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Body Temperature Monitoring System for Slaughterhouse Workers

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Abstract. The aim of this study was to develop a complete system to evaluate the thermal stress in slaughterhouses. The proposed system consists of a wireless sensor network (WSN) using Zigbee technology, providing a set of sensor nodes to measure the slaughterhouse workers body temperature in different regions simultaneously and a another set to measure the environment conditions. The data are collected by a USB Zeegbee module connected to a Windows PC and the PMV (Predict Mean Vote) is showed at real time. A test was conducted in the sector of cuts of a poultry slaughterhouse industry located in the south of Brazil. The results showed a virtually thermal comfort of the workers (by PMV analysis), but a dangerous low values which may cause disease to the worker.

Keywords: Poultry slaughterhouse · Body temperature monitoring system · Thermal stress evaluation

1 Introduction

One of the strongest economic activities of the south Brazil region is the chicken production for exporting. World rankings point to Brazil as the largest exporter of frozen poultry meat since 2004 and the third producer after USA and China [1, 2]. Most of the Brazilian exported chicken meat is in the form of cuts (54.7%), and the remainder consists of processed meat (4.6%), salted meat (4.5%), and whole chicken (36.2%) [1]. In Brazil, the poultry farming employs more than 3.6 million people, mostly being line workers. Due to the lack of machinery providing full automation in the sector, most of the chicken meat produced in Brazil is processed through manual labor, using of hand tools live knives and chainsaws. The frequently exposure to an artificially cold environment combined with the poor working conditions lead the slaughterhouse workers to develop a variety of cold related injuries [3].

According to Caso et al. [4], the slaughterhouse workers are exposed to biomechanical risk factors for development of work-related musculoskeletal disorders of the upper limbs (UL-WMSDs) such as repetitiveness, high-frequency technical actions, excessive use of force, inappropriate postures, insufficient recovery time, handling of frozen products and prolonged exposure to the cold environment.

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Through their studies in different Brazilian slaughterhouses, Tirloni et al. [5] and Reis et al. [6] reported that the majority of workers felt discomfort during their working day in a variety of body regions, such as shoulders, neck, spine, arms, hands and wrists.

The aim of this study was to develop a complete system to evaluate the thermal stress in slaughterhouses, evaluating both the environment conditions and the thermal discomfort of the workers.

2 Market Research

The present study started with a market research, in order to look for the existence of a product or complete solution capable of monitor the environment conditions as well as tracking the worker body temperature in real-time. The company 3 M™ has a product line dedicated to thermal stress analysis named QUESTemp™. QUESTemp™ II is a personal heat stress monitor kit capable to tracking the worker's in-ear temperature minute-by-minute. QUESTemp™ 36 is a heat stress monitor data logging kit, which offers logging of environment conditions in real time such as dry bulb, wet bulb and globe temperatures along with relative humidity and air speed.

Although interesting, both solutions are very expensive [7, 8] and neither have the capacity of tracking the temperature of different body parts of the worker, which is the key characteristic present in the proposed system. In fact, the in-ear temperature is an important measurement to identify thermal discomfort, but the anatomical regions associated with the most prevalent WMSDs are extremities such as the wrist and hand, and epidemiological research supports the evidence of injuries related to repetitive and forceful hand-intensive tasks [9].

3 Hardware and Software

3.1 Introduction

The proposed system consists of a wireless sensor network (WSN) using Zigbee technology, in which a set of sensor nodes is intended for the measurement of the slaughterhouse workers body temperature in different body regions simultaneously, while another sensor node evaluates the environment conditions, such as relative humidity, air speed, globe temperature and dry bulb temperature.

Both nodes send the sampled data in real-time over a radio link to a radio sink node connected to a computer through a USB-serial converter (Fig. 1). All the collected information is centralized in a friendly interface (Window system), which presents the data to the user. Also, the system should be non-intrusive and easily expansible.

