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Integrating wireless measurement and AI control in thermo-physiological clothing

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1. Introduction

During freezing cold winter conditions, no matter what clothes a person puts on, they are exposed to cold environment and need thermal protection. When a person travels from a warm place to a cold place, he/she has to carry a large package of winter clothing since he wears summer/spring clothing at the starting spot. Reversely, when a person travel from a cold place to a warm place, it's very troublesome and difficult to bear the large temperature change, get off the winter clothing and change for summer/spring clothing. Meanwhile, when a person is in fieldwork, his physiological signals should be monitored in case of emergency. During this condition, the protective and wearable physiological monitoring clothing is one of the solutions.

In the 21st century, clothing industry is breaking through the traditional design and manufacturing and begins to take interest in the research on smart, intelligent and functional clothing. Extensive research has been reported about the development of smart clothing and the technologies of smart or intelligent control in clothing design, making and functions simulation [1-7]. Steve Mann studied the wearable smart clothing [1]. The author pointed out that smart clothing – the combination of mobile multimedia, wireless communication, and wearable computing, offered the potential to make personal computers even more personal. C.K. Au and Y.-S. Ma developed garment virtual design system to achieve an intelligent mass customization approach [3]. However, the smart clothing only has passive control functions and it's the intelligent clothing that is the future of clothing industries [8]. Intelligent clothing is a challenge for textile technology and will bring the transformation of textile and clothing industries into high-technology branches [9].

People now care much more about their bodies, and the comfort becomes the principal target in much scientific research. Comfort has been highlighted as a key to the competitiveness in clothing markets. The research in the field of physiological comfort is directed to study the thermo-physiological properties of clothing. To perform this research, the latest measuring techniques and mechatronics equipment, including wireless communication, are used for measuring the heart beat, rectal temperature and skin temperatures [10, 11]. J.Coosemans et al. reported on the full realization of a garment embedded patient monitoring system, including wireless communication and inductive powering [11]. However, majority of these clothing only have simple functions, without intelligent thermal control system and wireless measurement functional design. Therefore, it's desirable to have intelligent thermal functional clothing, which is capable of having intelligent heating and cooling functions and the function to monitor body physiological status by wireless data acquisition.

2. Principle and methods

2.1. Clothing structure

A prototype of the thermo-physiological clothing has been developed, which provides intelligent thermal control for a wearer by means of integration of smart materials, transducers, microelectronics, Artificial Intelligence (AI) control and wireless data acquisition.

The thermo-physiological clothing includes three functional layers: the liquid moisture management layer, the thermal management layer with heating & cooling and wireless body physiological monitoring system and the outer layer that has the function of waterproof and windproof. Moreover, the clothing has a thermal control system, a wireless measurement system, a semiconductor cooling system, a LED light temperature showing system and the air circuit system. The clothing can provide automatic heating and cooling control according to wear conditions and the body physiological signals through a built-in microchip.

