Pneumatic system for an intelligent article of clothing with active thermal protection

Gojko NIKOLIĆ, Snježana FIRŠT ROGALE, Dubravko ROGALE, Zvonko DRAGČEVIĆ, Milivoj BARTOŠ

Abstract: The actuator system of an article of clothing with thermal protection is described as a unit that adjusts the optimum level of the necessary thermal protection of an article of clothing. The system consists of a microcontroller assembly that makes decisions on activating the actuator, measuring the amplifier and pressure sensors in the thermo-insulating chambers, the air fill and release electrovalves for the thermo-insulating chambers and the compressed-air microcompressor. All the elements constitute a complex actuator system that makes it possible to set the desired level of thermal insulation protection for an article of clothing.

Key words: control systems, electropneumatic systems, microcontrollers, intelligent clothing, active termal protection,

1 Introduction

At the meeting of the Thematic Expert Group, TEG n° 6 Smart Textiles & Clothing" within the European Technology Platform for the future of Textiles and Clothing organized by EURATEX (European Apparel and Textile Organization) and held in January 20, 2006, 37 experts coming from all the European countries accepted the definition and characteristics of the term intelligent clothing [1]. The experts agreed that three sets of instruments should be integrated into an article of clothing: sensors for measuring and information input which collect input information, processing unit for interpreting input information and making decisions (microcomputers, microprocessors or microcontrollers with accompanying programs) and output actuators for adapting an article of clothing and provide output information. This definition is in accordance with investigations performed in the sector of developing intelligent clothing and publications in the course of two previous years at the Department of Clothing Technology of the Faculty of Textile Technology of the University of Zagreb.

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The article of clothing with thermal protection can automatically adapt thermal insulation in conformity with the relationships between the outside environmental temperature and the microclimate inside the clothing and along the human body respectively, in the range -30 ^{0}C - + 10 ^{0}C. Its operation is based on the use of temperature measuring sensors, pressure in the thermoinsulating chambers, upon which the chamber thickness depends, and in line with these thermoinsulating properties, the algorithm of intelligent behavior and the actuator by means of which the decisions on the special behavior of the intelligent article of clothing are made. The paper deals with the actuator system of an intelligent article of clothing with active thermal protection. It consists of a microcompressor, three compressed air fill electrovalves, and three compressed air release electrovalves for the thermoinsulating chambers, plug-in connections and other smaller elements needed in order to be connected to the thermoinsulat-ing chambers. The microcompressors and electrovalves are connected over the buses directly to the circuit board of the microcontroller system. The experiments have showed that the actuator system can efficiently control the thermoinsulation properties of the intelligent article of clothing with thermal insulation. The elements of the actuator system are of small enough dimensions and of an appropriate mass in order to enclose them between the outer shell and the thermoinsulating chambers and the lining of the intelligent article of clothing with active thermal insulation, respectively [2].

2 The architecture of an intelligent article of clothing with active thermal protection

Based on the investigations performed, the whole architecture of an article of clothing with thermal protection is clear, and consists of the following technical subsystems, *Figure 1* [3,4]:

1. The system of the outer shell with a programmable variable thickness with an outer and inner protective fabric layer.
2. The system of the thermoinsulating chambers with a possible control of body heat conduction and convection.
3. The sensors and systems for measuring input variables.
   3a. The subsystem for measuring the temperature of the environment and microclimate of an article of clothing
   3b. The subsystem for pressure measuring in thermoinsulating chambers
4. The microcontroller measuring and control system for the intelligent article of clothing.
5. The actuator system for the intelligent article of clothing with an active thermal protection with the elements of micropneumatics for controlling output variables.
6. Power supply and
7. Measuring and controlling the microcontroller program with the algorithm of intelligent behavior of an article of clothing.