3.2 Zigbee Network Technology

The wireless sensor network (WSN) implemented in this project is entirely based on the Zigbee wireless technology, using Xbee-Pro 900 XSC S3B modules manufactured by Digi International, Inc. Zigbee communication is specially built for control and

Fig. 1. Implemented system to evaluate thermal stress in slaughterhouses.

sensor networks based upon IEEE 802.15.4 standard for wireless personal area networks (WPANs). The main reasons of using Zigbee network technology and Xbee modules are the small size, low power consumption, low cost of the modules, long battery life, simplicity to setup the network, long range and the built-in peripherals such as 4 10-bit ADC inputs, 2 PWM outputs, Serial interface (UART) and up to 15 digital I/O ports. Xbee module works with a power supply range from 2.1 to 3.6 VDC, and it's line of sight range can reach up to 15 km with appropriate antenna and configurable Data Rate. In terms of network topology, the implemented network was structured in the Star Topology, where all the network sensing nodes communicates directly to only one sink node, which is connected to the computer.

3.3 Personal Measurement Module

The Personal Measurement Module was configured to measure the slaughterhouse workers body temperature in different body regions simultaneously. Each module (Fig. 2) consists of a battery charger, a one-cell Lithium-Ion battery and a low-dropout DC-DC converter used to drop-down the 3.7 Vdc from the battery to the power supply range of the Xbee module.

The thermistors used are Murata Thermo String NTC thermistors, with the B-Constant of 3380 ± 1% and 10 k ± 1% Ohm resistance (at 25 °C). The "head" has a diameter equal to 1.2 mm, the wire has 0.30 mm diameter and length 80 mm. These thermistors are characteristic to provide an extremely precise temperature sensing, excellent long-term stability and high malleability. The sensors have been soldered in a flexible AWG 26 double wire plastic insulated

Each thermistor is connected to a Xbee ADC input through a voltage divider with a 10 K ± 1% Ohm precision resistor. A precision voltage regulator supplies a reference voltage of 1.2 Vdc to the sensors, to match with the internal Xbee ADC voltage reference, in order to obtain a full-scale conversion. The ADC sample rate is 4 Hz.

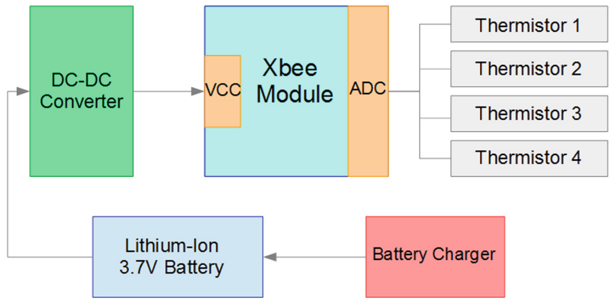

Fig. 2. Implemented system to evaluate thermal stress in slaughterhouses.

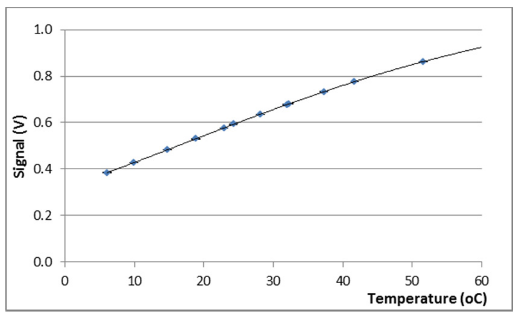

Fig. 3. Typical thermistor calibration curve.

Each thermistor was individually calibrated in water (thermostatic bath) using as reference a thermometer TESTO 735-1 (uncertainty equals to 0.01 °C). A fourth-order polynomial calibration curve was generated for each sensor with a R^2 better than to 0.999 (Fig. 3). The maximum combined error is 0.1 °C in the 5 to 40 °C range.

It was used three Surface Temperature Module per worker attached to the hand, foot and back (Fig. 4). The thermistors have been fixed with micropore tape directly on the worker's skin (Fig. 5). The gloves and socks were put on directly over the sensors. The ear temperature sensor was placed around a silicone earplug.

