Development of Smart Device-Based Thermostatic Control System Appling on Cooling Vests

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Abstract. This paper presents a smart device-based thermostatic control system for cooling vest application. The whole system consists of three parts: a pump-based circulating cooling system, a temperature sensing module, and an Android-based application software. The smart device uses Bluetooth technology to receive temperature sensor datum from the vest. The thermostatic control App determines whether to turn the pump motor on or off in order to transmit the motor signal to the vest. One smart device can control and record multiple cooling or heating vests at the same time in order to easily manipulate and save resources. A simple experiment was designed and implemented to verify the effect of thermostatic control to the vests. The results showed that this system helps to enhance the duration of the cooling or heating system and provides high efficiency and flexibility. The future work will focus on biomedical signal monitoring and web-based remote control.

Keywords: Smart device, cooling/heating vests, thermostatic control, Bluetooth.

1 Introduction

In equator or tropical areas, cooling is important necessity for labors working in open and harzard environment. A cooling vest is a piece of equipment worn to monitor temperature and to keep the user comfortable in fields where there are in extreme temperatures. Cooling vests are developed for industry workers, athletes, soldiers and for people with multiple sclerosis or Hypohidrotic Ectodermal Dysplasia. Most portable cooling vests use a highly specific heat coolant to cool down the temperature [1]. Due to lacking temperature control, users may feel cold and uncomfortable. Moreover, the temperature stability and cooling efficiency are weakened over time passing by, and re-cooling is necessary in an hour. Some cooling and heating vests [2] use highly specific heat mediums or filtered compressed air with vortex tube technology to work as thermostatic control system. A vortex tube which forces a simple heat exchange is connected to the vest and delivers continuous cooled or heated medium through its inner lining. The temperature is easily adjusted and stays on the setting temperature.

C. Stephanidis and M. Antona (Eds.): UAHCI/HCII 2013, Part III, LNCS 8011, pp. 603–610, 2013.

The related literature [3-5] discussed different portable, wearable or implantable devices, using mobile or stationary devices such as sensors, actuators or other information and communication technology components embedded in everyday objects. Smart devices, including mobile phones or tablet PCs, can offer advanced capabilities with PC-like functionality, boasting powerful processors, abundant memory and large screens. Smart devices are able to run complete operating system software, which provides a standardized interface and platform for application developers. It is possible to develop new graphical interfaces that can be easily used to perform tasks such as clinical and sensor data management, smart sensor data exchange and alarm generation. More and more healthcare systems have been developed on smart device platforms because of their prevalence and convenience with regard to development [6-9]. Related studies have indicated that combining feedback techniques with the convenience of smart devices is promising, and people can perform desired feedback anytime and anywhere. Postolache [10] implemented a wireless Bluetooth-enabled sensing network for indoor air quality monitoring, including humidity, temperature, gases and vapors. The experimental results showed that using this smart phone-based distribution measurement system can reduce the risk of asthma or chronic obstructive pulmonary disease. Zhang [11] presented a breathing bio-feedback system based on smart phone and Bluetooth technology, and this system was capable of guiding the user to breathe slowly and deeply in an effortless manner, eventually resulting in beneficial effects on the cardiovascular system. Postolache [12] used an Android smart phone through a Bluetooth communication-linked smart wrist-worn device to confirm user health. A web-based health information system was implemented for long term monitoring of vital signs and daily activities in patients using pervasive sensing and pervasive computing. Furthermore, different web-based information system architectures have been reported in the literature on electronic health records [13].

In our study, the developed cooling vest has a circulating cooling system [14] and uses a special gel as a coolant. The circulating cooling system offers an effective way to provide convenient and controllable cold temperature to the body by circulating cool water throughout the vest. This paper describes a new design for a thermostatic control system based on a general platform – smart devices. This system helps to reduce weight and unnecessary space, as well as having more efficiency and better flexibility. The LCD screen of the smart devices is used for feedback, and a temperature sensor with Bluetooth built in is used to sense and transmit a temperature signal [15]. The smart device receives data to assure immediate processing, graphical user interface and data synchronization. The application software (App) in Android OS Smart devices is developed by combining the capabilities of Android SDK, Java, and SQLite for embedded database. The temperature of the user's skin and motor signals are presented and recorded in the App. According to the experimental data or the working environment information captured from the smart device, the App in these smart devices is able to control the cooling motor effectively. One smart device can additionally offer control and records for multi-cooling vests at the same time in order to easily manipulate resources.