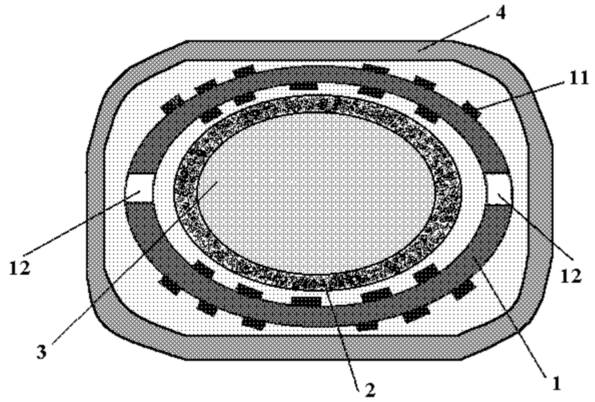


Fig. 1 The cross-section of the thermo-physiological clothing

Fig. 1 shows a cross-sectional view of the embodiment of the thermo-physiological clothing. The middle layer *1*, keeping close to the body *3*, is the thermal management layer, which has the function of heating & cooling and thermal physiological signals monitoring. The flexible heating pads *11* using conductive fabrics, located on the two sides of the middle layer, are made of high-polymer with carbon powders. A flexible rechargeable battery is installed and can be charged by solar batteries. Also various transducers such as temperature sensors, humidity sensors and infrared sensors, implanted on the two sides of the middle layer *1*, are used to monitor the thermal status of clothing microclimate, and provide the signals of temperature and humidity, even the blood pressure and heart rate. The middle layer *1* has two intakes *12* and a semiconductor cooling system for the air circulation. The inner layer *2* is the liquid moisture management layer of the thermo-physiological clothing. The outer layer *4* is the waterproof and windproof layer.

2.2. Artificial Intelligence control

The thermo-physiological clothing provides intelligent thermal control for a wearer by means of AI. Two operation modes are available: Manual and Auto. The control system with AI-chip can self-learn the condition and selections in manual mode, and then produces auto control when changing to Auto mode. The clothing control system has intelligent algorithm and the supporting hardware, built-in AI chip, for the intelligent thermal control.

Based on the AI control, the thermo-physiological clothing can provide the following functions.

1) Intelligent thermal control. The clothing has a built-in microchip to provide intelligent heating and cooling controls according to the wear conditions.

2) Body physiological monitoring, such as body temperature and moisture. The clothing has voltage output temperature sensors, humidity sensors and infrared sensors. The sensors can provide the signals of temperature and humidity, and the signals are sent to the control system for the intelligent thermal control by conductive fiber or wireless communications.

2.3. Wireless data acquisition and transmission based on Pocket PC

The clothing built-in microelectronics system – multi-sensory measurement system has Bluetooth wireless communication module, which can received data from sensors and send data to a Smartphone or Pocket PC, so that the body conditions can be visible immediately (Fig. 2).

a b

Fig. 2 Wireless body physiological monitoring: a - front side; b - back side

The thermo-physiological clothing can acquire and process the thermal physiological signals, such as the core temperature and relative humidity of the body, and the body biological signals, such as blood pressure and heart rate.

Furthermore, the body conditions can be sent to a remote computer by SMS (Short Message Service) message in case of emergency when a person is in fieldwork.

3. Experimental

3.1. Experimental protocol

For the evaluation of clothing functions, we have conducted laboratory thermal control tests and wear trials according to the following experimental protocol.

1) Experiments were being performed in a computer-controlled climatic chamber. The chamber and be controlled for temperature from -15 to 45°C and relative humidity from 0 to 100%.

2) Infrared camera was used for thermal images. During the experiment, the camera sends the information to the computer and gives a live displaying for the temperature changes of the clothing outer surface.

3) Temperature and humidity wireless measurements for the clothing, including the three functional layers. Totally we have ten RTD sensors and ten humidity sensors for the temperature and humidity measurement. All analog signals are conditioned and acquired by a DAQ (Data Acquisition) board inner the clothing and are sent to a Smartphone or Pocket PC by Bluetooth wireless communications.

3.2. Control tests

The control test is conducted to test the thermal control function of the clothing, including testing the ability of the control system with built-in microchip. During the thermal control tests, the configurations of the climatic simulation chamber are temperature 18°C and relative humidity 65%.

The temperature and humidity of the control points are acquired, pretreated and stored by the built-in multi-sensory measurement system. The data is saved in a text file by columns according to the time sequence.

The critical temperature and humidity data are sent to a Pocket PC by wireless communication (Fig. 3).