3.4 Environmental Measurement Module

The Environmental Measurement Module has a very similar block diagram to the Personal Measurement Module, differing in the type of battery (a lead acid 7.5 V battery) and the charger. The relative humidity is measured by a Honeywell HIH 5030 sensor, which provides a high level linear voltage output, very low drift, low power consumption and uncertainty around 1%. The sensor was connected directly to the Xbee module ADC input. The air temperature is measured by a thermistor similar to described at Sect. 3.3. The thermistor is installed inside a forced ventilated tube (Fig. 8) to prevent error due the radiant exchanges. A micro-ventilator (20 mm diameter) is positioned downstream.

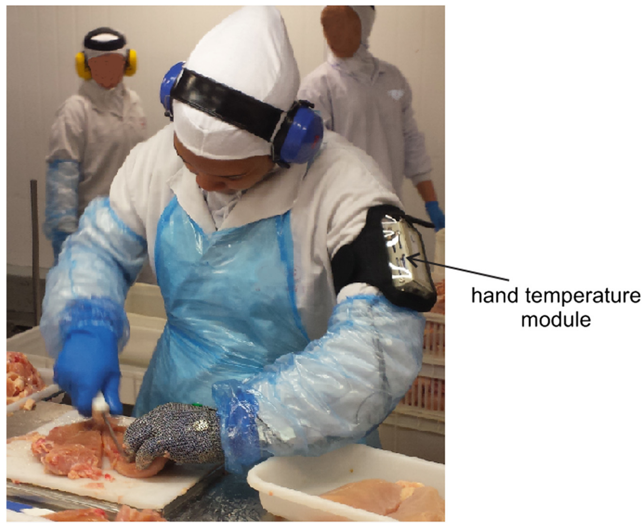

Fig. 4. Worker (Participating staff freely consented to the research protocol, which was submitted and approved by the Ethics Committee of the Federal University of Santa Catarina and fulfilled all legal recommendations. Anonymity and confidentiality of information were maintained in data record) with the Personal Measurement Module.

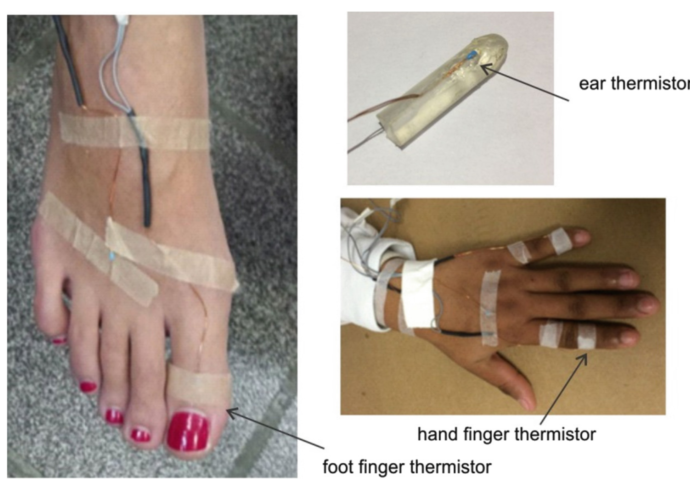

Fig. 5. Surface temperature sensors.

The air speed is measured by a thermo-anemometer made by a thermistor heated by a constant heat source. A Constantan wire (0.1 mm diameter 30 mm long), has been wrapped in the thermistor and a constant 3.3 VDC was applied. A metalic shining cap has been glued onto the assembly as show at Fig. 6.

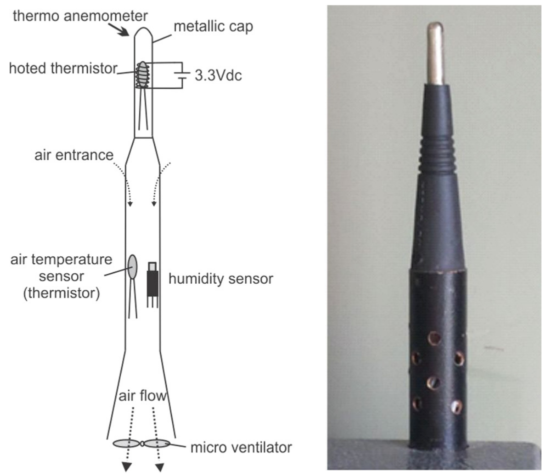

Fig. 6. Details of the anemometer, humidity and air temperature sensors.

