Development of Knitted Temperature Sensor (KTS)

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ABSTRACT

This report discusses the development of a biomedical sensor that can be knitted into outer and next-to-skin garments for the measurement of human body temperatures. The overall objective is to produce an easy to care garment capable of providing round the clock ambulatory monitoring of a patient in all circumstances. Although the ambulatory monitoring of a patient would require a range of different sensors, however the focus of the proposed research is to develop a knitted temperature sensor (KTS). The KTS would be developed by laying-in a fine metal wire (as sensing element) into the knitted structure. Operating principle of KTS is based on the inherent propensity of metal to exhibit change in electrical resistance as a result of a change in its temperature.

1.1 INTRODUCTION

Human body temperature is one of the four vital signs which are standard in medical settings in addition to heart rate, blood pressure and respiratory rate. It is an important indicator of human body physical condition and related with comfort, performance, and heat or cold stresses.

Some critical patients require to be monitored their vital signs continuously e.g. real time body temperature data could be used to detect any thermal abnormalities related to pathologic conditions. In order to enhance the mobility of such patients, an enormous effort is being pursued worldwide since last decade for the development of wearable health monitoring systems (WHMS).

The detailed literature review demonstrated that most of the research has been carried out in the development of textile based ECG and respiration sensors. While for temperature sensing, majority of research work relied on temperature sensor (mainly thermistors and ICs) as external attachment to the garment of WHMS [1-11]. Moreover, not enough experimental and modeling data is available regarding performance of temperature sensor for measurement of skin and core body temperatures in steady state as well as in dynamic environment. Relevant research work in context of WHMS is listed in Table 1 along with their status of temperature sensing.

One genuine effort towards the development of totally integrated textile based temperature sensor was carried out by Locher, et al., in 2005 at ETH, Zurich [12]. They developed a woven temperature sensor by integrating, insulated copper wires into warp and weft along with polyester yarn, and devising a special routine technique for making interconnection points. However in the accuracy analyses, errors associated with the effect of environmental parameters e.g. strain or moisture were not considered. Further the sensors were only tested in steady state conditions at some specific temperature points in laboratory. Finally developing interconnecting points in sensor patch is manual and cumbersome process which is itself a source of error towards the sensing characteristics.

The aim of the research is to develop a textile based knitted temperature sensor (KTS), which can be integrated with a garment, to measure body temperature. However the scope of proposed research may be increased to other fields where wearability is prime requirement e.g. sports, military, firefighting etc.

1.2 KTS Construction

A detailed literature review has demonstrated that the measurement principle of RTD (Resistance Temperature Detector) can be applied in the development of the Textile based Knitted Temperature Sensor (KTS). The KTS was constructed by integrating a defined length of a fine metal wire (as sensing element) within the courses of a knitted structure as shown in Figure 1. The metal wire was packed within the courses as densely as possible. Extreme care was exercised to prevent the surface of individual strands of wire from touching, and to achieve the maximum ratio of “wire length to sensor area”.

Table 1: Status of temperature sensing in context of Wearable Health Monitoring Systems (WHMS)

Project	Product description	Application	Sensors	Temperature Sensor
WEALTHY	Knitted smart shirt	Remote health monitoring	Vital signs	I²C sensor chips as optional attachment to the shirt [1, 2]
ProeTEX	Jacket Vest Rescuer patch	Fire fighter Rescuers First responders	Vital signs GPS Activity Heat flow	A monolithic temperature sensor (LM92) for measuring the core temperature and thermocouple for measuring the environment temperature [3]
Intelligent Vest by SmartLife	Knitted smart vest	Healthcare, Sports Hazardous environment Military	Vital signs	Thermistor (as an attachment) [4, 5]
Smart Shirt by Sensatex	Woven or knitted smart shirt.	Remote health monitoring	Vital signs	Thermistor or IC (as an attachment) [6]
Mu-Huo, C., et al.	Knitted smart vest	Remote healthcare and wellness	Vital signs Sweatiness Activity	Thermistor (as an attachment) [7]
MERMOTH	Knitted smart shirt	Remote health monitoring	Vital signs Activity	Thermistor (as an attachment) [8]
VTAMN	Smart shirt	Remote health monitoring	Vital signs	I²C interface based sensors for human body and environment temperature [9]
LifeShirt by Vivometrics	Shirt with sensors as an external attachments	Sleep diagnosis First responders Biohazards Research	Vital signs GPS	By using optional serial expansion module, any temperature sensor may be attached [10]
Pandian, P.S., et al.	Woven smart vest.	Remote health monitoring	Vital signs GPS, PPG	Thermistor (as an attachment) [11]

