted alarm messages are temporarily stored on a central alarm web server and are transferred to the health professional office (Dittmar et al., 2004).

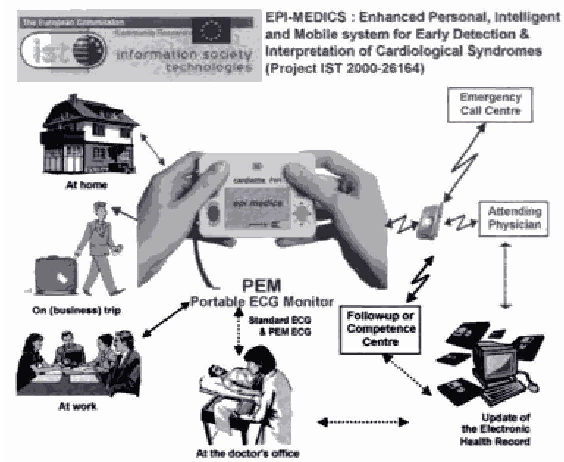

Figure 10. Enhanced Personal, Intelligent and Mobile System for Early Detection and Interpretation of Cardiological Syndromes (Dittmar et al., 2004)

The VTAM (Clothes for Tele-Assistance in Medicine) project developed smart wear technology with biosensors and bioacuactors woven into the fabric. Figure 11 shows the T-shirt included ECG electrodes, temperature and fall sensors, and a GPS receiver (Dittmar et al., 2004).

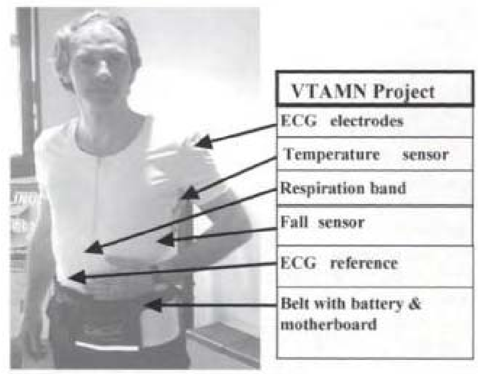

Figure 11. VTAMN prototype (Dittmar et al., 2004)

Vivometrics Inc. has been producing a smart LifeShirt (Figure 12). The LifeShirt included textile sensors for respiration, electrocardiogram electodes, accelerometers for blood oxygen saturation and provides monitoring of EEG/EOG, leg activity, pulse oximetry, capnography, blood pressure, and temperature. A data logger called as Palm TM is able to record raw data. Then, doctors and patients are able to receive the data.

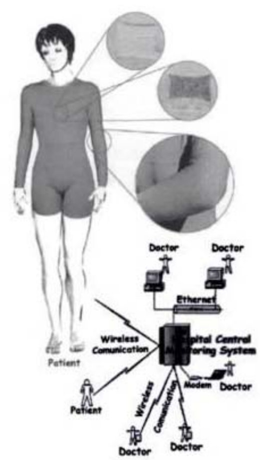

Figure 12. Wearable Health Care System: WEALTHY (Dittmar et al., 2004)

Mohan and Picard (2004) described an innovative healthcare and lifestyle management wearable system called as Health0. Figure 13 shows the Health0 architecture consists of a central device wirelessly connected to a sensor network. The PDA is connected wirelessly to the sensors through a sensor hub that provides data acquisition. The recorded data is transmitted to the cell phone/PDA and computer. This system is able to be used for diabetic patients. For example, a glucose monitoring sensor and an ECG sensor are connected to PDA and the recorded data is transmitted to the computer of home, office, and medical center. Therefore, patients are able to control the glucose level. The PDA can be web-enabled to provide access to the information for the effective control of diabetes depending on patients' condition.

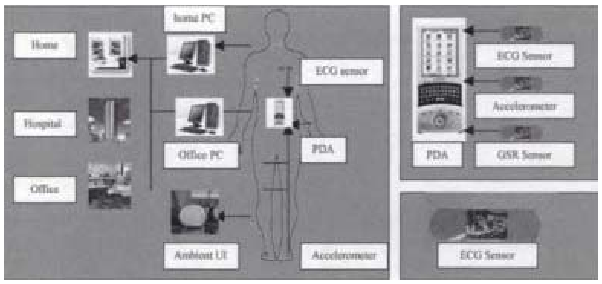

Figure 13. The Health0 architecture (Mohan & Picard, 2004)

2.4 Healthcare Sensors and Monitors

European project BIOTEX developed biosensors for inclusion in smart textiles. These biosensors in a textile patch (Figure 14) can analyze body fluids as small as a tiny drop of sweat, and provide an excellent assessment of someone's health indicators. BIOTEX probes using pH sensors cause an indicator to change color which is then detected by a portable spectrometer device. The BIOTEX oxygen probe measures levels of oxygen saturation in the blood around the thorax using a technique called reflective oximetry. The pH sensors are used to monitor people with obesity and diabetes, as well as athletes (ScienceDaily, 2008).