The thermistor heats aproximately 18 K above de room temperature at zero air speed. Increasing the air speed the hoted thermistor temperature decrease. The temperature difference (Delta_T) between the hoted thermistor and the air temperature sensor is the output signal of this anemometer. The Fig. 7 shows the calibration curve using as reference a TESTO 435 anemometer, (uncertainty equals to 0.01 m/s) as reference in a wind tunel. The combined incertitude is 1% + 0.02 m/s.

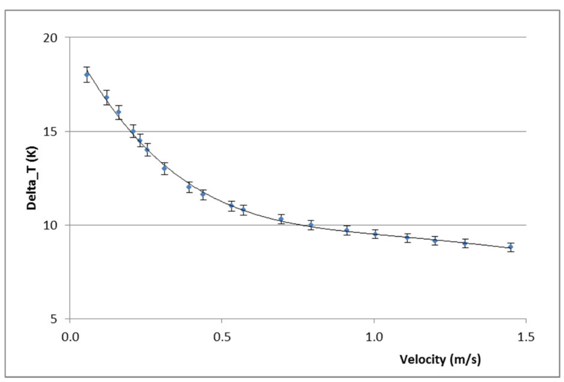

Fig. 7. Thermo anemometer calibration curve.

The globe temperature measurement consists of a hollow aluminium sphere of 150 mm diameter (thickness 1 mm) painted matte black (IR emissivity 0,93) with a temperature sensor (thermistor) at its centre. Figure 8 shows the prototype of the Environmental Measurement Module.

Fig. 8. Prototype of the environmental measurement module.

With these sensor is possible to determine de PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied). These indexes, defined by ISO 7730 and ASHRAE 55 based on Fanger studies in 1970, predicts the mean comfort response of a group of people practicing an activity and wearing a certain clothing. However this study does not take account of the discomfort caused by thermal assimetrie of the environment or the contact with hot or cold surfaces.

3.5 User Interface

The graphical user interface was developed in C++ language using Borland C++ Builder IDE for Microsoft Windows. All data received goes through a moving average filter to remove the noise and are also show to the user through a graphical interface. A post processing software allow modify the metabolic rate and clothing index (Fig. 9).

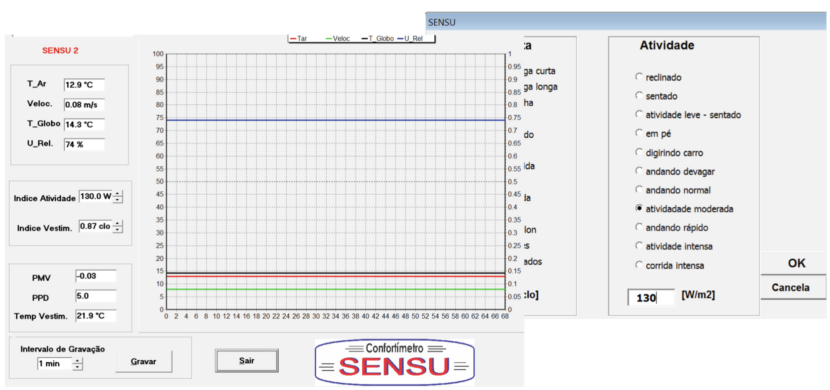

Fig. 9. User Interface.

4 Results and Discussion

A test was conducted in the sector of cuts of a poultry slaughterhouse industry located in the south of Brazil. A worker was instrumented with three surface temperature modules connected in his left hand (hand that holds the product), on his right foot and on his back. He was using a latex glove (0.15 mm thickness) overlaid with a cotton glove (1.5 mm thickness) and also a steel mesh glove (2.5 mm thickness) in the hand holding the product. He was wearing a PVC boot (4.0 mm thickness) and cotton sock (2.2 mm thickness).

The Environmental Measurement Module has been placed near to the worker and the recorded values are showed at Fig. 10-a. It can observed that the air temperature reach a minimal temperature equal 12.5 °C, not considered unhealthy by the Brazilian worker protection law.

