SMART TEXTILES FOR HEALTH MONITORING DURING PREGNANCY

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Abstract: The primary function of textile is to shield humans but with advancement in technology, textile industry is rapidly developing with varied special features in addition to its primary function. Smart Textiles are the textile materials that have the ability to sense and hence react to external stimulus with the help of electronic sensors incorporated. Along with its application in different fields like sports, military, fashion/lifestyle etc, it has applications in health care for continuous monitoring of patients and one such example is of pregnant women. Pregnant women have many health issues and frequent visit to hospital is troublesome so scientists have come up with a technology in which the sensors incorporated in the fabric are capable of monitoring blood pressure, ECG (Electrocardiograph), etc of mother as well as child inside the womb. Such readings are continuously recorded and sent to the healthcare professionals via a communication module. The name of such device is LIFEBELT which is in the form of a jacket. Major benefits are continuous monitoring and early diagnosis. It consists of two components Sensing Module which is a jacket with sensors embedded and electrodes and Handheld device to get the results which is a Tablet PC. Another advancement in this technology is PregSense which have more number of sensors thereby giving better accuracy. Knitting technology and bellyband antenna sensor are such developments in this field. This system does not require any surgery. The obtained signals are extracted and separated by many techniques and one of the important techniques is B.S.S. This device is predictive and hence saves lives. This review encompasses smart textiles with an insight on LIFEBELT in more details.

Index Terms **- Smart Textiles, E.C.G, LIFEBELT, Pregnancy, PegSense**

1. INTRODUCTION

Smart Textiles are intelligent materials that have the ability to sense and respond according to the external stimuli (Langenhove and Hertleer, 2004). Many of us think that smart textiles have recently gained importance, however it is shocking to know that Edward Thorpe in 1955 had developed a computer which is wearable (Thorpe,1998). Smart Textiles have evolved and has a remarkable impact on the Textile Industry. Healthcare, lifestyle and business application can be made better by incorporating sensors in the structure of the fabric (Park et al, 2002, Axisa et al, 2003, Paradiso et al, 2005, Mattman et al, 2007, Pola and Vanhala, 2007, Luprano, 2008) which includes smart uniforms for workers working continuously in hazardous conditions, lightening fashion and even toys (Berglin, 2005), safety and security, sports and wellness, geo-textiles, automotive and transport construction, defence, agro-textiles, lighting, industrial applications, home and interior textiles, architecture, packaging, energy, telecommunications and displays. Textile fabric is made by using specialized type of fibres and yarns which have electrical and physical properties in order to detect electrical (electromyogram, electrocardiogram] and mechanical signals (respirogram, motor activity). Daily procurement and processing of data for early detection of disease without interfering daily life is possible only because of wearable smart textiles (Sclingo et al, 2005). Conjoining the digital and the physical world is the main task of a sensor. The users wellbeing is directly or indirectly related to the parameters of sensors. There are many technical requirement of a sensor for both wearable devices or any other applications (Korhonen et al, 2003). A sensor converts as well as measures physical quantity like light, heat, etc into a signal which is readable by an observer or by an electronic instrument. Most of the sensor used till now is silicon based however many new type of sensors is also applied which includes:

1. Pressure Sensors: This type of sensor is being used inside the mattress for health monitoring (Engin et al, 2005) of patients. It also has application in textile keyboards, touchpads used in sportswear etc. Pressure sensors are developed by using spacer material using two conductive textile electrodes (Meyer et al, 2006)
2. Heart Rate Sensors: This type of sensor is used to detect ECG and respiratory activity. This has been reported the MagIC system which is a wearable device (Rienzo et al, 2005)
3. Temperature Sensors: This type of sensor is based on the resistance change in the conductive coating on the textile materials or metals fibres (Zieba and Frydrysiak, 2006)
4. Strain Sensors: It is used to detect joint movements and body postures which are very important for rehabilitation of patients to train athletes. Strain sensors are also fabricated inside the mattresses to obtain respiration rate, heart rate and body movements during sleep (Mondal, 2008). These are made by incorporating piezo resistive materials or optical fibres into the fabric in order to detect breathing rate or body positions. We can also print piezo electric films on the textile substrates to work as a strain sensor (Calvert et al,2007)
5. Biological Sensors: The presence and composition of biological fluids can be detected by chemical and humidity sensors. These sensors are fabricated using carbon nanotubes embedded in polyelectrolyte which is screen printed on fabrics (Yang et al, 2010) or coated on the textile fibres (Shim et al, 2008). Various Biological sensors are used to measure EMG and ECG in order to assist cardiac health (Coosemans et al, 2006, Pola and Vanhala, 2007)
6. Optical Sensors: These are the sensors which work based on the change in the intensity of light when a fibre is deformed. This type of sensor reacts with the outside environment and changes the light intensity. This sensor has a customized cladding layer which reacts with the external stimuli. Optic fibres have been integrated into the military uniforms to detect warfare threats (El-

Sherif et al, 2000). Sensatex commercialized this product named Life-Shirt which uses this type of sensor in the fabric to measure heart rate and temperature of the wearer (Wang et al, 2010).

7. Gas Sensors: In this method we coat the textile with a gas sensitive layer (Collins and Buckley, 1996, Kincal et al, 1998) or weave gas sensitive nano-fibres into the textiles (Ding et al, 2009). In industries, efficiency of production can be increased, as well as wastage can be reduced by the application of electronic sensors. Besides, they are used for monitoring systems which helps to prevent accidents. One of the major issue that pertains in manufacturing smart textiles is its power supply. Sensors incorporated in the fabric needs continuous supply of energy. These requirements can be fulfilled by rechargeable batteries, but the problem with these batteries are they are heavy and large, hence using conventional batteries in smart textiles is impossible. There is a dire need to develop alternative flexible and low weight storage and power generation devices. Examples of such devices include flexible (Lee, 2005, Coyle et al, 2007) elastic (Kaltenbrunner et al, 2010) batteries, super capacitors (Futaba et al, 2006), solar cells (Pagliaro et al, 2008, Yoon et al, 2008), energy harvesting devices like thermos and piezo generators (Ariyatum et al, 2003, Jung et al, 2003, Thomaset et al, 2006, Hanson et al, 2009). However, none of these batteries have power capacity and efficiency as compared to that of the conventional batteries, hence urgent research is needed to overcome this limitation.

We also need output devices to communicate the message of the sensors. Usually we use display devices like watches faces (Zhang, 2006), coloured LEDs (Buechley et al, 2008) and optical fibres (Harlin et al, 2003).

Colour changing textiles can also act as displays. Output device can also be in the form of vibration next to the skin which can be done by using very small electric motors (Toney et al, 2005) in the fabric. This type of textile can be used as emotions generators, jackets for gaming and therapy applications (Lemmens et al, 2009).

Transistors are also used as output devices. Research is in full swing to make a unified functional transistor and fabric at fibre level (Cakmakci et al, 2001, Bonderover and Wagner, 2004, Lee and Subramanian, 2005, Hamedi et al, 2007, Cherenack and Liesbeth, 2010). Transistors will control the flow of information within the textile material.

Another major problem with product development and commercialization of smart textiles is imbalanced contribution of electronics and clothing industry (Ariyatum and Holland, 2003). Product development is very costly and even after successful product development the average consumer are not able to afford it. The product developed through this field should have specific applications such as for health and safety and should be available at cheaper prices. This type of product will have more demands in the future.