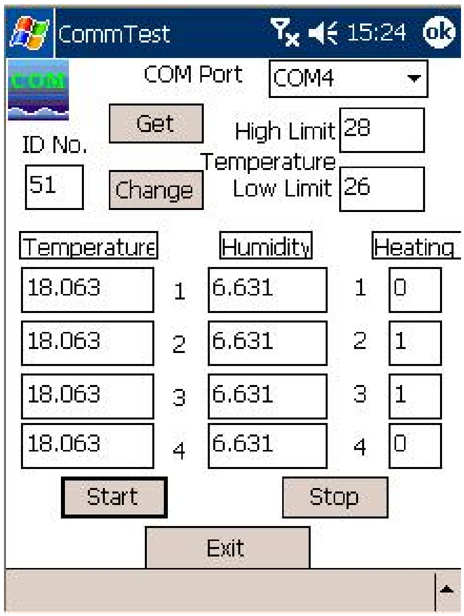


Fig. 3 Data acquired by wireless communication

3.3. Wearing trials

Fig. 4 Wearing trial in climatic chamber

The wearing trial was conducted in a climatic chamber (Fig. 4) in the ambient condition controlled at temperature of 18°C and relative humidity of 65%. Since the clothing has three functional layers, we placed 3 temperature sensors and 3 humidity sensors on each layer. The three layers have 9 temperature sensors and 9 humidity sensors in total.

All analog signals are acquired, pretreated and stored by the built-in multi-sensory measurement system, then all source data is saved in a text file by columns according to the time sequence for analysis.

4. Results and analysis

4.1. Wearing trials

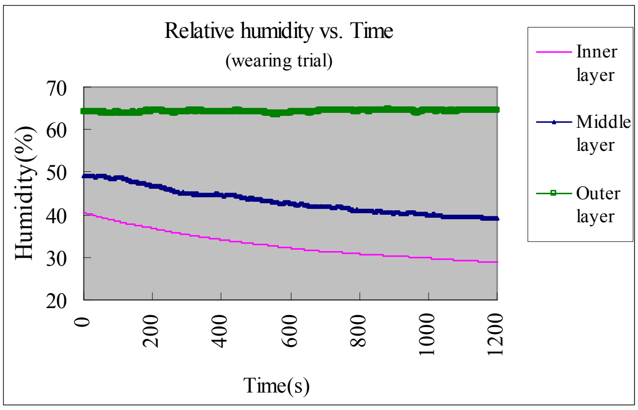


Fig. 5 Relative humidity distributions in the clothing during wear ing trial

The test results are shown as Figs. 5 and 6. For each layer, the average of the data from 3 sensors is used for analysis. During the trial, the temperatures of the inner layer and middle layer tend to rise, and the humidity of the inner layer and middle layer tend to decline. The temperature and humidity on outer layer are stable in accordance with the chamber ambient condition. The temperatures and humidity of the inner layer and the middle layer reach steady state and become stable due to the intelligent thermal control effect of the clothing.

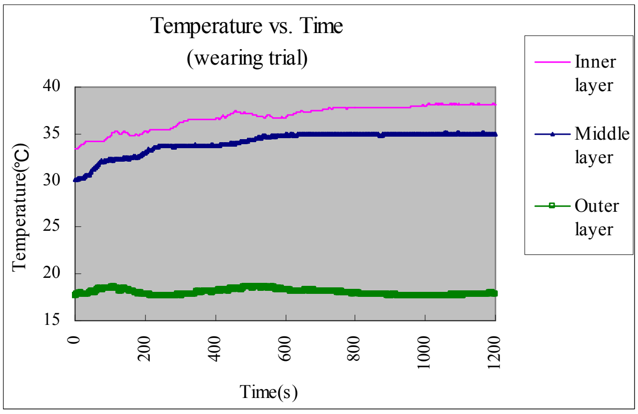
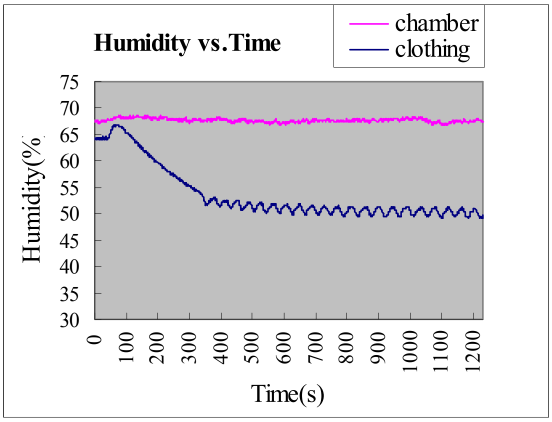