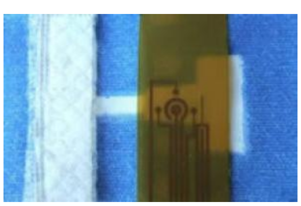

Figure 14. BIOTEX biosensor in a textile patch (ScienceDaily, 2008)

Orbital Research Inc. has developed a disposable dry electrode (Figure 15) intended for long duration and ambulatory ECG. The success of the technology is largely due to surface micro-structures that function as the sensing element of the electrode. These micro-features augment the electrode/skin interface by mechanically connecting the skin and the electrode, thus facilitating the transmission of the ECG signals from the body through the electrode and reducing motion artifact. They also developed a dry electrode which has a sencing element, housing, and snaps together as a single part. The single unit design offers advantages over traditional electrodes which typically are comprised of three separate components. Innovative manufacturing processes enable both the single unit design and the fabrication of the micro-features (Sparks & Rood, 2006).

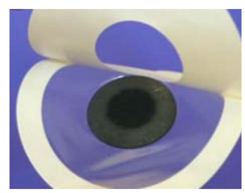

Figure 15. Dry electrode of Orbital Research Inc. (Orbital Research Inc., 2008).

DexCom™, Inc. developed the SEVEN system for diabetic patients. This system called as glucose sensing bio-implants needs a minor surgical implantation of the sensor. It is a wireless device that measures glucose levels and consists of a sensor, a transmitter, and a receiver (Figure 16). The sensor is a tiny, flexible, platinum wire-based device that goes just under patient's skin to read glucose levels, and is attached to the skin by a small, adhesive patch. The glucose information of patient is sent through the transmitter to the receiver. It helps patients to control high or low glucose level through safety alarm.

(a) (b) (c)

Figure 16. The SEVEN system (DexCom™, 2009) (a) Sensor, (b) Transmitter, (c) Receiver

3. Smart Underwear Design

The smart underwear for patients must be compatible with the function of the clothing: comfortable, durable, washable, and reliable as they measure physiological parameters of patients.

Some new methods to monitor blood glucose levels are glucose sensing bio-implants and noninvasive technologies. In the glucose sensing bio-implants, the sensor is input into the skin through a minor surgical implantation. It allows patients to monitor their blood glucose levels without the finger tip to draw blood. In the noninvasive technologies, there are several methods; urine glucose monitoring, shining a beam of light onto the skin or through body tissues, measuring the infrared radiation emitted by the body, applying radio waves to the fingertips using ultrasound and checking the thickness of fluids in tissue underneath the skin.

This study suggests the prototype of smart underwear for diabetic patients with the built-in ability to measure a range of physiological data using glucose sensing bio-implants and biosensors. Figure 17 shows the architecture of smart underwear for diabetic patients.

This smart underwear has some functions including sensors, data processing, central monitoring system (CMS), storage, and communication. Biosensors measure biomedical parameters from a body such as ECG electrodes, temperature, respiration, motion, blood pressure, etc. The glucose sensor captures the blood glucose levels under patient's skin. The main function of data processing is communication with the network. In other words, the data is transmitted to PC through wireless communication technique. In this smart underwear system, wireless device such as PDA or mobile phone is used as central monitoring system. The glucose level information is sent to the places of hospital, home, office, etc. If the blood glucose level is low or high, the alarm system works during the night time and the working time. Comfortable and unobtrusive biochemical measurement equipment plays a significant role in the function of smart clothing.

