CHAPTER 10

SUMMARY AND CONCLUSION

10.1 SUMMARY

Wearable Electronics are an emerging transdisciplinary field, bringing together concepts and expertise from a variety of disciplines, ranging from materials science, through computer engineering to textile design. This research work addresses an emerging new field of research that combines the strengths and capabilities of electronics and textiles in one: electronic textiles, or wearable electronics. In this thesis different types of yarn and fabric production techniques, miniaturized wearable electronic circuits has been integrated into the fabric to develop wearable electronic products, software for integration of wearable electronic products to the remote station, development of garment to power the wearable electronics products and development of fabric integrated wearable electronics products were discussed. In this research work, the following fabric has been developed for wearable electronic products.


- Copper core conductive yarn and Optical core conductive yarn were developed for the production of Communication Garment.
• Polymeric Optical Fiber (POF) integrated illuminated fabric has been developed for Illuminated Garment.

• POF integrated teleintimation fabric has been developed for Teleintimation Garment.

• Cotton fabric has been embedded with flexible solar cells for the development of Flexible Solar Tent.

• Graphical User Interface Software has been developed for communication between the wearable electronic products and the remote station.

• Garment integrated wearable electronic products like solar Jacket, E-Jerkin and Heating Gloves has been developed for commercial and military applications.

10.2 CONCLUSION

(i) Cotton wrapped nichrome yarn was produced using braiding machine to develop nichrome wire embedded cotton fabric in knitted fabric for heating garment. Two patterns were made for developing heating garment, out of this sleeve round neck shape T-shirt pattern is taking high resistance when compared to sleeveless round neck shape T-shirt pattern, because length of the nichrome yarn used in sleeve pattern is higher. Therefore the power consumption is higher in sleeve pattern when compared to sleeveless pattern. The comfort test of the fabric has been carried out and the insulation (clo) values were in the range of 0.625 to 1.064, which is ideally suitable for extreme cold regions. From the tests, sleeveless round neck shape T-shirt pattern has been selected for the development of
heating garment. The heat generating circuit has been developed for heating garment using LM35 temperature sensor and PIC 12F675 microcontroller to control the temperature. This heat generating circuit has been integrated with the nichrome fabric to develop heating garment. The performance of the heating garment have been analysed by conducting tests at different ambient temperature. The test results shows that the heating garment responds to the room temperature and the wearer temperature instantly and heat up the Nichrome fabric with time delay of less than 3 s.

(ii) The conductive yarn that contained copper wire as core was fabricated by using special guide mechanism on DREF-3 spinning system. A comparison of three different core-sheath ratios of DREF-3 conductive yarns such as 67/33, 80/20 and 90/10 were produced. The physical characteristics of the conductive yarn were studied using different tests and found that the 67/33 core/sheath conductive yarn was having the highest tenacity of 3.27cN/tex and elongation to break 5.27% when compare to other core-sheath ratios, due to its better core-sheath interaction factor $\text{CSI}_{T}$ -21.22%. It is also observed that the core-sheath interaction factor of 90/10 core-sheath ratio conductive yarn was found less core-sheath interaction factor $\text{CSI}_{T}$ - 9.21% and it exhibits lower breaking tenacity and elongation to break, due to its behavior of copper filament. The electrical properties of these conductive core spun yarns were exhibited very low resistance (3-28 M$\Omega$) at 6 V, 12 V and 24 V applied voltage.

The performance of the communication garment integrated with temperature measurement circuit has been tested by
measuring the body temperature of the wearer in open-air at
day time and the test results are compared with the standard
clinical thermometer. The test results shows that the value of
the body temperature measured through copper core
conductive fabric is similar to that of the temperature
measurement through standard clinical thermometer. The
performance of the copper core conductive fabric also
analysed using integrating the fabric with mobile phone
charging circuit for charging the Nokia mobile phone. The
result shows that the copper core conductive fabric is charging
the mobile phone, almost at the same time as that of the time
taken by the conventional mobile phone charging circuit.

The optical core conductive yarn has been developed using
DREF-3 spinning system using two different POF yarns
namely ESKA and CK-20 of 0.5 mm and 1 mm respectively.
The aerial density of the ESKA type optical core conductive
fabrics are 52% heavier than the CK-20 type optical core
conductive fabrics due to its higher linear density (1028 Tex)
and diameter as 1000 µm for the wearable electronic garments
CK-20 type optical core conductive fabrics are more suitable
and it has higher air permeability due to the finer optical fiber
(500 µm) and lesser fabric thickness (0.74 +/- 0.13 mm) when
compare to the thickness of ESKA type optical core
conductive fabrics (1.24 +/- 0.20 mm). It was found that the
signal loss in terms of light intensity was higher due to the
stress to the optical fibre during spinning and fabrication
processes. The communication garment developed using
optical core conductive fabric is used for signal transmission
as well as to locate the number and the place of the bullet
wound. From the test results, the optical core conductive fabric shows the maximum output voltage resulting minimum signal loss.