Around 830 women die from childbirth related issues or pregnancy each day, as reported by WHO. They also face certain health issues like cramps, backache, headache, nausea fatigue and so on. A number of times, such conceived women live in remote areas and they face problems or feel uncomfortable when they have to frequently visit hospital for prenatal monitoring. Also, the heavy equipment's and lengthy examination process possibly increase stress levels which affects the foetus and health condition of the mother. Hence to make life simple, scientists started developing a wearable health monitoring device which stores information about the health conditions of the mother and the foetus. This stored information is then forwarded to the healthcare professionals which is obtained in the form of a report. It gives an insight of the health conditions of the mother and the foetus. Scientists were successful in developing such device in the form of a wearable jacket along with electronic sensors which can easily monitor health of both, the mother and baby in the womb.

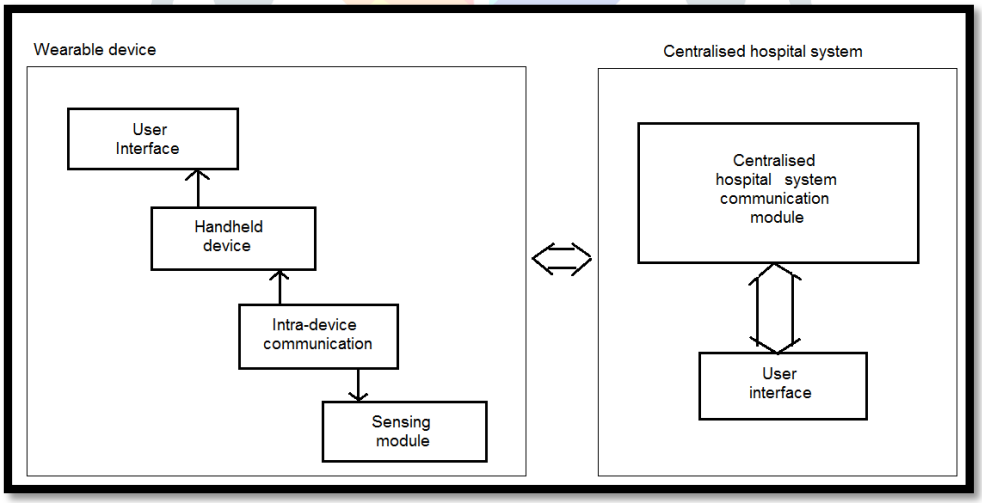

Fig 1. The LIFEBELT Architecture

With the advent of this device, continuous monitoring with reduced stress levels became possible. The major advantage of this technology is that, healthcare professionals from any part of the world is able to analyze any changes in the patient's health and hence can give immediate treatment. This leads to the significant reduction in the hospital's load. The efficiency of hospitals can be largely increased, thus providing improved quality of service.

LIFEBELT plays a vital role as a supportive device for obstetricians who enable them to monitor patients from anywhere and obtain data about their preliminary conditions.

Another important goal which is achieved by LIFEBELT is detection of diseases and abnormalities at a very early stage. These garments incorporated with electronic sensors should be developed in a manner such that it can be wearable in normal environment without any complications.

The following are the characteristics of an ideal textile material for home based healthcare products-

1. Reliability: The most important parameter of smart textile material is its reliability since they will be worn by the patients, safety is of utmost importance.

2. Washability: Garments should be washable. Earlier commercial smart textiles which was developed by Phillips and Levi required to remove the electronic components before washing it but nowadays textile materials have come up with circuits

properly water proofed packed so that there is no need to remove the circuits hence can be washed as it is without any damage to the circuits (Lee, 2005).
3. Durability: Another important parameter is durability of the garment. It should be sufficiently strong. The circuits used should not get damaged, since they will be worn continuously in the external environment, also during fabrication they might undergo extreme conditions. (Cherenack et al, 2012).
4. Comfort: The circuits should be incorporated in the interior of the fabric such that they do not cause uneasiness to the wearer (Khandelka, 2000)