2 Method and Materials

A block diagram of the implemented system is shown in Fig. 1, including Bluetooth protocols associated with data communication. The entire cooling vest with a thermostatic control system consists of a temperature sensing module, a pump based circulating cooling system, a Bluetooth module, and an Android OS smart device (smart phone or tablet PC) with a running application and audiovisual user interface. The Bluetooth connection is set up before connection. The temperature sensed from the user's skin by temperature sensor and a micro control unit, MCU 8051[16] with embedded software written in C language with low power consumption performed data acquisition, filtering and wireless transmission through a Bluetooth module. The thermostatic control application software determined whether to turn the pump motor on or off and transmitted the motor signal via Bluetooth to the cooling vest. When the temperature of the coolant is over a present temperature or the battery is running out, the App will automatically send a warning signal to alert the user.

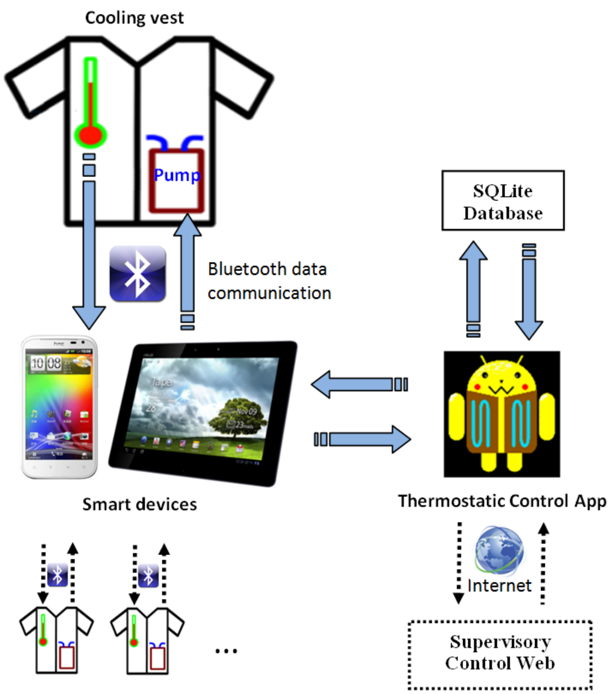


Fig. 1. Block diagram of the cooling vest thermostatic control system

As an extension of this concept, when one smart device is connected to several cooling vests at the same time, the thermostatic control App can do all the immediate controls and data representation for each of the cooling vests at the same time. If these data captured from vests and processed signals are also transmitted to a website through the Internet or a Wi-Fi Mobile Internet service, the users' temperature situation and the time to change the coolant can be monitored.

3 Thermostatic Control Application Software

The thermostatic control application software used in this study was developed in Java programming language (compiled by Eclipse IDE) with Android SDK 4.0.3 in order to implement the BT communication, thermostatic control, data management, and representation on the smart device display [17]. Important elements of the embedded software are the Activity Classes, which are mainly related to the implementation of the user interface. The presenting App implemented a set of activity classes:

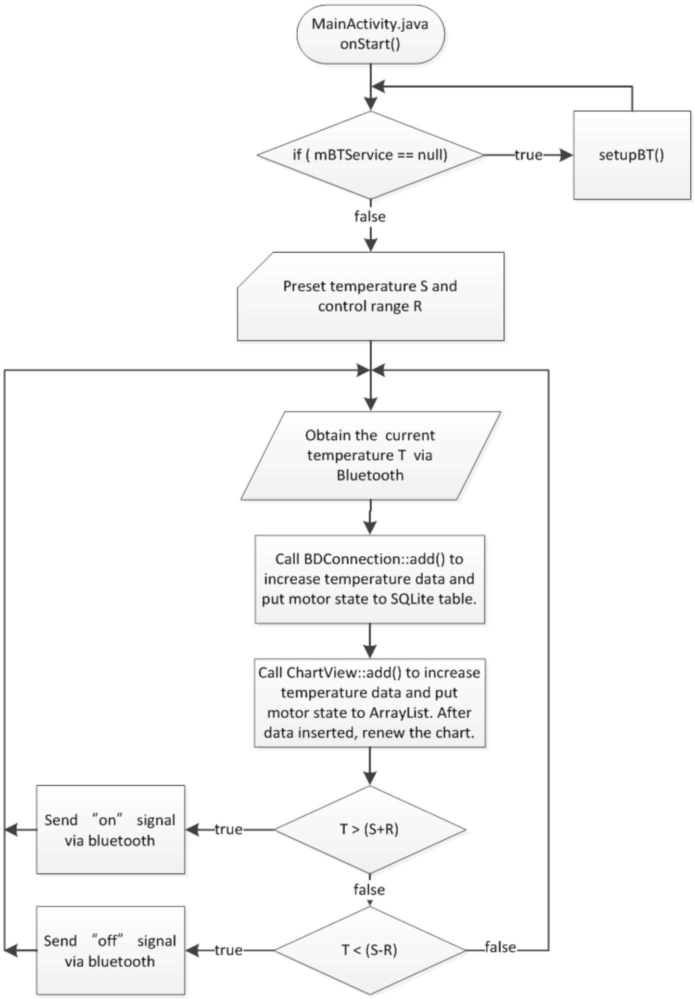


Fig. 2. The flowchart of the thermostatic control system in *MainActivity.java*

BluetoothService.java related with Bluetooth data communication which can identify the existing Bluetooth devices near the smart device and receive data in numerical format; *DeviceListActivity.java* displays a list of Bluetooth devices which are paired with the smart device. The selection of the Bluetooth-compatible module can be done manually or automatically using the information previously been stored in the smart device memory; *MainActivity.java* is the main program used to manage all the information. It also displays the data received from the Bluetooth device as well as providing graphical representation. Fig. 2 shows the thermostatic control part in the *MainActivity.java* activity class interaction with Bluetooth Service, list and chart drawing.

Additional activity classes used in the SQLite database engine are: *DBConnection.java* that sets up a SQLite table for data access, which is recorded by date to store information such as acquisition time, temperature, and the status of motor; *ListActivity.java* that inserts an Activity to display the data in the SQLite table; *ChartView.java* that draws line charts to show the temperature changes by using the charting library for Android- AChartEngine.

4 Results and Discussion

The smart devices used in this study are the HTC Sensation XL smart phone and the ASUS Eee Pad TF201, both of which run the Android 4.0.3 mobile OS. The user interface status and settings are shown at the right side of Fig. 3. The time axis (horizontal-axis) can be scaled and adjusted in order to get detailed information, and the status of the motor (on/off) is displayed in different colors. The life-expiration data on the chart is deleted automatically in order to save memory space. Fig. 4 shows the lists of SQLite data, including acquisition time, temperature, and the motor status. The list is built as a view that can be added to intent, and all the data is stored in the smart device and can be removed manually.

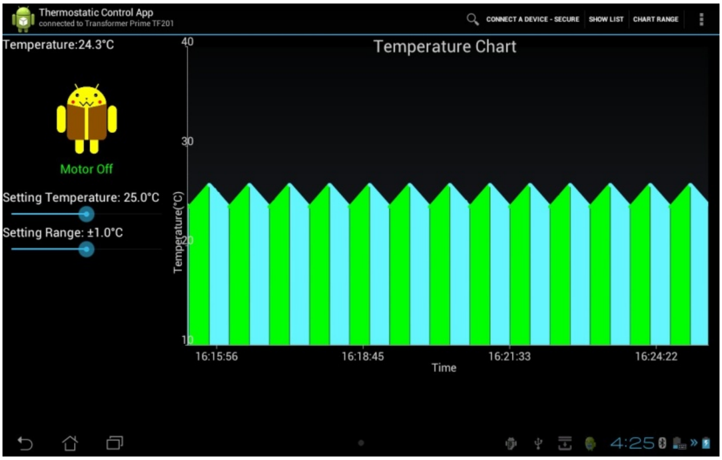
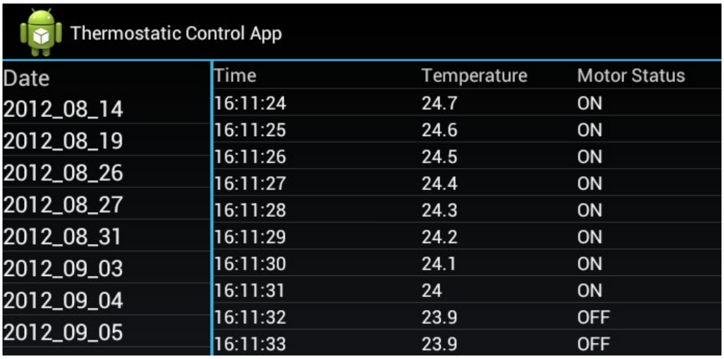