Fig. 6 Temperature distributions in the clothing during wearing trial

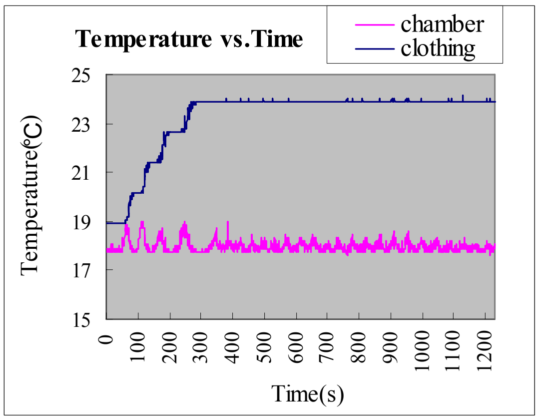
Since the inner layer is close to the skin, it has higher temperature and lower humidity than the middle layer.

4.2. Control tests

The control test results are shown in Fig. 7, in which Fig. 7, a shows the dynamic humidity distributions and Fig. 7, b shows the dynamic temperature distributions with the controlling system.



a



b

Fig. 7 Control test on the prototype clothing: a - humidity distribution; b - temperature distribution

Since the ambient temperature is 18°C and below the setting point 24°C in the control system, the power of heating element/heating pad is switched on, and the heating is started. About 30seconds, the temperature increased, and the humidity decreased due to the temperature rise. Two minutes later, the temperature and humidity reach a steady point (control point), which is set and selected by the control system, and becomes stable. This shows that the control system is able to keep the temperature & humidity at the setting point.

5. Conclusion

Thermo-physiological clothing has been developed, which has the functions of intelligent thermal control, wireless measurement and body physiological monitoring. Experiments have been carried out to test the functional performance of the clothing and results show that the intelligent thermal control and the thermo-physiological monitoring functions can be achieved. The thermo-physiological clothing gives a solution for wearing in fieldwork or in the large temperature change conditions, such as traveling from warm environment to cold environment, or vice versa.

Acknowledgment

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INTEGRUOTAS BEVIELIS ŠILUMINĖS-FIZIOLOGINĖS APRANGOS MATAVIMAS IR DIRBTINIO INTELEKTO KONTROLĖ

R e z i u m ė

Sukurtas integruotas bevielis šiluminės-fiziologinės aprangos su intelektualios kontrolės sistema matavimo metodas. Intelektualiai kontrolei ir fiziologinio stebėjimo funkcijai atlikti naudojamos šiuolaikinės medžiagos, jutikliai, mikroelektronika, dirbtinio intelekto kontrolės ir bevielio duomenų gavimo sistemos). Apranga turi šiluminės kontrolės sistemą, bevielio matavimo sistemą, puslaidininkių aušinimo sistemą ir oro kondicionavimo sistemą. Apranga automatiškai reguliuoja šildymą ir vėdinimą priklausomai nuo eksploatacijos sąlygų. Pateikta aprangos struktūra, intelektualios kontrolės sistema, bevielis matavimas, eksperimentai ir dėvėjimo bei kontrolės tyrimų rezultatai.

Bao-guo Yao, Yi Li

INTEGRATING WIRELESS MEASUREMENT AND AI CONTROL IN THERMO-PHYSIOLOGICAL CLOTHING

S u m m a r y

Thermo-physiological clothing integrated with intelligent control and wireless measurement was developed, which provides thermal control and physiological monitoring function for a wearer by means of integration of smart materials, transducers, microelectronics, Artificial Intelligence (AI) control and wireless data acquisition. The clothing has a thermal control system, a wireless measurement system, a semiconductor cooling system and the air circuit system. The clothing can provide automatic heating and cooling control according to wear conditions. The structure of the clothing, the technologies of intelligent control and wireless measurement, the experiments and the results of wearing trials and control tests are introduced.

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