International Journal of Advanced Information Science and Technology (IJAIST) *ISSN: 2319:2682*
Vol.5, No.1, January 2016 DOI:10.15693/ijaist/2016.v5i1.30-39

COMPREHENSIVE ASSESSMENT OF WEARABLE SMART TEXTILE SENSORS.

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ABSTRACT:

This paper illustrates the comprehensive assessment and performance overview of wearable textile sensors .The manuscript depicts the challenges, state of art, merits and demerits of various wearable textile sensors developed till date. Much advancement has been made in the field of textile sensors. Wearable sensors are steadily becoming an integral part of health, fitness, biomedical, childcare and many other industries. For various applications the wearable sensor are integrated into the garments then comes the demand for the material of the sensor to be thin and flexible enough to withstand any sort of changes with the material. The evolution of wearable textile sensors depended on many factors some of them being materials being used, high performance, and miniaturization, low cost and non-invasive nature. The paper also gives a brief review about the integration technologies which make the wearable sensors easy to wear thus provide comfort with continuous monitoring. With the technology undergoing a sea change, in this field advancements are going on in wireless sensing and body sensing network.

Keywords: ***Wearable's; Sensors; Textile; Smart Sensors; Electrochemical; Gas Sensors.***

I.INTRODUCTION:

The field of wearable sensors in the recent years has been developing steadily with a rapid pace. The integration of nanotechnology and nanoelectronics in the field of textile has in itself brought a boom in the wearable sensor industry[1,2].The concept behind developing wearable sensors was which could monitor the health, comfortable to wear as well as to promote the non-invasive ways which would further ease the process. With the progress the concept made its way into many fields also namely medical [3-5], for the disabled persons [6, 7], distributed sensor networks [8-10], sports and fitness industry. In this paper we would be discussing briefly about different types of wearable sensors, their integration technologies, sensor placement techniques, merits and demerits of various types of sensors, remedies of the disadvantages and future scope. With the amount of research being done in the field till now has resulted in evolution of various kinds of wearable sensors which include electrochemical sensors, gas sensors, sweat sensors, saliva sensors, tear sensors and many more. Prior to the introduction of wearable sensors technology the health industry adopted the traditional invasive ways for health monitoring (though still quite prevalent) for e.g. blood test for a homophobic, anaemic and aged patients can prove to be quite challenging and hence non-invasive ways of analyte monitoring were developed and hence developed the concept of electrochemical sensors which include tear ,saliva, sweat sensors which provides a better continuous assessment of the patient's health[11-13].

There are various substitutes to blood available for analyte monitoring these days like sweat, tears, saliva etc. which show case similar relationships with the analytes present in blood like glucose, electrolytes etc.
There monitoring through the non-invasive ways will be a better option than using the invasive way of monitoring.

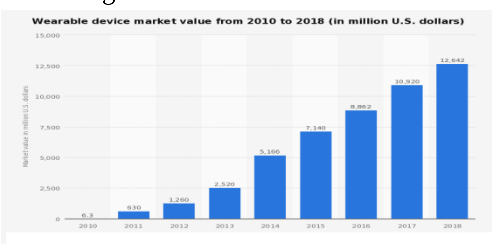

Figure1: Indicates the market share in terms of revenue of the wearable devices including sensors [62].

Now after development of the sensor the main concern should be that it should be comfortable since it is wearable and unnoticeable and hence various integration technologies which make that possible are discussed here. Then comes the need for proper placement of the sensor, indeed it is the most essential part since the signals may vary with the position of the body part and hence proper positioning is deemed necessary [14].

Automatic detection of sensor placement site may be helpful as they provide information where to place the sensor as the irregular placement of the sensor results in faulty readings .Sensor placement is deemed necessary because few sensors are site specific and will give correct readings only when placed at correct sites otherwise which would lead to corrupt readings.

The major advantage of recognising the correct sensing sites is that it will curb the error misplacement rate and will enhance the information content extracted from thus facilitating suitable data extraction.