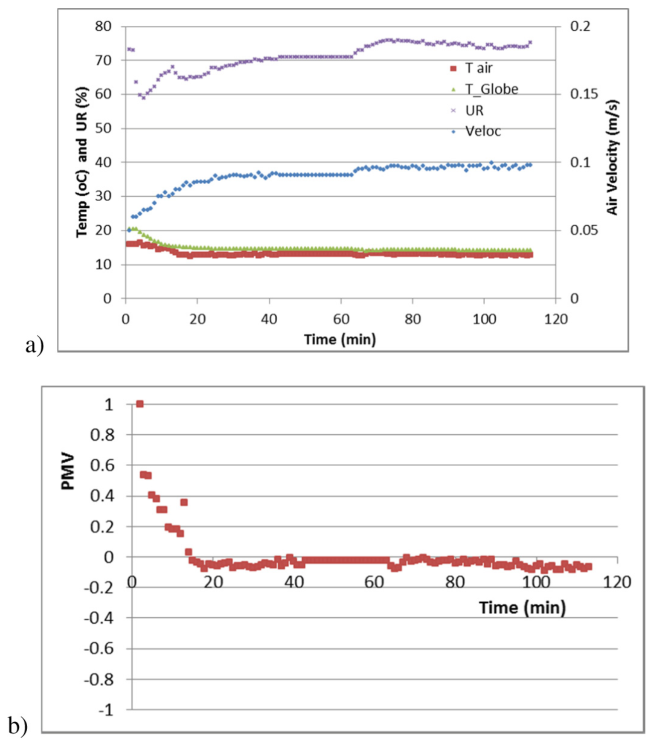

Fig. 10. (a) Environmental data, and (b) PMV values.

The PMV (Predict Mean Vote) is showed at Fig. 10-b, considering a metabolism rate equal 130 W/m^2 and a clothing index equal 0.87. These values have been respectively obtained by ISO 8996/04 for this kind of activity and by ISO 9920/0 considering the usual clothes of the workers. It can be observed that the PMV is close to zero which means that the worker are in thermal equilibrium and theoretically in thermal comfort condition. But the Fig. 11 shows the low temperature of the hand finger and the foot finger. The hand finger temperature reached 16 °C for certain period and the foot finger temperature has been between 17 °C and 20 °C during the major part of the period. Kaminski et al. [13] and Ilmarinen e Tammela [14] have been realized study in slaughtering industry where the finger temperatures were quite similar. They showed that this condition can induce health problem, particularly the Raynaud's Disease.

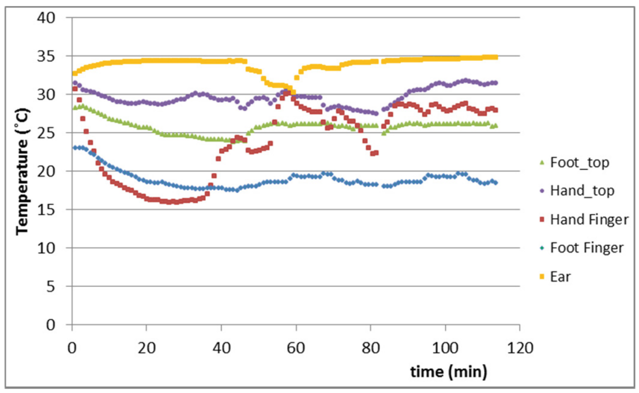

Fig. 11. Surface body temperature.

5 Conclusion

The proposed system met the design requirements, being able to acquire the worker's temperature with a precision of 0.1 °C, due to the meticulous procedure of calibrating the thermistors. Moreover, the arrangement of thermistors did not disturb the activity of the worker. The sensor responsible for acquiring environmental conditions data maintained the same reading accuracy of temperature, relative humidity and air speed data. The construction of the anemometer showed simple and it has a robustness suitable for an industrial application. The presented system has been proved as an easy and reliable way to Ergonomists and Security Engineers to evaluate the environment conditions and thermal stress inside slaughterhouses.

The tests performed in an industrial slaughterhouse showed despite an adequate PMV and a lawful air temperature, the hand and food finger temperature reach dangerous low values which may cause disease to the worker.

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