ECG, EMG, heartrate, ANS activity, electro-tomography, vigilance, stress level, and EEG (Electroencephalogram) are studied by electrical parameters like conductance and electrical potential measurement (Axisa et al, 2003). Regular track of health condition and progress of pregnancy is kept by LIFEBELT.
This device has the potential to measure foetal and maternal ECG i.e. fECG and mECG. This is a unique development in the field of medical science.
It has two major applications:
1. Detecting congenital heart disease.
2. Detecting twin to twin transfusion during foetal stage
The second application is a major application since twin to twin transfusion leads to birth defects.
The following are the benefits provided by the LIFEBELT.
• It provides smart personalized health tracking system which safeguards health of both the mother and the baby which leads to a better quality of life.
• Continuous monitoring is possible that results in better safety of foetus as well as mother.
• It is an early diagnostic and decision tool.
• It is a personalized tool for monitoring parameters like abdomen growth, maternal heart rate, oxygen saturation, blood pressure, temperature, oxygen saturation and weight. All of this is done in an organized format and the reports can be obtained at any point of time.
• It enhances the ability of pregnant women to be in her regular routine for personal and professional commitments.
• It provides medical statistical data.

2. RESEARCHES IN ELECTRONIC SENSORS AND CIRCUITS IN HEALTH CARE PRODUCTS

2.1 Light weight harness with sensor-laden straps:
A total of 13 sensors around the belly were used, like acoustic and ECG sensors to monitor heartbeat, motion sensors to track kicks, contractions and other movements. The results are sent back to the user's smartphone, once the information is processed by a cloud server, reassuring them that the foetus is still alive and kicking. The device used is called RITMO.
Another medical grade version of this device is PregSense. This device has more number of sensors for better accuracy. Another research by Purdue University researchers is trying to develop a similar wearable technology which will be connected to the smart phone at a very low cost. This device will be able to infer at a very early stage whether they are susceptible to conditions which could lead to serious health complications for them or their unborn child.
The advantages are as follows: -
1) Pregnant women will have peace of mind.
2) Not a heavy clothing to bother the body's comfort.
3) Help doctors to track clinical information of patients having high risk remotely.
4) New insights about pregnancy might be revealed.
5) Will be able to monitor about how certain activities like meditation, music etc. affect the heartrate of mother and baby.
6) It will intimate women if she is under too much stress or have to change her sleeping or eating patterns in order to avoid complications.
This device needs to undergo rigorous and accurate clinical testing before putting it in actual use since it is possible that it will gives false reassurance or unnecessary anxiety if not properly calibrated.
2.2 Knitting Technology:
Development in fabrication technologies and special materials had led to development of products that have application in medical field. Knitting technology brings about the creation of garments with seamlessly integrated sensors and actuators. Garments produced using this type of technology offers hefty savings since there is significant reduction in material waste as well as manufacturing cost.
2.3 The Bellyband fabric antenna sensor:
Using Shima Seiki industrial knitting machines, Yarn having silver coating is knitted into an antenna pattern. Stretching of the knitted fabric causes change in shape, size and tension in the fabric. These changes are observed that leads to change in the properties of the antenna which is called as Centre frequency. These changes are wirelessly detected using passive UHF RFID. This leads to the passive nature of UHF RFID, the Bellyband sensor can be used without a continuous power source such as a battery. This is one of the biggest achievement. Contraction monitoring in pregnant women, Infant respiration monitoring are two important function carried out (Ibahimy et al, 2003). The strength of the signals changes as the antenna is stretched. Sensors which are knitted and RFID biosensors enable continuous tracking of bio-feedback.