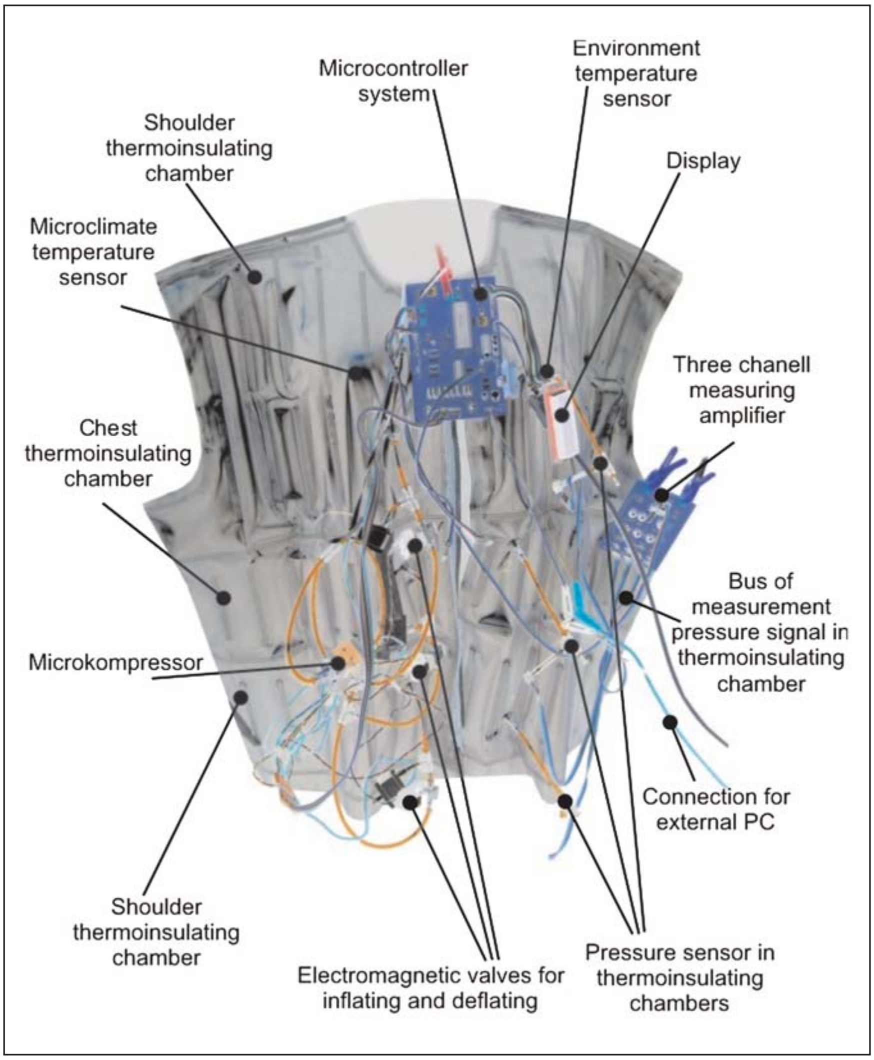

Figure 1. *Architecture of the intelligent article of clothing with active thermal protection*

3 Integration of technical subsystems of the intelligent article of clothing with an active thermal protection

The integration of all the technical subsystems and the first practical design of the prototype of the first intelligent article of clothing with thermal protection was performed in accordance with the Croatian patent **PK20030727** and the world patent application **WO 2005/ 023029 A1** [5].

The basis of the integration of technical subsystems is the shoulder, breast and waist insulating chamber to which the printed circuit boards of the microcontroller system and the measuring amplifier for the pressure signal are attached. From the printed circuit board of the microcontroller system a group of conductors goes to which a data display of work parameters and actual state of the intelligent article of clothing with active thermal protection, sensors of microclimate and environment temperature as well as other usual wiring to control the actuator system are connected. The actuator system is connected by means of micropneumatic components, and it consists of three air fill and three air release electromagnetic valves for the shoulder, breast and waist thermoinsulating chamber and the microcompressor which supplies the system with compressed air. Three groups of connection elements with pressure sensors in the shoulder, breast and waist thermoinsulating chamber as well as the connection of the microcontroller system with the external PC for programming the microcontroller and the control of its operation, the connection for the battery charging system and other auxiliary wiring form the subsystem. By integration of all technical subsystems it is made possible that the article of clothing with active thermal protection operates in a way that it independently measures environment and microclimate temperature in the article of clothing, it properly interprets and makes decisions on a necessary response in terms of necessary thermal protection and in line with the flowchart from the algorithm of intelligent behavior.

