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Development of Flexible Self Adhesive Patch for Professional Heat Stress Monitoring Service

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Abstract-**Too much exposure in a very hot environment can cause heat stress which leads to the fatal heat stroke. To prevent heat stress related diseases, fle xible self adhesive patch for professional heat stress monitoring service has been developed. By using Flexible printed circuit board (PCB) and Silicone based packaging, high level of robustness and ease of usage has been accomplished. This patch can be repeatedly attached to the chest of the user with comfort. And it can stand the sweat and be washed with water to reuse. For this patch is small in size (9 cm triangle shape) and light in weight (55g), it can be used in the most demanding situation. To analyze the heat stress of user, it records 1 lead electrocardiogram, body temperature, humidity and 2-axis acceleration. It's Bluetooth ™ communication module can connect various terminal device according to the configuration. With the body weight input by user and 3 week work log it can estimate user work load, acclimatization, total amount of work done, wet bulb globe temperature (WBGT) index, which is the screening criteria for heat stress exposure.**

I. INTRODUCTION

On May 29, 1997, a 21-year old firefighter died, another firefighter was overcome by heat stroke and two others by heat exhaustion during the construction of a fire line during a wild land fire in California, USA. The investigator concluded that in order to prevent future occurrences, fire agencies should require supervisors to regularly monitor firefighters, using generally accepted methods during periods of high heat stress [1].

Korey Stringer, a lineman with the Minnesota Vikings football team, died from heat stress during preseason practice on July 31, 2001. His death occurred just one week after a Florida freshman football player, Eraste Autin, died of complications related to heat stroke following a voluntary summer conditioning session.

As we can see in these tragic accidents, there is occupational risk related to the heat stress. Too much exposure in a very hot work environment can cause both acute health effects and chronic health effects. Examples of acute health effects are heat stroke, heat exhaustion, heat cramps, fainting and decline of performance. Examples of chronic health effects are loss of ability to tolerate heat, hypertension, heart muscle damage, reduced libido and sexual impotence [2].

Estimated 220 workers in Canada and the United States die annually from occupational heat stress. Furthermore as global climate change makes summer even hotter; it will be more important problem. A record heat wave scorched Europe in August 2003, claiming an estimated 35,000 lives [3]. Besides firefighters and football players, examples of high risk professions are policemen, soldiers, agricultural worker, construction workers and blasting furnace workers. To prevent the heat stress, a method to assess the heat stress exposure and a method to alarm the user about heat hazard is required.

It is commonly accepted that occurrence of heat stress related disease depends on the temperature, humidity, physical work and acclimatization. In hotter conditions, where the temperature is significantly above 25°C, the body must try to shed heat to maintain thermal equilibrium. The evaporative cooling of sweat from the skin becomes an important cooling factor. The efficiency of this cooling depends environmentally on the humidity. A high humidity reduces the effectiveness of evaporative cooling significantly. The amount of clothing will also affect this cooling efficiency due to its restriction of the air flow over the skin and increasing the air humidity near the skin.

Especially wet bulb globe temperature (WBGT) offers a useful, first-order index of the environmental contribution to heat stress. By comparing naturally ventilated wet bulb glove temperature and the dry bulb glove temperature, the four main environmental parameters –temperature, relative humidity, radiation effect, air flow- that affect heat stress can be measured. It is specified in ISO 7243 under 'Hot Environments.' Estimation of the heat stress on is based on the WBGT-index.

The previous method for heat stress monitoring service is on site deployed heat stress monitoring device. Though the system offers valuable information about temperature and humidity, this kind of devices has the limitation that it can not consider the effect of the work load and acclimatization. Furthermore because these devices measure humidity and temperature at environmental atmosphere, it can not measure humidity and temperature inside of protective suit which is more direct representative for human heat exposure.