3. LIFEBELT

The wearable device, LIFEBELT is a health monitoring device that will look after the health of both baby and the mother by contributing to disease prevention and early illness detection.
This device is made up of two components:
1. Sensing Module

2. Handheld Device

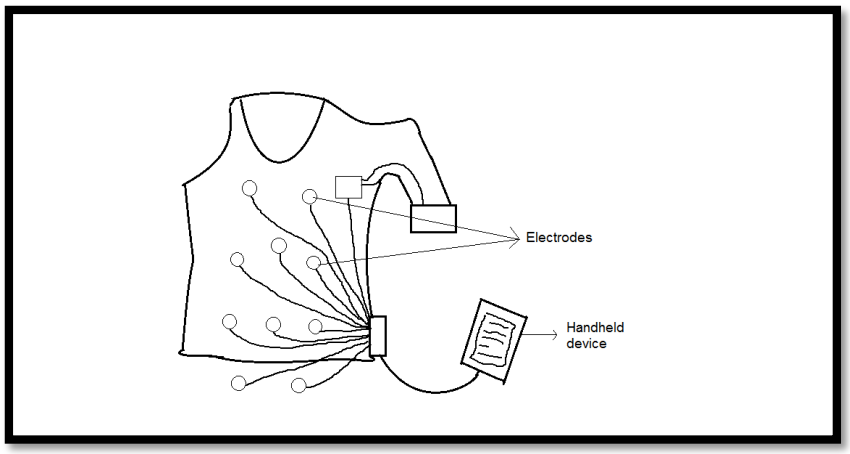

Fig 2. Smart Textile [54].

The sensing device is a multisensory jacket which records signal. It uses two electric boards which acquires the abdominal fECG (fetal ECG) and mECG (maternal ECG), the maternal saturation oxygen saturation (SpO_2), Blood Pressure and Temperature in digital form. The sensors chosen are light weight, accurate and easy assessable. The ECG electrodes are simple to apply, disposable and pre-gelled. CHEOPE which stands for Chip for Health monitoring of Pregnancy. This is an ASIC chip used in the main board which acquires signal from all the sensors digitizes it and transmits to handheld device. Data processing is done using a 16-bit micro-controller. The handheld device is the Tablet PC which carries out the implementation of fECG extraction and signal pre-processing. It carries out preliminary diagnosis, checks the monitoring schedules and starts the monitoring process by considering all the needful data in the handheld device. It is also an interface for communication with the centralized system. The handheld device is integrated with a storage unit, user interface, a signal pre-processing and the communication module. All the acquired signals are recorded and checked by the pre-processing unit. With the help of this we can authenticate that the recorded vital signals are not interrupted or tampered and necessary transformations like preliminary filtering, signal enhancement, A/D conversion are made. The handheld device temporarily stores the processed signals. The pre-programmed user interface is customized for each specific user. According to a personalized schedule, the pregnant woman can start the monitoring procedure. If the signals are not up to the desired level the device is capable of alerting the signal levels. After monitoring, all the collected medical data/reports are sent through a GSM/UMTS cellular infrastructure with the help of communication module to the centralized hospital system. Combined diagnosis about pregnancy status is provided by the centralized system.

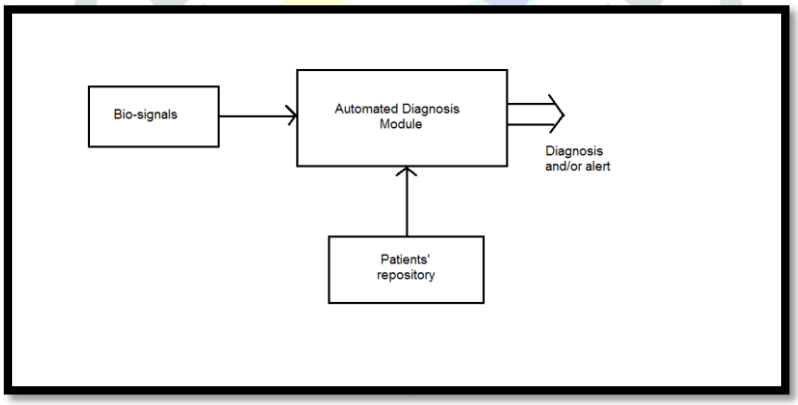

Fig 3: The Automated Diagnosis Module

The algorithms obtained are utilised to generate statistical data. In case of potential problems, alerts are generated. A comfortable vest or jacket that's easily wearable is collocated with all the electronic parts and the sensors. The preferred fabric for the garment is cotton, in order to avoid any kind of allergic reaction. **Figure 2** illustrates that the garment has only one sleeve to which a cuff for measuring pressure is attached, a temperature gauge for temperature measurement is also connected. There are two pockets on the vest to accommodate the auxiliary board and the main board. Apart from signal processing and diagnosis, the specific functions provided by the LIFEBELT are as follows,