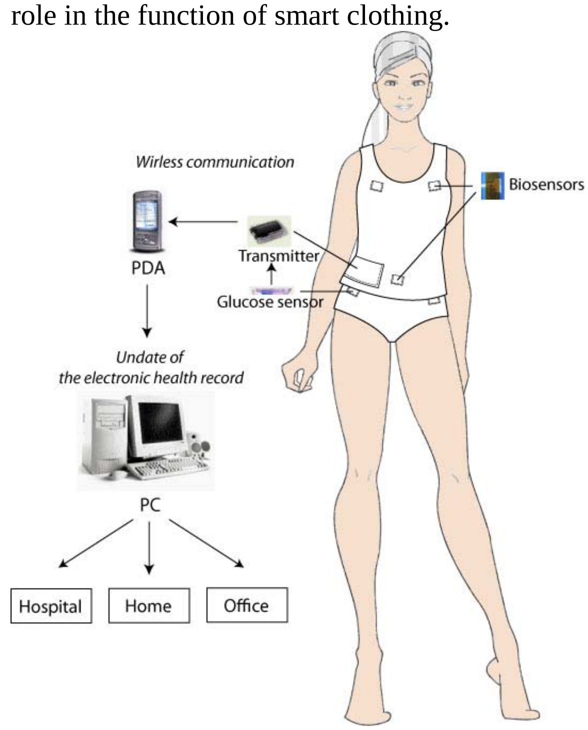

Figure 17. The architecture of smart underwear for diabetic patients

3.1 Design of Smart Underpants

Women's underpants are composed of a front body, a back body, elastic waistbands, and a gusset lining (Figure 18). The body and elastic waistband are made from 94% Nylon and 6% Spandex. The gusset lining is made from 71% Nylon, 24% cotton, and 5% Spandex. The glucose sensor is placed in the pocket sewed onto the front waistline of underpants and measure blood glucose levels painlessly. This sensor which receives the signal from a chip inserted under a skin measures the glucose levels. Also, the biosensors are placed onto the front and back waistline of underpants and measure biomedical parameters.

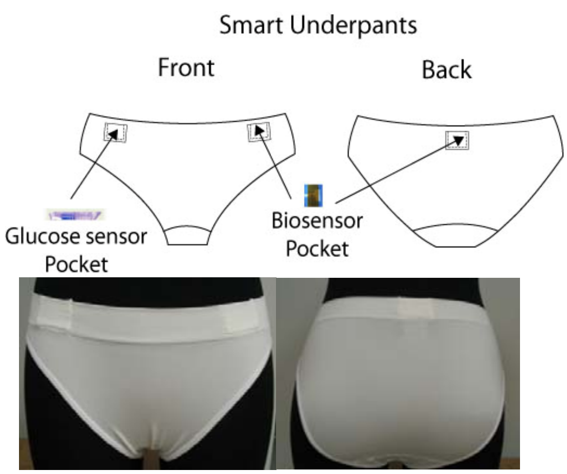

Figure 18. Smart underpants for diabetic patients

The pattern of underpants was made by Gerber's Pattern Design System (PDS). Grade rule tables were created in Missy sizes 8, 10, 12, and 14 using Gerber's Accumark system (Figure 19).

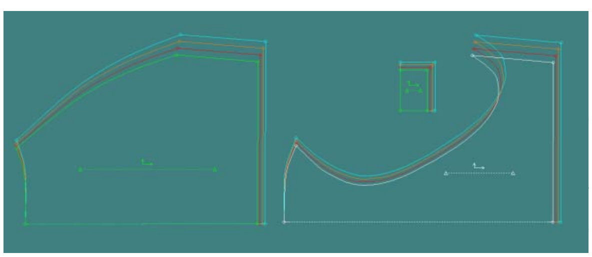

Figure 19. Patterns of the smart underpants

3.2 Design of Smart Tank Top

The tank top is composed of a front body and a back body as basic tank type shirt (Figure 20). This prototype is made from 100% Cotton. Biosensors are placed in the chest, back, and waist outside pocket sewed on the surface of the tank top. These sensors also can be detached from this pocket when tank top needs to be laundered. These health sensors measure body temperature, ECG electrodes, respiration, motion, blood pressure, etc.

The transmitter is put in the right pocket of a front body. Hook-and loop fasteners are attached to the outer pocket for easy opening when underwear is changed or washed. The wearer can view their biomedical information through wireless PDA or mobile phone.