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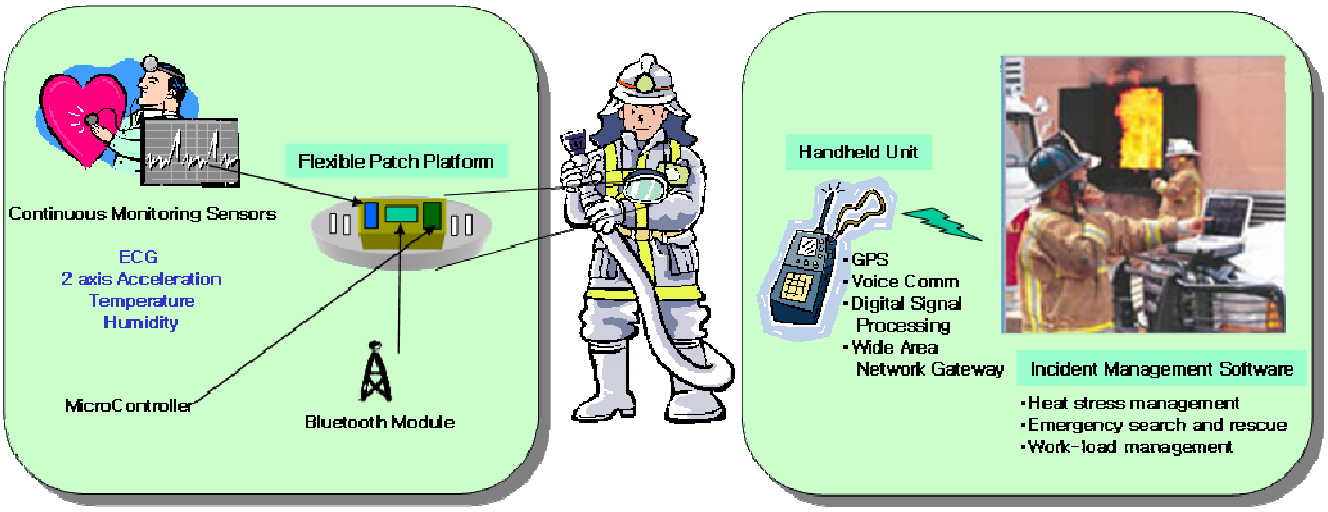

Fig. 1. System Block diagram of Professional Heat Stress Monitoring Service

To improve current standard for heat stress monitoring service, we developed flexible self adhesive patch for professional heat stress monitoring service. The target user groups are people whose jobs are hazardous like soldiers, police, firefighters, athletes. Figure 1 shows the system block diagram of professional heat stress monitoring service. The user attach flexible patch for heat stress monitoring. The various factors that determines heat stress exposure is sent wireless to the management system to respond for given situation.

II. MATERIALS AND METHOD

The novel approach in our work can be divided in four sections. First we will analyze the usage scenario and user requirements. Then we will design the sensor board according to it. Second the packaging technique to enable its robust and comfortable use will de explained. Third the communication system will be explained. And the algorithm design for heat stress detection will be explained.

A. Sensor Design

As explained in introduction, the heat stress depends on the temperature, WBGT, work load and acclimatization. Previous on site heat monitoring device can detect only temperature and WBGT index in atmosphere. Figure 2 shows our strategy to overcome this limit.

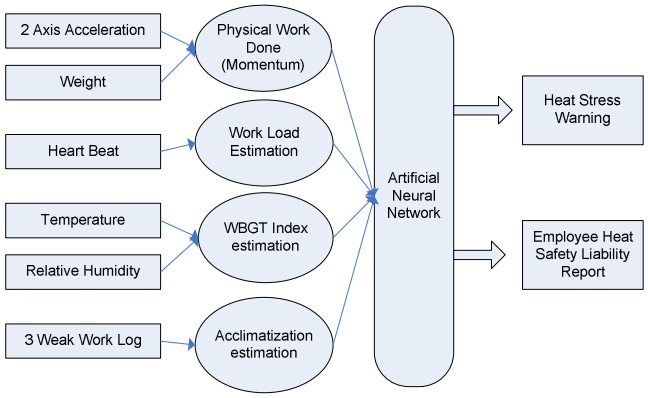

Fig. 2. Data flow chart for heat stress management service

By combining the acceleration data and the weight input by user, total physical work can be estimated. This estimation is for those people whose job involves mainly moving the whole body like athletes. But for those people whose job involves mainly moving arms and legs, this estimation does not apply well. To overcome this problem work load estimation can be used. It is commonly known that heart beat represents work load [4]. To measure the acceleration 2 axis accelerometer (Analog Device, USA) was used. And to measure heart beat 1 lead electrocardiograph (ECG) was used. To measure the temperature and relative humidity a single chip temperature and relative humidity sensor (Sensirion, Swiss) was used. The relative humidity of a gas strongly depends on its temperature. Therefore it is essential to keep humidity sensors at the same temperature as the air of which the relative humidity is to be measured. With single packaging the distance between sensors is 0.1um. it is the advantage of using single chip solution.