Need of real time monitoring is increasing though these devices are limited development is going at a rapid pace. Wireless body sensors networks are widely prevalent these days in personal care systems [15].

The real time monitoring of various wearable sensors have indeed given a boost to personalised home care systems and has certainly shifted the treatment methodologies from clinical diagnostics to home based personal management.

This has certainly brought a revolution in the health industry and will certainly lower the health care costs.

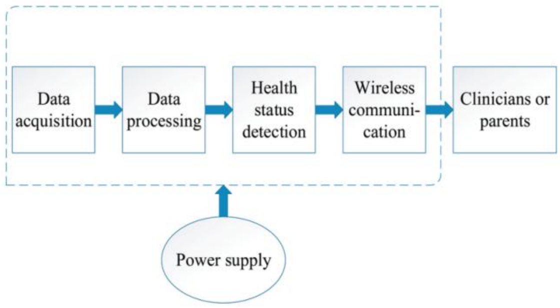

Figure 2: It indicates the basic block diagram of the functioning of the wearable sensors by using health industry as a base[63].

II.RELATED WORK AND DISCUSSIONS:

A. DESIGNING OF WEARABLE SENSORS:

Before starting the discussion let us first deal with the designing part of wearable sensors. As we all know that wearable sensors are a blend of electronics and textile engineering hence this in itself increases the complexity of the sensor system. Hence creating an optimum design of the sensor in itself is a herculean task because it involves integration of the electronics platform (memory, power management, receiver etc.) into the textile platform. Hence creating a wearable device which in itself is comfortable to wear and is disguisable also. The older techniques involved board level and package level integration technologies which have several demerits one of them being the finished product made using these integration technologies is that it becomes uncomfortable to wear due to the bulky nature.

Hence several new technologies were devised in order to tackle the demerits and hence creating comfortable smart wearable smart devices. Technologies to be discussed here are organic and large area electronics (OLAE) and thin film technologies [16].

B. Organic and large area electronics platform for sensors

This mainly targets low end applications and cheap devices. Application on thin flexible plastic foils and materials used are polyesters PET and PEN.

As mentioned earlier deals with low end devices with less complexity and uses screen and inkjet printing as printing techniques[17]. Advancements are still in progress in this field to generate more complex systems through this technique.

C. Thin film electronics platform

This technique is used for more complex high end applications and for more advanced devices .Can be termed as advanced version of OLAE technology.

Thin film electronics platform is realised by combining spin-on polyimide films with thin-film metallization.

To get the final stretchable product from the flexible foils there exists a technology named thin chip integration technology. In order to get the final finished product which is stable and can be deformed in more than one direction optimum designing techniques should be employed starting with flex foil (polyester, polyimide or other plastic foil materials), circuit made through printed circuit board techniques and then using adhesives, soldering used to assemble the components.

The chief aim of the technology is to provide comfortable wearable devices which are reliable as well as resistant to the stress which is distributed accordingly and thus fulfilling the design requirements which in turn can be used to realise any type of sensors.

III.TYPES OF WEARABLE SENSORS:

A. ELECTROCHEMICAL SENSORS:

The need of non-invasive monitoring has further triggered the importance of electrochemical sensors which include saliva, sweat, tear and skin interstitial fluid monitoring. Since all these can be used as substitutes for health monitoring instead of blood since it involves the invasive ways of checking the health status of a person which can be a tedious task in case of elderly, children and people suffering from anaemia and other blood diseases. Hence the sensors are mentioned below:

B. TEAR SENSORS:

Tears are composed of lipids, electrolytes, metabolites .There is a relation between the glucose composition of blood and tears [18] hence can be used as non-invasive monitoring for the diabetes patients and thus aiding in clinical diagnostics.

The initial ocular sensors were based on strip based flexible sensors in them the electrodes were fabricated with the stretchable platforms [19-24].It used low cost printing technology in order to obtain the finished sensor product [25].