(iii) The illuminated fabric has been developed with two different types of weave namely twill and sateen weave using hand loom with 0.5 mm PMMA POF. The pointed twill illuminated fabric sample shows very low illumination effect because of the more weft bending angle due to higher warp and weft interlacement. The sateen weave shows better illumination when compared to twill fabric, the structure of sateen weave has more weft float. Since the weft bending angle is less that causes more illumination when compared to twill fabric. The colour red LED has the minimum Lux value which is due to the maximum wavelength of red colour. The fabric produced using Poly Methyl Metha Acrylate (PMMA) is used to develop Illuminated Garment of POLICE design and duck design. The subjective evaluation is carried out for the end user; the specific attributes are selected and given the rating scale. The user should wear the garment and rate the attribute; these values are consolidated for the final scale rating.

(iv) The teleintimation fabric has been developed using POF of 0.25 mm, 0.5 mm and 1 mm diameters. The fabric was developed by sequential method, hand loom and power loom. Teleintimation fabric developed using handloom was considered to be suitable for commercial applications, though it is also possible to develop using power loom, major modifications has to be carried out and it is not possible to integrated the POF yarn using sequential method since the
POF yarn come out very quickly when the POF integrated fabric was made into garment.

The physical characteristics of the teleintimation fabric have been tested to assess its properties. It is noticed that the tensile strength is more in the warp way than in the weft way in both handloom and power loom POF integrated fabric. Bending rigidity measured with KES-FB2 Bending Tester, it was observed that the bending tolerance for the POF located in the warp way and weft way is 7.3 cm and 5.2 cm respectively. Air permeability was tested with KES F8 AP1, the air permeability of handloom Fabric is 44 kPa/ Sq.cm and power loom fabric is 18 kPa/ Sq.cm. The tensile test, done on the KES-FB1 Tensile-Shear Tester, it is noticed that the tensile strength is more in the warp way than in the weft way in both the POF integrated fabric. The signal transferring efficiency of the handloom, power loom and sequential integrated woven POF fabrics are analysed. From the signal transferring analysis, the signal loss percentages for power loom, handloom and sequential integrated POF fabrics are 37.44%, 22.40% and 39.84% respectively. It is noticed that the signal transferring loss percentage of handloom fabrics is less when compared to other fabrics.

The bullet wound intimation circuit was designed and developed to indicate the number and place of bullet wounds in the teleintimation fabric. For this purpose, bullet wound intimation circuits was developed using different controllers like AT89C51, AT89C52, AT89S52, PIC 18F877A and PIC 18F4550 for different POF matrix arrangements. The processed signals from the controller has been send to the
remote station using RF and GSM technology for monitoring
the status of the soldier. From the test results it was concluded
that, the number of POF lines required for the efficient
number of bullet counts and bullet wound location is 80 POF
lines with 0.5 cm distance each in vertical section and 80 POF
lines with 0.5 cm in the horizontal section. The performance
of the teleintimation garment has been tested using standard
test rig developed for assessing the signal loss percentage. The
performance analysis of teleintimation garment circuits has
been assessed using USB-1208FS DAQ card.

(v) The smart shirt has been developed for medical monitoring,
athletics and military uses. The body temperature, pulse rate
measurement and respiratory rate measurement circuits have
been developed for smart shirt. Three different temperatures
measurements are taken at different conditions and the test
results are compared with the standard clinical thermometer
and it shows that the developed circuit results are almost same
with that of the standard measuring instrument. The test
results obtained from the pulse rate module and these results
were compared with the standard clinical pulse oximeter of
StarPlus LT make and it shows that the developed circuit is
almost giving the same values as that of the standard testing
instrument. The test results acquired from the respiration rate
module and these results were compared with the standard
clinical respiration rate measurement device of StarPlus LT
make and the developed circuit results were almost same with
that of the conventional measuring device. The measured vital
signs are transmitted to the remote system using
telemonitoring system consisting of PIC16F877A
microcontroller is used for processing the signals received from the measurement circuits. Mobile phone with GPRS enabled like Nokia 6070 can be used as a modem to send data to the remote station.

(vi) The software have been developed at the user end to monitor the wearer are conversed also the various communication methods used to interface the wearable electronic products to the remote end were discussed. Whenever a soldier got bullet wounded, the vital signs from the smart shirt has been transmitted to the Soldier’s Status Monitoring (SSM) software through the telemonitoring system by means of GSM technology.