Acclimatization is a process of adaptation that involves a stepwise adjustment to heat over a week or two. Once acclimatized, the body will sweat at lower skin and body temperatures resulting in a lower accumulated heat load on the body. While the person's current status of acclimatization is hard to measure, estimation is possible by analyzing the previous work log.

B. Packaging Design

To be used practically in professional work environment, the device worn by user should satisfy following requirements:

- Minimal constriction
- Water-proof
- Light weight
- Easy and quick installation

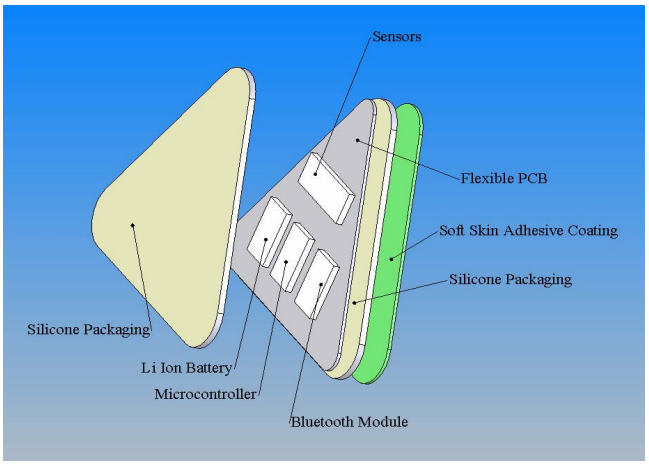

Fig. 3. Developed Flexible Patch with Silicon packaging

- Low cost
- Adapt to various physical shape

To satisfy these requirements, the following approach was used:

- Flexible printed circuit board
- Silicone rubber packaging
- Silicone rubber adhesive
- Lithium ion rechargeable battery

Due to the FPCB and silicone rubber packaging the total system is flexible and can be attached to the user's chest. The silicone rubber adhesive can be washed and used repeatedly.

C. *Communication Design*

To enable the real time management of the heat stress, acquired sensor data should be passed to the central monitoring station. The communication specification will vary according to the situation in which the device is used. So the communication is divided into personal area network and wide area network. Bluetooth was used for personal area network. Various personal gateways with Bluetooth module can be used for wide area network. Figure 4 show

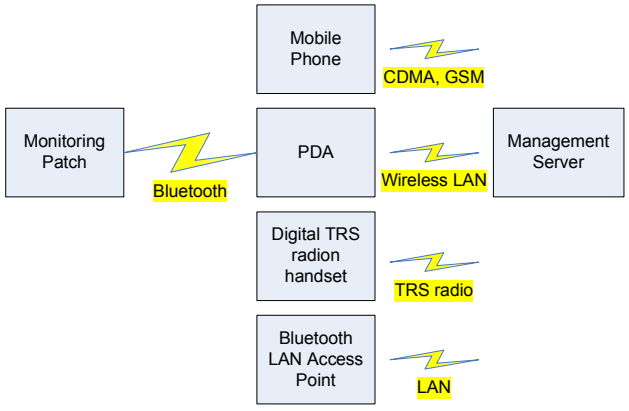

Fig. 4. Various communication schemes using Bluetooth Personal Area Network

TABLE I
Screening Criteria for Heat Stress Exposure
(WBGT values in ˚C)

	Acclimatized				Unacclimatized			
Work Demands	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
100% Work	29.5	27.5	26		27.5	25	22.5	
75% Work 25% Rest	30.5	28.5	27.5		29	26.5	24.5	
50% Work 50% Rest	31.5	29.5	28.5	27.5	30	28	26.5	25
25% Work 75% Rest	32.5	31	30	29.5	31	29	28	26.5

examples of wide are network.

D. *Analysis Algorithm Design*

Table I shows screening criteria for heat stress exposure provided by American conference of governmental industrial hygienist (ACGIH) [5]. This offers initial start point of analysis.

The work demands used in this table should be estimated from heart beat. And the acclimatization estimation is based on users work log. Working and rest classification can be done by analyzing acceleration data.