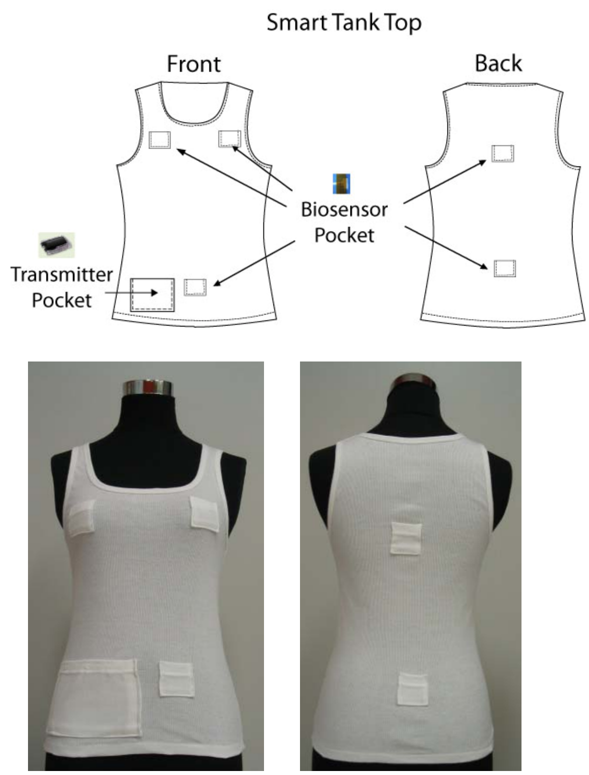

Figure 20. Smart tank top for diabetic patients

The pattern of tank top was designed using Gerber's Pattern Design System (PDS). Grade rule tables were created in Missy sizes 8, 10, 12, and 14 (Figure 21).

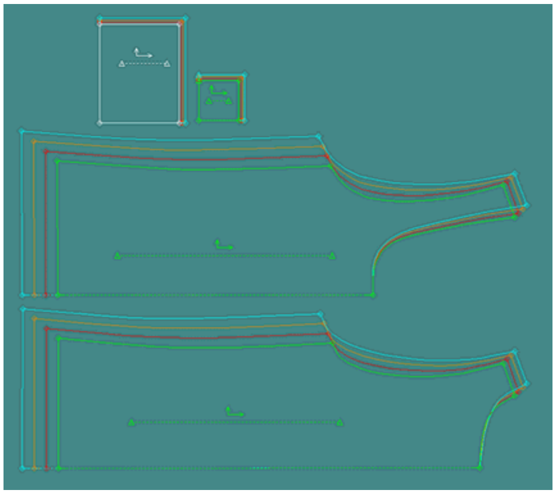

Figure 21. Patterns of the smart tank top

This smart underwear provides easy access to information for diabetic patients. These sensors based on smart wear enable us to record physiological signals and the sensed vital signs are transmitted to an operating PC, receiver, PDA, or cellular phone. Patients are provided with real time information about their vital signs and glucose levels and other data bearing upon their health conditions. This central monitoring system (CMS) is connected to a healthcare site which analyzes and reports health conditions to the wearer and helps them with dietary management, recipes**,** and menu choices in restaurants. At this site, the program is designed to provide diverse diabetic meal plans for patients enabling them to control their calorie and carbohydrate intake to promote weight loss and/or control blood sugar levels.

They are able to contact their counselors or doctors by phone and online with the monitor and hear professional comments and diagnosis comparing current data with past medical data. A diagnosis of celiac disease (Allergy to wheat gluten) necessitates what may be a dramatic change in their daily sources of carbohydrate. The wireless instrumented underwear can continuously monitor the health condition of the wearer throughout the day. The biosensors functioned as global positioning system (GPS) are able to monitor the wearer's position at a state of emergency.

4. Conclusion

This study suggested a prototype of diabetic patients' smart underwear which takes advantage of newly emerging technological convergence. The purpose of this design is to integrate the glucose sensor and biosensors, transmitter, and connections in the smart underwear, and to show the possibility of the simultaneous acquisition of biomedical data through wireless central monitoring system (CMS). The data is transferred to the places of hospital, home, and office. Patients can monitor their health condition through this smart underwear system and control their glucose levels. This smart underwear for diabetic patients will provide the information used in conjunction with a physician's diagnosis and treatment. The smart clothing still has the problems including the battery weight and the harmfulness electromagnetic wave, but these issues can be solved through continuous study.

Intelligent textiles and smart clothing will play great roles in the apparel industry of the near future. As the market's demand for medical information increases, this smart underwear will provide part of the answer for patients.

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