Utilisation of strip based sensors was done in monitoring keratoconjunctivitissicca [19], transcutaneous oxygen [20], and glucose [21–25].The more advanced version for ocular sensor developed was soft contact lens with a blend of wireless electronics [26-28].In the initial stages of the work it was hand wired later on integration of wireless electronics happened for data storage and charging purpose, the work was again modified to reduce interference [26, 27]

In the recent developments Novio sense glucose sensors being developed in Netherlands for glucose monitoring with the placement of the sensor being within eyelids [29].Real time monitoring with wireless platform still remains a challenge in the industry.

DISADVANTGES/CHALLENGES OF TEAR SENSORS:

Evaporation of the tear sample may take place before the analysis which may affect the concentration of analytes and thus hampering the final results of the diagnosis. Since eye is one of the most delicate organs of the body utmost care needs to be taken while collecting the sample.

The sensors uses flexible and stretchable materials but still are hard which may cause irritation in eyes which may trigger eye to release reflex tears which may cause recording of false readings thus altering the diagnosis data.

While monitoring the glucose levels in an eye prolonged eye closure, exposure to vapours any sort of mechanical disturbance may cause altering of glucose levels in an eye [30].Real time monitoring using wireless platform still remains a challenge to be addressed at a larger scale.

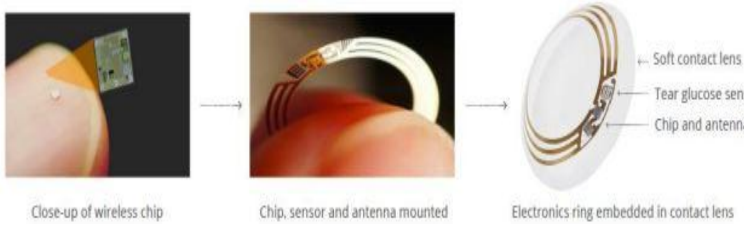

Figure 3: Tear based sensors[64].

C. SWEAT BASED SENSORS:

Sweat is composed of water (99%) and electrolytes, urea, pyruvate and lactate [31, 32].Among the sweat the concentration of sodium (Na+) is highest among all the electrolytes [33].

The PH level of sweat and the concentration of sodium level are inter related, the PH and sodium level are directly proportional to each other.PH amount gives a brief idea about the hydration and dehydration levels of the body which can be utilised to monitor these levels in the body of an athlete.

As the PH level as shown is related to the health of a person and if it changes this promotes various kinds diseases [34].The sweat is a perfect medium which carries information useful for various medical pathologies in general. Sweat is used to monitor electrolyte imbalance[39],physical stress[40],bone mineral loss[41],persons intoxication level[42],drug abuse[43],osteoporosis[44].Real time sweat monitoring while using calorimetric and electrochemical sensors has been a major achievement in the given field [35, 36].

The integration of sensors into textile is feasible; sol gel process is used to form a fully functionalised fabric. Sol gel technology has various organic and inorganic additives related to it. The major advantage of sol gel technology is thermal and mechanical robustness .Sol gel technology is basically used to obtain the PH performance. Major disadvantage being long response time keeping this in mind caldra et.al [37optical monitoring] proposed the use of mesoporous thin film prepared by sol gel chemistry and low temperature block co polymer extraction this can work quite efficiently as a PH sensor and it also improves the response time.

Sweat was also used as a medium to test ethanol using a device based on an amperometric biosensor characterized by a graphite electrode with embedded alcohol oxidase, horseradish peroxidise and ferrocene, in the presence of a working solution (0.05 M, pH7.4), separated by a PTFE membrane from the contacting skin, used to detect and monitor ethanol within 5 mins thus making these sensors multitasking operators [38].