The WBGT values are based on the four factor which are air-flow (wind), air temperature, air humidity, and radiation (the sun and nearby hot surfaces). However there exists an approximation assumes a moderately high radiation level in light wind conditions [6]. WBGT values can be estimated from temperature and water vapor pressure using the following equation:

$$WBGT = 0.567 \times Ta + 0.393 \times e + 3.94 \quad (1)$$

where Ta is Dry bulb temperature (°C) and e is Water vapor pressure (hPa)[humidity]. The vapor pressure can be calculated from the temperature and relative humidity using the equation:

$$e = rh / 100 \times 6.105 \times \exp(17.27 \times Ta / (237.7 + Ta)) \quad (2)$$

where Rh is relative humidity [%].

III. RESULTS

Flexible self adhesive patch for professional heat stress monitoring service has been developed (Fig. 5). The shape of the system is triangle with side length of 90mm. The weight of the system is 55g. Power consumption is 15mA without Bluetooth module. Bluetooth module alone consumes 20mA when transmitting. The maximum power consumption of the Bluetooth module is 60mA when scanning for the nearby Bluetooth module. Battery capacity is 180mAh and the battery size is 30 mm by 18 mm. The estimated working hour is more than 4 hour. Microcontroller 16LF877 from PIC is used. It has 8 built-in Analog to digital converter of 10 bit resolution. 3 dry

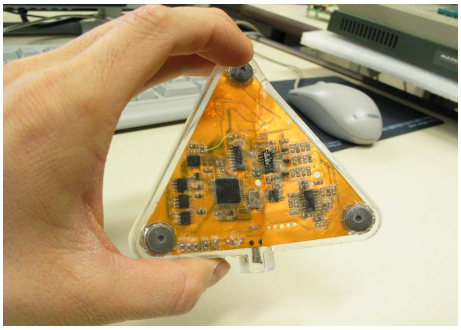

Fig. 5. Developed Flexible Patch with Silicon packaging

Ag/AgCl electrodes without gell was used for 1 lead ecg monitoring. Temperature accuracy is 2%. Humidity accuracy is 0.3˚C. Acceleration accuracy is 0.01g. Dow Corning 7-9800 is used for Soft skin adhesive. Figure 6 shows the screen of the monitoring software. However at current point, the heat stress analysis algorithm is not yet completed. As we can see in fig. 7 the flexible patch can be bended according to the user's shape which improves signal integrity.

IV. DISCUSSION

The wearable health monitoring system has many requirements to be used practically. Flexible self adhesive patch for professional heat stress monitoring service developed has the following advantage over jacket type wearable monitoring system. Though the jacket type monitoring system shows necessary functions, for daily use the user have to have 3~4 pieces of jacket type monitoring system, which will contribute system cost. For example, firefighters have sweat, so the jacket type inner wear have be washed. Furthermore it takes more time to take on these clothes like system.

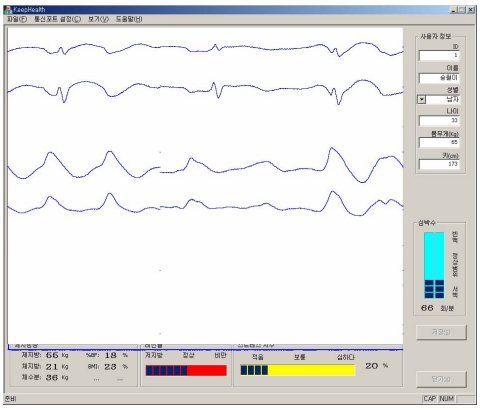

Fig. 6. Screen capture of the PC monitoring software

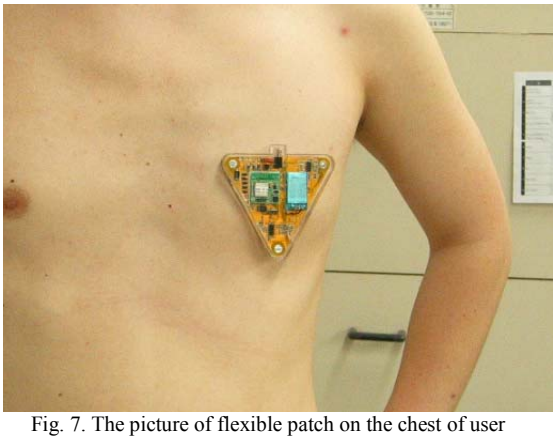

Fig. 7. The picture of flexible patch on the chest of user

IV. CONCLUSION

We developed flexible self adhesive patch type system for professional heat stress monitoring system. With the future development of the employee safety management system, this will contribute to increase worker's safety.

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