The measurement principle of KTS is based on the inherent propensity of metal wire, which changes its electrical resistance with change in temperature. Relationship between the resistance of sensing element (RT) at corresponding temperature, including KTS and wire dimensions is modeled as:

$$R_T = \frac{[(L_s \times W_S \times D_C) + L_S]\rho}{a}(1+\alpha\Delta T)$$

Where, resistivity (ρ) and temperature resistance co-efficient (α) are the metal properties and are constant for certain range of temperature (ΔT). While length (l) and cross-section area (a) are the wire properties. (L_s) and (W_s) define the length and width of KTS respectively while density of laying-in is represented by (D_C).

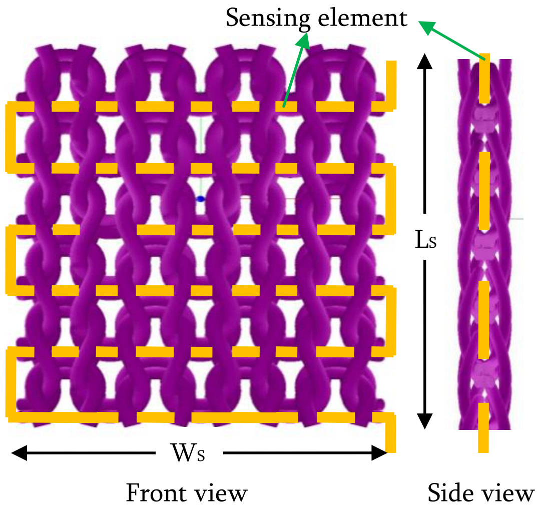

Figure 1: KTS fabric showing in-laid sensing wire in a rib knitted structure

1.3 Sensing Element

Various metal wires may be used as a sensing element of KTS. The sensing element was selected on the bases of important properties, of which are graphed relatively in Figure 2. The desirable properties of sensing element are:

- High temperature resistance coefficient & high resistivity (for high sensitivity);
- High resistivity (for high nominal resistance);
- Low thermal mass (for less response time);
- High thermal conductivity (to minimize the self heating)

Platinum is regarded as the best sensing element for RTDs due to its high resistivity, low thermal mass, and stability over wide range of temperature sensing however it is quite expensive.

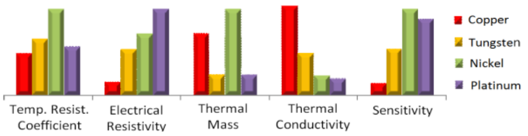

Figure 2: Important properties of KTS sensing elements

1.4 Temperature-Resistance Testing

In order to provide the uniform thermal environment to KTS fabric and to measure the temperature along with its corresponding resistance, a test rig has been designed. As it is shown in Figure 3, the KTS fabric is sandwiched in between two copper plates while bottom copper plate is placed on surface of Fischer Scientific hotplate. Heat energy transfers via conduction from the hotplate to environment by passing through the bottom copper plate, KTS fabric and top copper plate, respectively.