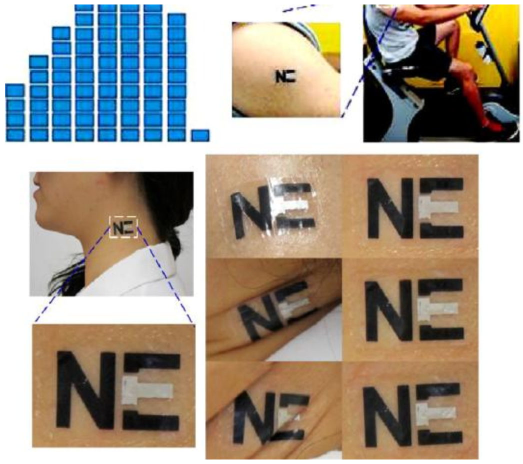

Figure 4: Indicates the stretchable tattoo based sensor[65].

The non-invasive sweat monitoring for monitoring sweat may be of two types:

Fabric/flexible plastic based [45]; Epidermal based sensors [46]

D. FABRIC/FLEXIBLE PLASTIC BASED:

Fabric used to development of sensor due to contact with skin. They provide large surface area and thus integration of electronics in that area. Fabrics such as wool, cotton and nylon etc have physical and chemical properties associated with them and thus facilitate the integration of chemical sensor with it.

The textile should be inert in nature as being inert in nature is advantageous in a situation where there shall be no effect on the chemical behaviour of the analyte. Thus there is need of complete coordination between sensor and textile so as to operate smoothly.

Sensors show response when in direct contact with the skin.Eg being sensor installed on the waistband of the undergarments which monitors the sweat [47] another example being PH sensor on bandage for keeping a check on the wound [48].Main advantage of printed textile sensor is that they are bendable and stretchable platforms thus providing themselves flexibility of placements.

When contact with electrode surface and bio fluid takes place confirms smooth functioning of wearable sensors, since skin contact is quite limited hence this is quite challenging for the fabric based system and may be termed as one of the demerits of these systems.

This triggers the need of epidermal electrochemical sensors.

E. EPIDERMAL BASED SENSORS:

Analyte monitoring over the skin by using epidermal electrochemical sensors. Electrodes printed directly on human epidermis [49].Process involves wetting of customized stamps with conductive ink then comes printing of electrode design on the skin. This was further resolved by using tattoo based electrochemical sensors [50].Tattoo based sensors are resistant to such deformation by using carbon fibres. Electrical energy harnessed from human sweat known has epidermal bio fuel cell [51].

Sweat based sensors measuring PH has certain advantages:

Has high signal to noise ratio, longer life time, they are reversible, fast response, durable, cheap, comparatively safer than ocular based sensors.

Some of the disadvantages mainly are as follows:

They have a poor selectivity and long term instability. As the physical activity of the person increases there is a deformation in the sensor.

Figure 5: Sensor present at the strip of the underwear used for sweat monitoring[65].

F. SALIVA BASED SENSORS:

Saliva is another substitute and the most effective non-invasive monitoring technique available .Saliva also has few of its components same as that of the blood according to the research it has successfully been used to monitor several neurological parameters [52].Major advantages of saliva is its easy availability, relation of its analyte concentration with blood, certain initial treatment procedures before using it for diagnosis are less.

The developments that has been accomplished in the field of saliva based sensors are

Because of its vicinity with the teeth it is widely used to monitor fluoride levels in a teeth [53].Disadvantage of the above technique is it's difficult to provide each tooth with sensor. In future need for real time monitoring with the integration of wireless electronics in this field is also the need of the hour.

Recent development of the dental tattoo with wireless electronics integrated used to monitor bacteria in the mouth was a real success [54]

Involvement of wireless electronics with the sensors generate many advantages few of them being they have less response time which makes the functioning faster, they are highly specific about the test, they can detect a single molecule also if needed.

The monitoring of PH level and glucose level to test the diabetes by using saliva as a medium is still very popular.PH level is also used for GERD testing which otherwise is tested by using invasive oesophagus surgery[55].

Saliva is also used for testosterone monitoring, the process is carried out is as follows the saliva is first treated with charcoal then by using the process of centrifugal the charcoal was removed this was done because the analyte corresponding to it was in lesser concentration in saliva so in order to be specific this was done. This later facilitates in the real time monitoring of the system and the results were displayed within 10 minutes of monitoring the whole system [56].