Figure 2 shows a practical design of the microcontroller system with the connected sensors of environmental and microclimate temperature of the article of clothing.

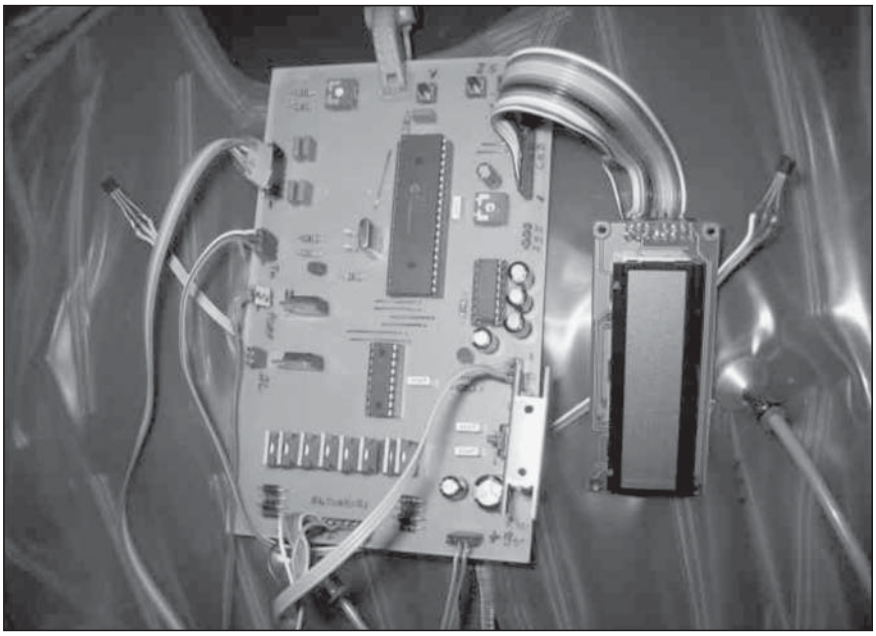

Figure 2. *Microcontroller system with temperature sensors and display*

On the circuit board, the main microcontroller houses the basic control program for the intelligent article of clothing with an active thermal protection, the auxiliary microcontroller for rational controlling electric power systems and the integrated circuit for the serial communication with the external personal computer. The connected LC display for the communication between the wearer of the article of clothing and the microcontroller system can be seen as well. The mentioned figure shows a series of MOSFET transistors to control actuators, and wiring parts of the intelligent article of clothing with active thermal protection [6,7].

Figure 3 shows a three-channel measuring amplifier for amplifying pressure measuring signals in the thermoinsulating chambers. The upper part of the figure shows the integrated circuit with four operating amplifiers, beneath a row of three trimmer potentiometers for regulating the operating amplifiers. The trimmer potentiometers for regulating the misadjusted measuring bridges and for indicating zero voltage, when there is no air pressure in the thermoinsulating chambers, are located in the second row. Wiring part is visible in the figure the. The bus wiring with three pressure sensors runs to the bottom part of the circuit board from the shoulder, breast and waist chamber, and in the upper part of the board a multi-strand bus for amplified measuring pressure signals is located. They are introduced into the microcontroller system. The system of the thermoinsulating chambers can also be seen.

Figure 4 shows the pressure sensor [8] of the breast chamber, the connection connector and the two-piece conical connection element for the air duct. The mentioned sensor is connected to the air duct made of a highly flexible plastic tubing and a T plug-in connection made by FESTO [9]. The air duct is connected over the two-piece conical connection element to the thermoinsulating chamber so that the air pressure within the chamber could be transferred to the pressure sensor. Voltage data in the measuring bridge of the pressure sensor is transferred to the plug-in connector and afterwards by means of the signal bus of transducers for measuring pressure to the measuring amplifier of pressure signal. There are two more fully identical pressure sensors for the breast and waist thermoinsulating chamber in the designed prototype.

Figure 5 shows the fill and release compressed air electrovalve for the shoulder thermoinsulating chamber with part of the air duct system and T plug-in connection. The 2/2 microelectromagnetic valve is used to fill the compressed air into the thermoinsulating chambers, and to release the air from the chambers. In the designed prototype there are two more fully identical pairs of electromagnetic valves for the breast and waist thermoinsulating chamber.