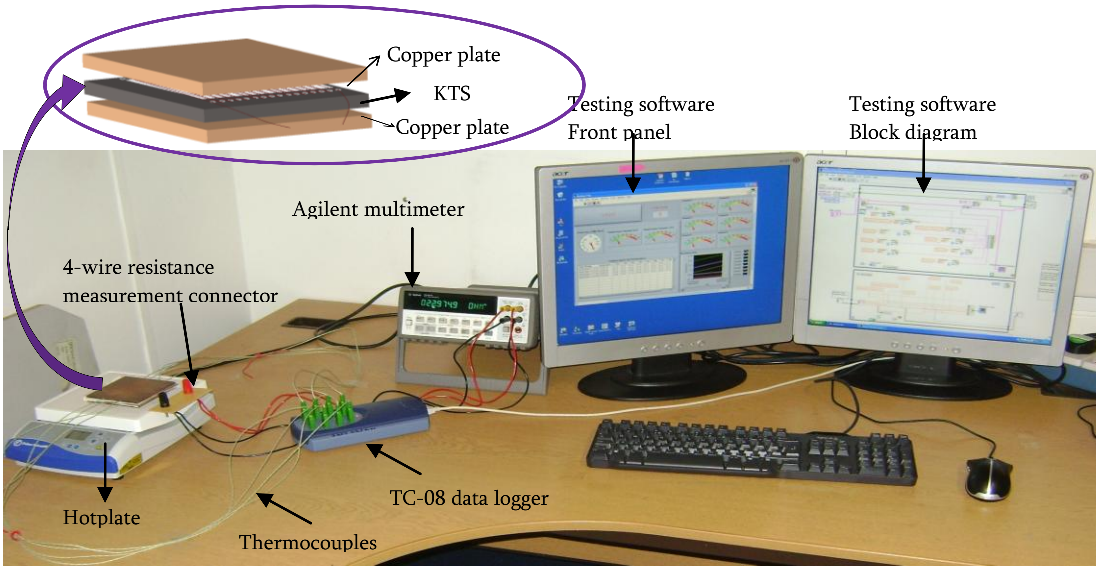

Figure 3: Test Rig for the measurement of temperature and corresponding resistance

Each copper plate was fastened with four K-type thermocouples and Picotech TC-08 data logger is used for the temperature logging. The temperature of sample was approximated by averaging out the top and bottom copper plates' temperature. Agilent multimeter and 4-wire resistance measurement system was setup to measure and record the minute changes in electrical resistance. Tailor-made LabVIEW based software has been created in order to visualize the temperature and resistance signals side by side.

1.5 Result & Discussion

Some preliminary tests were carried out on 8 x 8 cm of KTS fabric, integrated with 2 meters of two different sensing elements i.e. copper wire with diameter of 0.127 mm, and nickel wire with diameter of 0.09 mm. The experimental Temperature-Resistance data was compared with the modeled ones as shown in Figure 4. Copper exhibits very low nominal resistance i.e. 2.6 Ω at 30 °C and low sensitivity of around 0.01 Ω / °C. Nickel exhibits much higher nominal resistance i.e. 22 Ω at 30 °C and sensitivity of around 0.1 Ω / °C. We could infer from our modeling and preliminary testing results that copper may not be better options for sensing element of KTS, due to its low sensitivity and nominal resistance. Keeping in view the cost, physical properties, and the application temperature range (25 to 45 °C), nickel and tungsten was chosen over platinum and copper. A 5 meter long nickel wire with diameter of 0.07 mm can offer the base resistance of 100 Ω with a sensitivity of 0.70 Ω/ °C. Similarly 5 meter long tungsten wire with the same diameter can offer the base resistance of 70 Ω with a sensitivity of 0.35 Ω/ °C.

The Response Time expresses how quickly the sensor responds to temperature changes. Response time has direct relationship with the thermal mass of sensing element and size of KTS. Nickel is least responsive due to its high thermal mass comparing other sensing elements. On the other hand, tungsten is four times more responsive than nickel due to low thermal mass.