1) Noise cancellation
2) Myocardial Ischemia diagnosis
3) ECG extraction of baby and mother
4) Arrhythmia Detection
5) Data fusion and overall diagnosis

3.1 Maternal and foetal ECG extraction:

The primary function of the system is to extract maternal as well as foetal ECG using eight leads of recordings. Maternal ECG (mECG) with very less contribution of foetal ECG (fECG) is provided by the thoracic signals. The composite signal is recorded and the extraction of the two ECGs is done on the basis of processing of all the recorded signals. It is analysed to its main components by both thoracic and abdominal recordings. After analysis, key features like accelerations, short term variability, decelerations are extracted. Dysfunctions and foetal abnormalities can be detected causing these signals. Blind source separation (BSS) is a source separation method used to obtain unobserved signals.

3.2 Noise:
Noise is unavoidable in ECG recording. Noise such as power line interference (A/C), baseline wandering (BW), the electromyography contamination (EMG) makes detection a difficult task. A technique has been developed to remove BW and to accurately detect as to where the ECG is mixed with A/C and EMG noise.

3.3 Arrhythmia detection:
Arrhythmia is detected by the LIFEBELT using an efficient method. The variability signals of heart rate which is obtained from ECG must be first constructed for arrhythmia recognition. With set of knowledge rules Arrhythmia beat classification is performed. Finally, the results are obtained which is capable of detection of 6 rhythm types' i.e. ventricular bigeminy, trigeminy, couplet, tachycardia, flutter/fibrillation and 2nd heart block (Mongan et al, 2016).

3.4 Myocardial ischemia diagnosis:
For ischemic episode detection, a four-stage procedure was developed. These four stages are corresponded to noise handling and ECG feature extraction, beat classification, window classification and identification of ischemic episode's duration. To each lead, the four stages are applied separately.

3.5 Data fusion and overall diagnosis:
Data like Electric fatal heart rate, baseline fatal heart rate, changes in baseline fatal heart rate i.e. acceleration and deceleration, maternal blood pressure diagnosis, maternal SpO_2 diagnosis, maternal temperature diagnosis are all recorded, collaborated and sent in textual form to the doctor. This is done with the small handheld device which is integrated with well-designed interactive software. The information produced is of tactical value and is in the form of textual report which includes bleeding notifications, discharge, bruises, nausea, difficulty in breathing, etc. Evaluation of fatal and maternal health is done using this data (Patronet al, 2016).
The main tool utilized by Obstetrician for evaluating the well being of a pregnancy is Doppler ultrasound. This wearable platform cannot replace Doppler but supports accurate monitoring and diagnosis.

4. CONCLUSION

The importance of this Technology is that Healthcare Professionals from any part of the world is able to analyse any changes in the patient's health and hence, can give immediate treatment. This may lead to notable reduction in the hospital's burden (Brown et al, 2014). Efficiencies of hospitals can be enhanced and hence quality of their service can be improved significantly.
LIFEBELT plays a vital role as a supportive device for obstetricians which enables them to monitor patients from anywhere and obtain data about their preliminary conditions. Another important goal which is achieved by LIFEBELT is early detection of diseases. The problems faced by women in frequent hospital visits can be solved without any surgery and can be used in house environment with no complications. This feature makes it unique. This device is predictive and protective which makes it a unique and precise device which can save lives. However, more research should be conducted in this field to get safe and more accurate monitoring system.

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