Figure 6 shows the Clark microcompressor that is located under the thermoinsulating chambers and connected to the air duct of the micropneumatic system [10].

The actuator system uses micropneumatic elements illustrated in *Figure 7*.

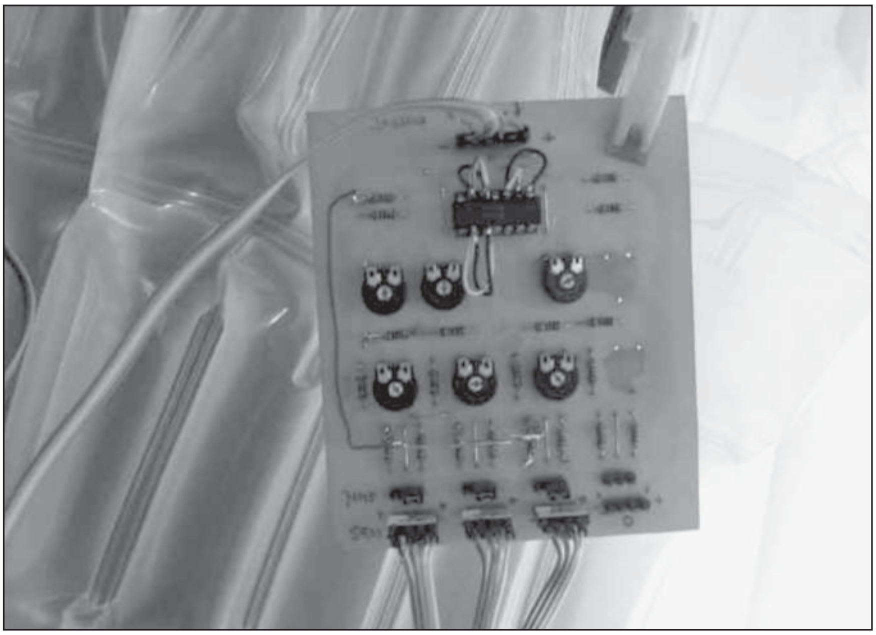

Figure 3. *Three-channel measuring amplifier*

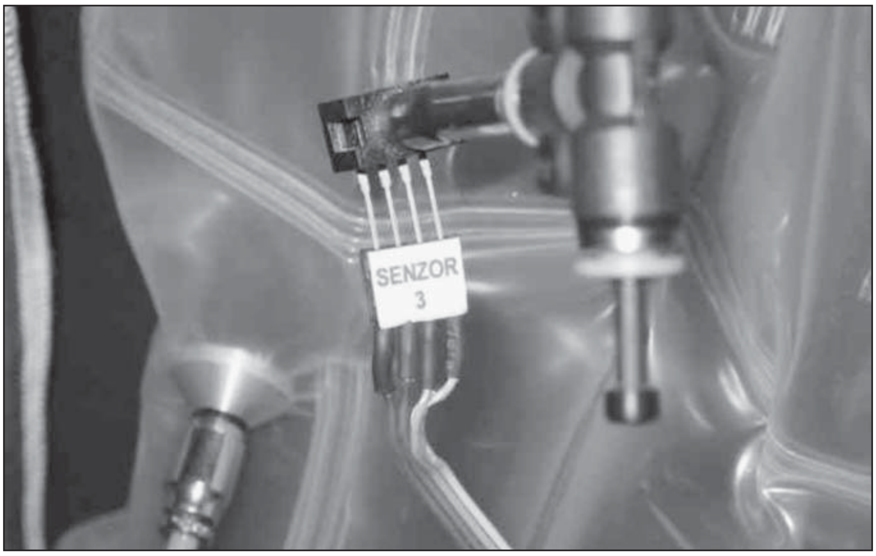

Figure 4. *Pressure sensor connection connector and tow-piece conical connection element for the connection of the air duct*