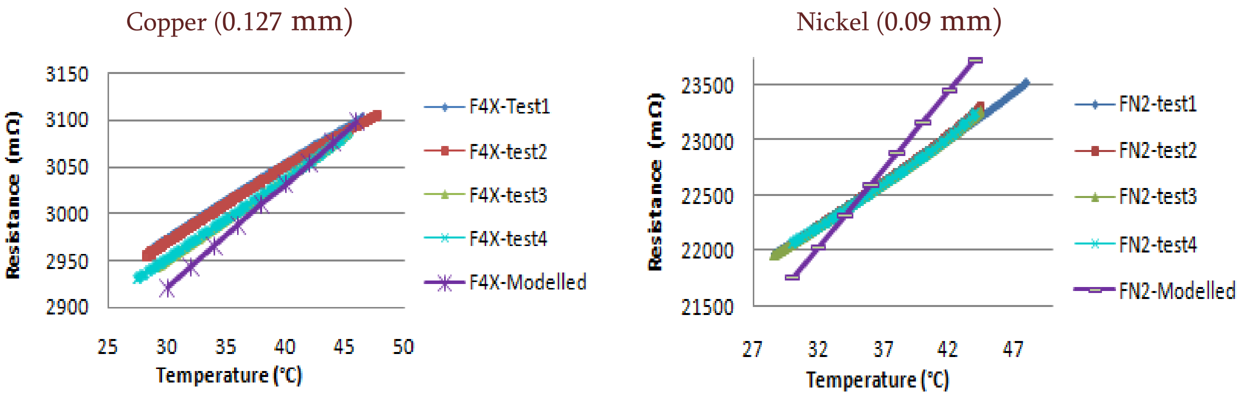

Figure 4 Experimental and modeled Temperature-Resistance curves

1.6 Conclusion

This report discusses the ongoing development of a textile based knitted temperature sensor (KTS) that can be integrated into garment, for the measurement of human body temperature. A detailed literature review has demonstrated that the measurement principle of RTD (Resistance Temperature Detector) can be applied in the development of the proposed temperature sensor. Nickel and tungsten wires has been selected as sensing elements of KTS after considering the temperature-resistance relationship, electrical properties, and thermal properties of four metals, as well as the intended application. The major advantages, to consider nickel and tungsten, are their high nominal resistance and sensitivity. Experimental T-R curves of samples shows the same inclination as modeled curve.

1.7 Future Work

Primary future tasks include: development of models to define baseline characteristics; testing of T-R relationships of KTS fabric and its validation with theoretical models; integration of KTS fabric in garment and its evaluation; and determination of KTS sensitivity to external parameters e.g. strain, moisture. So to summarize the goal of the present research is to specify the baseline characteristics of a KTS by determining the effect of the KTS structural characteristics, and investigating the influence of external parameter, on the KTS performance. The final stage of the research will be to build a demonstrator garment.

REFRENCES

1. R. Paradiso, G. Loriga, and N. Taccini, *A Wearable Health care System based on Knitted Integrated Sensors.* IEEE Transactions on Information Technology in Biomedicine, 2005. **9**: p. 337-344.
2. Smartex, *Description of WEALTHY System*. 2007: Smartex s.r.l. Prato, Italy.
3. D. Curone, et al., *Smart Garments for Emergency Operators: Results of Laboratory and Field Tests*, in *30th Annual International IEEE Engineering in Medicine and Biology Society (EMBS) Conference*. 2008: Vancouver, British Columbia, Canada.
4. T. Dias, R. Wijesiriwardana, and K. Mitcham, *Fibre-meshed transducers based real time wearable physiological information monitoring system*, in *Eighth International Symposium on Wearable Computers (ISWC)*. 2004. p. 40-47.
5. T. Dias, et al., *KNITTED TRANSDUCER DEVICES* 2004, Smartlife Technology Limited: United Kingdom.
6. S. Park and S. Jayaraman, *Enhancing the quality of life through wearable technology.* IEEE Engineering in Medicine and Biology Magazine, 2003. **22**(3): p. 41-48.
7. M. H. Cheng, et al., *A vital wearing system with wireless capability*, in *Second International Conference on Pervasive Computing Technologies for Healthcare*. 2008. p. 268-271.
8. J. L. Weber and F. Pirotte, *MERMOTH: MEdical Remote MOnitoring with cloTHes*, in *PHealth*. 2006: Luzerne, Switzerland.
9. N. Noury, et al., *VTAMN - A Smart Clothe for Ambulatory Remote Monitoring of Physiological Parameters and Activity*, in *26th Annual International IEEE Engineering in Medicine and Biology Society (EMBS) Conference*. 2004: San Francisco, California.
10. *VivoMetrics Inc. VivoMetrics LifeShirt.* [cited 30-07-09]; Available from: http://www.vivometrics.com/
11. P. S. Pandian, et al., *Smart Vest: Wearable multi-parameter remote physiological monitoring system.* Medical Engineering & Physics, 2008. **30**: p. 466–477.
12. I. Locher, T. Kirstein, and G. Troester, *Temperature Profile Estimation with Smart Textiles*, in *International Conference on Intelligent textiles, Smart clothing, Well-being, and Design*. 2005: Tampere, Finland.