Fig. 3. The chart of recorded temperature data

A simple experiment was designed and implemented to verify the effect of thermostatic control of the cooling vests. Three pieces of circulating cooling vests were measured in the same situations (ambient: 32℃, skin: 35℃, coolant: -7℃, setting temperature: 24.5℃, control range: 0.5℃). One of the vests was without thermostatic control; the others were both monitored by the App. A lightweight type cooling vest had 250 mg of coolant gel and 210 mg of circulating water, and the other vests had 400 mg of coolant gel and 300 mg of circulating water. The results are shown in Fig. 5.


Thermostatic Control App

Date	Time	Temperature	Motor Status
2012_08_14	16:11:24	24.7	ON
2012_08_19	16:11:25	24.6	ON
2012_08_26	16:11:26	24.5	ON
2012_08_27	16:11:27	24.4	ON
2012_08_31	16:11:28	24.3	ON
2012_09_03	16:11:29	24.2	ON
2012_09_04	16:11:30	24.1	ON
2012_09_05	16:11:31	24	ON
	16:11:32	23.9	OFF
	16:11:33	23.9	OFF

Fig. 4. The list of recorded temperature data

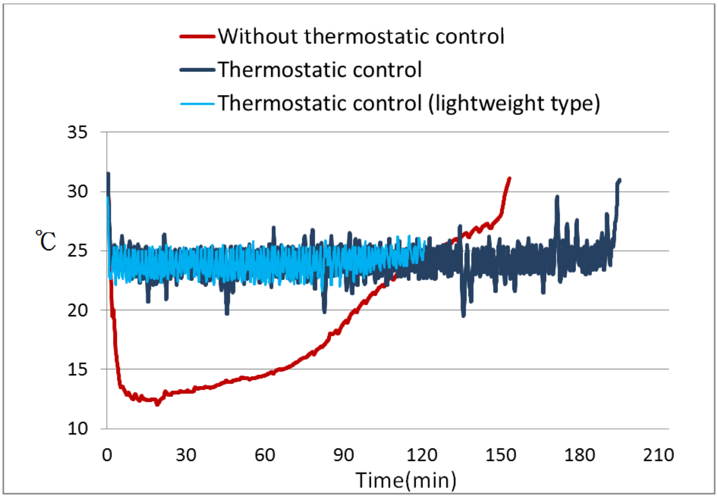


Fig. 5. The experimental results

The results showed that the cooling vest without thermostatic control is not able to provide a comfortable and stable temperature for the user. Even when using the circulating cooling system, it was still colder than the setting temperature in the beginning and lost its cooling effect after 2 hours. The cooling vest with thermostatic control gave the user a stable temperature for up to 3 hours, and the lightweight type stayed cold for almost 3 hours (170 minutes).

5 Conclusions

Smart device technology is getting more and more powerful in its specifications, and the adoption *rate* of *smart devices* is 10X faster than during the 80s PC revolution. It is an interesting idea that someday an embedded intelligence system in portable products might be superseded by smart devices, and we implemented this concept on a circulating cooling vest. In this paper we developed a novel thermostatic control App based on smart devices and Bluetooth technology, and a simple experiment was executed to verify the feasibility. This application platform receives temperature information from user's skin via Bluetooth and provides a corresponding reaction to the motor of a circulating cooling system. Using smart device, the heat exchange situation can be dynamically adjusted, and coolant waste can be reduced in order to enhance the duration of the cooling system. The interface also provides *real-time audible* and *visual feedback* for the *user*.

Future work will additionally involve simple biomedical signal monitor on the cooling or heating vest in order to provide the latest and complete information for workers/users in extreme temperature areas. We also plan to focus on remote control - a web based information system that can monitor and ensure whether individual cooling vests and smart devices are working or not. Furthermore, data backup and the planning of coolant replacement time could be done on the server-side. Base on the experiment in this study, this smart device-based application could be used on medical instruments or other embedded intelligence systems, especially for applications in the field of medical care.

Acknowledgement. The study is granted by National Science Council, Taiwan, under the project number of NSC 101-2815-C-006-042-E.

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