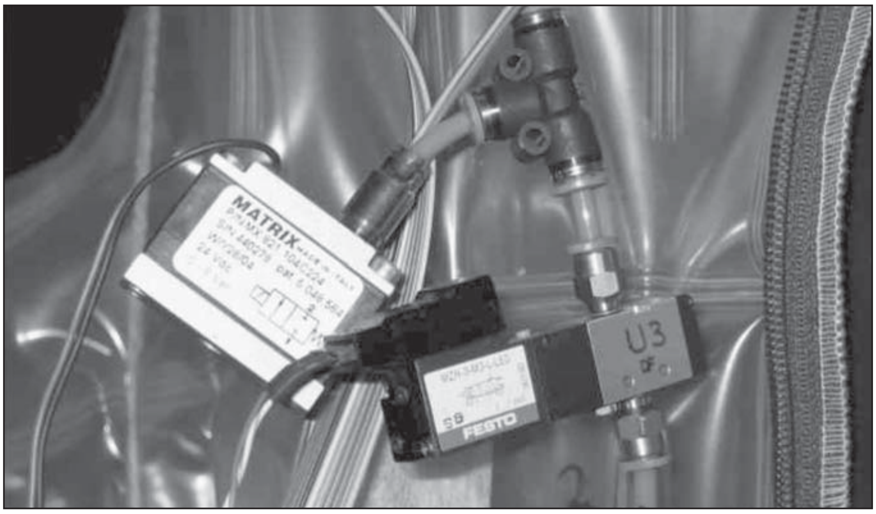

Figure 5. *Compressed air fill and release electromagnetic valves for the thermoinsulating chambers with part of the air duct system and T-plug-in connection*

Compressed air is generated by microcompressor (11). The microcompressor operates on a diaphragm principle and is supplied with a direct current of 9 to 14 V consuming 200 mA. Maximum work pressure of the microcompressor may be 0.75 bar. Compressed air is led through small tubes (12) to the shut-off valve (14) behind which there is the pressure regulator (15). The value of the regulated pressure is measured by the sensor (16). 2/2 electrovalves (18), (19) and (20) are used to inject compressed air into the thermoinsulating chambers. The pressure in the thermoinsulating chambers is measured via a sensor (16). 2/2 electrovalves (21), (22) and (23) are used to discharge the air from the thermoinsulating chambers. The microcontroller system used in line with the decisions based on the algorithm of intelligent behavior controls the operation of the electrovalves.

The microprocessor is activated when it is necessary to inflate the thermoinsulating chambers, and it is supplied directly from the electric power supply system.

All the elements of the technical systems integrated into the intelligent article of clothing with active thermal protection are relatively thin, thinner than the thermoinsulating chambers.

4 Conclusion

The paper describes the actuator system of an intelligent article of clothing with an active thermal protection. It presents the final and proven variant which has exhibited excellent results in controlling the adaptation of the thermal insulation of the article of clothing. The presented system will serve as a basis for further investigations of the properties and behavior of an intelligent article of clothing with thermal protection in the changed conditions of microclimate environment and physical activity of the wearer of this kind of clothing [11, 12].

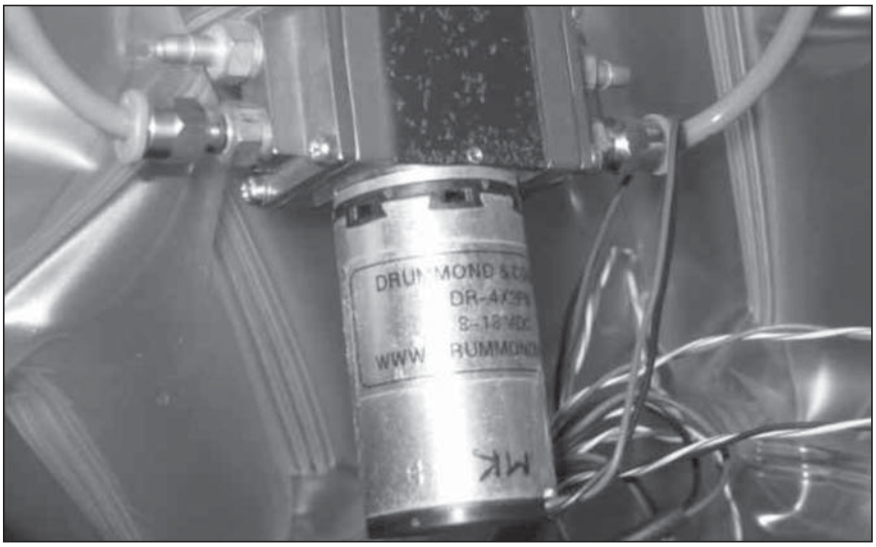

Figure 6. *Microcompressor for filling the thermoinsulating chambers connected to the air duct system*