The various communication methods were tested to send the vital signals to the remote end server. The RF transmission technique is limited to short distance communication, whereas, the mobile communication technique uses long distance signal transmission irrespective of the distance. From the tests it was found that the mobile communication technique provides the optimum way of signal transmission.

(vii) The bullet wound in the teleintimation garment, the corresponding location is highlighted in the software developed by using Visual Basic and LabVIEW. The data receiving methods are programmed using VB 6.0 and LabVIEW, in such a way that the row and column information were received in a sequential manner. A low cost tracking system using GPS/ GPRS of a GSM network, suitable for wide range of applications like soldier tracking in defence
fields has been developed. The combination of the GPS and GPRS provides continuous and real time tracking.

(viii) Flexible solar cells integrated cloth has been developed for solar tent applications. The solar tent is equipped with PT 15-300 flexible solar cells which can be utilized for the power generation. It was developed with the help of fusing and stitching method and also it can be used for make shift office in the defence field to power the wearable electronic products. With the help of this tent a load up to 1 kW can be powered and in future this load can be increased depending upon the requirements.

(ix) In this research work Solar Jacket has been developed by integrating garment and the solar panel and it is tested for functionality by using the conventional method of testing the Solar panels. The technology would then be beneficial to those living in remote areas, where there is no supply of electricity from the grid, fuel may be scarce and expensive, and maintenance of equipment is uncertain. Moreover, it could be used to get power quickly to disaster areas, hit by earthquakes, hurricanes, floods or fire.

(x) Electronic Jerkin has been developed by integrating Fleeced Polypropylene Fabric integrated with Bluetooth and MP3 system. This microelectronics could improve our everyday life and offer a new way of interacting with microchips.

(xi) Heating gloves is the development of the intelligent heating solutions integrated with the gloves. The temperature control system has been programmed to automatically measure the body temperature and the outside temperature. And based on
the preset temperature value the heating system has been operated.

(xii) The pneumatic glove was designed successfully with textile material and pneumatic regulators. The pneumatic glove has been used for stroke affected and physically challenged personnel to perform rehabilitation exercises with the pneumatic clothing in homes or workplaces without the assistance of physicians.

(xiii) The developed product has been conducted with physicians of various discipline and patients with associated problems for validation. The evaluated result shows the advantage, functionality and the need of the product.

In this research work, cotton wrapped nichrome yarn, copper core conductive yarn, optical core conductive yarn POF of different diameters were used to produce, nichrome fabric, copper core conductive fabric, optical core conductive fabric, illuminated fabric, teleintimation fabric. By integrating miniaturized low power electronic circuits in the fabrics, heating garment, communication garment, illuminated garment, teleintimation garment were developed and performance were assessed by conducting suitable field trials. In phase II of the research fabric integrated wearable electronic products, solar tent, solar jacket, electronic jerkin, smart shirt, pneumatic gloves and heating gloves were developed and various tests were conducted to analyse the performance.

Microprocessors and controllers of different technologies were used in this research work to accomplish the task of
integrating textile and electronics. The usual method of measuring the vital parameters of the human beings and the physical status monitoring was devised using miniaturized and flexible circuits which can consume low power. These garments are developed with integrated circuits and operating at very low voltages. The fabrics and the garments produced were tested using a dedicated test rig developed for this research work and the test results were compared with that of the conventional method of measuring the biological and vital parameters. Dedicated software has been developed to communicate these garments at the remote end and testing of these software has been conducted. This research work provides the wearable electronics development needs to progress on the issue of user acceptability.

10.3 SCOPE OF THE RESEARCH WORK

Today, the interaction of individual humans with electronic devices demands specific user skills. In future, improved user interfaces can largely alleviate this problem and push the exploitation of microelectronics considerably. Possible applications include medical (infant or patient) monitoring, personal information processing systems, or remote monitoring of deployed personnel in military or space applications. Today the cost level of important microelectronic functions is low enough and enabling key technologies are mature enough to exploit this vision to the benefit of society.

Wearable Electronics market yet to see significant exploitation of this technology in terms of the emergence of mass market commercial products. The essential stimulus for much of the basic research in this field has been and remains military, but market drivers are beginning to emerge in potential applications such as healthcare, high performance sportswear and
high value-add leisurewear. One of the perennial criticisms of work in the field of wearable technology is that nobody seems to be wearing it! This is despite stunning advances in the underlying technology. This research work provides the wearable electronics development needs to progress on the issue of user acceptability. Producing two versions of the survey, one for potential consumers and another for developers, would enable us to compare what the consumer wants to what the designers think they want.