G. TEXTILE GAS SENSORS:

The textile gas sensors are a somewhat refined version of old wearable sensor concepts. Pressure and temperature sensors are quite feasible to operate as compared to gas sensors.

Disadvantage of gas sensors being they possess complex structure, the exposure to environmental conditions of the gas sensitive elements in a sensor is the major drawback of the sensor. Since if used as a air filter then exposure to external environmental conditions may lead to malfunctioning of the air filter which may prove to be fatal.

Thus the above reasons pose a difficulty in realising gas sensors which have their utility in disposable air filters and other clinical diagnosis garments i.e., basically utility in health sector itself[57].

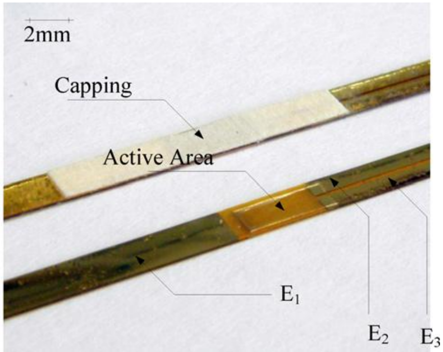

Figure 6: Shows gas sensors with and without capping layer [66].

Recent developments in the gas sensor have been:

General long strip like designed sensor has an acrylic co polymer layer which aids and shields against the environmental conditions which has been the main cause of concern while designing gas sensor. Gas sensing is done by planar capacitor and resistor. Other less bulky light weight sensors using plastic foils as a platform were also reported [58, 59].

Fabrication process is simple and is quite cheap.

Necessary requirements for the smooth functioning of the sensor are: at first the active area of the sensor should be isolated from the external environmental conditions so that it could be saved from the malfunctioning.

Another important factor being that repeated bending test should be done so as to test the mechanical robustness it's so that future performance of the sensor can be judged accordingly.

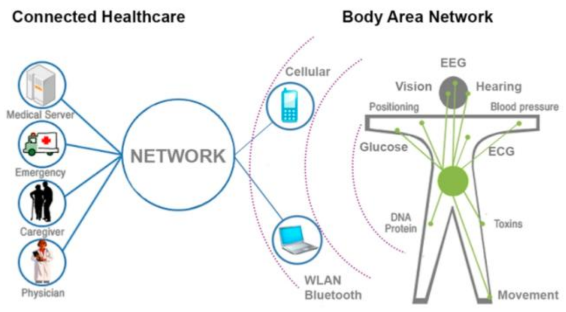

Figure 7: Shows the interconnection between body and various wearable platforms [67].

IV.CONCLUSION AND FUTURE TRENDS:

The field of nanotechnology has developed with a rapid pace hence increasing its applications in various fields. Wearable sensors are one such kind which involves blend of physics, chemistry, electrical and textile engineering with a special integration of nanotechnology and material sciences. Wearable sensors have now established their utility in many fields and will continue to grow with the amount of research opportunities growing in this field. More widely accepted in the field of healthcare is expanding its area of application with time. Wearable sensors with large area are generally easy to realise whereas when miniaturization takes places and the area of interest shrinks then several variations are needed to be made in order to develop a sensor which is best suited with the appropriate changes in area. With the development of wearable sensors it also encounters several challenges as the work progresses. First problem is faced while printing as the dimension of the printed work is quite larger than the actual dimension [60] which then causes the problem of irregular shape. At first the wearable sensors were aimed at only producing disposable sensors but as the time progressed washable wearable sensors have slowly started dominating the markets because of their advantage of reusability but with the advantages they also address few challenges the biggest of them being maintaining that same strength, flexibility even after washing and the internal functioning and circuitry is saved from all types of external agents which may hamper the productivity and performance of the sensors. Now while discussing about the external agents we can install temperature sensors in the sensors as the environmental changes also affects the performance of the sensors. Since electronic circuitry is also involved complete encapsulation of the sensor is required of that area against any sort of aqueous solution so as to prevent malfunctioning. As the wearable sensors finds their application in health care industry the nanomaterials used while designing of the sensors should be checked of their toxicity levels which in case if not happens then prove to be fatal though it is a non-invasive method but still even direct contact with the skin of the toxic materials may be harmful. But they prove to be a merit over the invasive techniques as they may cause infections. Now after ensuring the safety of the user the sensors safety is also necessary proper covering should be there in order to save it from any sort of virus, fungal and bacterial attack which ensures correct data reception without any fail. Bending test should be conducted of every sensor so that durability of the sensor can be known. Ideal characteristics of an wearable sensor is that: low cost, low power consumption, mechanically robust,can perform complex tasks, minimizing size &maximizing comfort ,highly efficient, showcases long term stability,biocompatibility,user independent sensor,selectivity,durable,supports wireless platform. These are the characteristics desired in a wearable sensor. In recent years a lot has been to done to achieve these characteristics by various methods and techniques. In order to develop sensor in this field there has to be some sort of coordination between the research universities and the manufacturing companies so as to promote the idea and finally realise it because these two factors go hand in hand. Real time monitoring system development has certainly become the need of the hour where several devices are solely focused to monitor the actual situation in which the person is gives accurate results within a small response time. This brought the health diagnosis to your door step. A lot of work still needs to be in integrating wireless platform as it not only decreases the response time but also makes the sensor more efficient but with this the wearable sensor becomes more complex because of integration of wireless modules. Challenges go hand in hand with the new inventions thus a lot needs to be done in this field. Also this is quite popular with the health industry for diagnosis and medical checkups whereas shifting the focus and using it in sports and different other fields would be an added advantage to it.

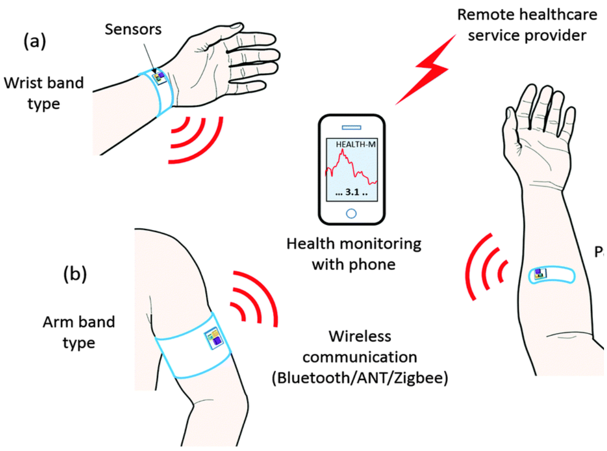

Figure 8: Real time monitoring through wireless platform [68].

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Figure 9: Apple watch a revolution in the wearable electronics market[69].

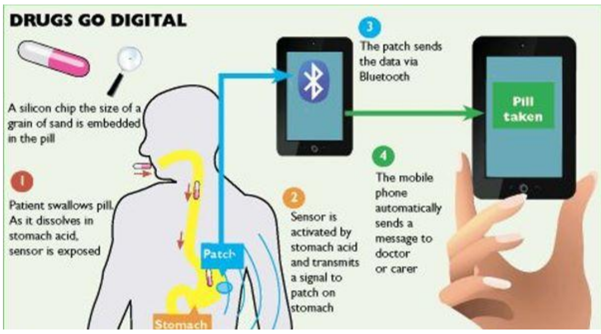

Figure 10: Future scope of the wearable sensors monitoring the operations inside the body [70].

ACKNOWLEDGEMENT:

We have taken efforts in this research work. However, it would not have been possible without the kind support and help of many individuals and organizations. We would like to extend our sincere thanks to all of them.

We would like to express our gratitude towards Hon. Chancellor SVKMs NMIMS; Management; Higher Authorities and Faculty Members for their kind co-operation and encouragement which helped us a lot. We would like to express our sincere thanks to industry persons and fellow colleagues for their kind attention and time.

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