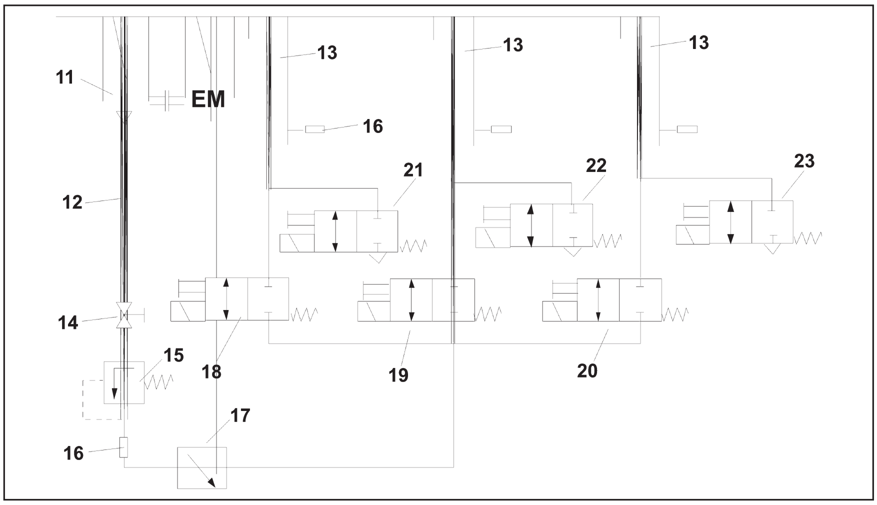

Figure 7. *Pneumatic circuits for actuator system of the intelligent article of clothing*

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Pnevmatični sistem aktivnega kosa oblačila z aktivno toplotno zaščito

Razširjeni povzetek

Predstavljen je aktivni elektro-pnevmatični sistem toplotne zaščite kosa oblačila z možnostjo prilagajanja in optimiranja toplotne izolacije vsakokratnim zahtevam počutja nosilca oblačila, delovnim razmeram in stanju okolice.

Inteligentno oblačilo z aktivno toplotno zaščito je bilo razvito v Zavodu za oblačilno tehnologijo pri Tekstilno-tehnološki fakulteti Univerze v Zagrebu.

Toplotna izolacijska zaščita je odvisna od temperaturnih razmer v okolici in stanja mikroklime znotraj oblačila, tako da se smiselno optimizira njena vrednost. Vrednost toplotne izolacije se doseže s spreminjanjem delovanja vložkov v obliki paketov, polnjenih s stisnjenim zrakom. Pnevmatični sistem ima lastni vir stisnjenega zraka, ki se pridobiva s pomočjo membranskega minikompresorja in krmili z ustreznim številom elektromagnetnih ventilov. Od tlaka je odvisna debelina toplotnih izolacijskih paketov in njihovih tesnilnih lastnosti. Sestav miniaturnih elektromagnetnih ventilov polni oz. prazni prekate v odvisnosti od algoritma inteligentnega obnašanja sistema. Stanje termodinamičnih parametrov znotraj oblačila in v okolici sledijo temperaturna zaznavala, mikrokrmilniški sestav pa odloča o debelini toplotnih izolacijskih paketov in s tem o termoizolacijskih lastnostih oblačila. Dodatna toplotna zaščita pa se zagotavlja z različnimi kombinacijami aktivnih in neaktivnih tesnjenih paketov.

Inteligentno oblačilo z aktivno toplotno zaščito je zahteven tehnični sistem, ki ga krmili mikrokrmilnik, katerega osnova delovanja je program, oblikovan na temelju algoritma obnašanja oblačila.

Ključne besede: krmilni sistemi, elektropnevmatični sistemi, mikrokrmilniki, inteligentna oblačila, aktivna toplotna zaščita,