A Wearable Intelligent System For Real Time Monitoring Firefighter's Physiological State and Predicting Dangers

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Abstract: Since firefighters usually work in high risky working conditions, like high temperature, toxic gases, flames, explosion or collapse. It is extremely important to monitor their physiological states by analyzing in real time the firefighter's information on their health states. Moreover, it is certain that transmitting the firefighter's physiological information to the fire information center by wireless network is an important task for ensuring firefighter's safety. For this purpose, we propose a wearable intelligent system, which is embedded into the firefighter's garments, permitting to estimate the physiological state of firefighters according to the data from the embedded physiological sensors and transmit the relevant information to the command center by wireless network. The system can also collect environmental information, like air temperature and CO2 (smoke level), which is useful for evaluating the gravity of the risk scenario and sending predicted warning messages in advance.

Keywords: Firefighting safety; Mobility monitoring; Wearable system; Risk scenario evaluation

1 Introduction

Nowadays, since the frequency and scale of fire disasters are increasing [1], a great number of firefighters lose their lives due to the fact that they have no time to escape from the fire filed [2]. This phenomenon can be caused by many reasons like physical stress, unconscious, badly injured, etc. However, despite the excellent performance of novel protective equipment and garments, the death rate of firefighters has been steadily increased [3]. In this situation, for the designer of the firefighters' garment, it is a tough job to keep a balance between personal protection and mobility. On one hand, firefighters should wear heavy protective garments to protect themselves from thermal injury, on the other hand, the high shielding performance weaken the sensory and cognitive abilities on the environment, especially the fire [4]. What's more, in the strenuous fire fighting action, firefighters can easily get exhausted by wearing the heavy protective garments [5], which may make the firefighters not easy to evacuate from the fire filed.

Most researches about the firefighter's protective garment are concentrated on thermal performance improvement [6]. Some paper proposed the sensor-based systems for protecting firefighters from thermal injury [7]. The intelligent garments designed by Viking Life-Saving Equipment Company integrated thermal sensors into the fabrics [8], and it will flash with different frequencies when the temperature in the fire filed changes. In this way, the firefighters can get environmental information from the garments wore by his teammates or himself. European Union develops the sensor network to promote the project of developing intelligent garment systems [9] that can get information of the fire-related field and monitor the individual biological abnormalities on firefighters. Thus, it enables crisis commanders to remotely monitor the evolution of the fire. Researchers at Worster Polytechnic Institute in the United States are scrambling for the test to develop a sensor system [10] that can protect firefighters by measuring the temperature of fire ignition on a real-time basis before the temperature reaches at the point of flashover. Luprano developed an intelligent garment system with the sensor network that can detect the risk factors on the fire and monitor the individual biological abnormality on a firefighter [11]. However, most of the existing studies on firefighter garments are restricted to thermal sensors. It is hardly to find a paper proposing the fire-field network system to show the physical states of individual firefighter through the real-time based vital sign monitoring such as temperature, heart rate, etc.

In this paper, we propose a wearable intelligent system in order to protect the firefighters and transmit in real-time the individual information to the command center. The system consists of an accelerometer sensor, a heart-beat sensor and other fire-related sensors to acquire environmental information like temperature and smoke level. With all these data, the system can estimate the physiological state of firefighters and send warning message before the arrival of danger. The system can also transmit information to the command center though the ZIGBEE network.

The rest of this paper is organized as follows. Section 2 provides a intelligent garment for firefighting. Section 3 describes a monitoring sensing system model for firefighting. Section 4 shows system analysis and evaluation for the proposed system of Section 3. Finally,

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conclusion and future works are given in Section 5.

2 Intelligent garment for firefighting

2.1 Sensors and components of the garment

The intelligent garment of Figure 1 can be largely divided into three components including physiological sensors, fire-related sensors and computing node. Firstly, the physiological sensors consist of many bio-sensors like temperature sensor, heart-beat sensor, accelerometer sensor for checking the condition of the firefighter's body in real-time. Secondly, the fire-related sensors that including field-temperature sensor and smoke sensor can be activated in the real-time mode when the firefighter get into the firefighting field, which are able to collect

Figure 1 Firefighting garment model

the environmental information automatically. Finally, the computing node, which embedded with a digital signal processor and a ZIGBEE communication module, can analyze data from the sensors and be connected to the external network by wireless links.

2.1 Functions of the firefighting garment

First of all, the firefighting garment should provide functions that protect the firefighters from the dangers in the fire field [12]. To prevent the inside dangers, like exhaustion, dehydration and unconsciousness, the garments collect and analyze the data from the body-temperature sensor, heart-beat sensor and the accelerometer sensor. Then it comes out the physiological state of the wearer. If there is any sign of inside danger, a warning message will be sent to both the firefighter and the command center by buzzer and the wireless network. As to the outside dangers like high temperature, toxic gases, if all the data are collected by one node in one spot, the result might be inaccurate. So a sensing network that can collecting environmental data from all the wearers in the fire field is desperately in need to determine the firefighting team should evacuate or not.

3 Monitoring sensing network

By monitoring the firefighter's physiological signal (heart rate, activity, body temperature.), collecting the environmental information and transmitting it to the command center through a real-time communication, the monitoring sensing network should enhance the safety level of the firefighters and improve the efficiency of the firefighting action [13]. The structure of the monitoring sensing network is shown in Figure 2.

First, the firefighting garment senses the wearer's mobility and monitors the physiological status of the firefighters through the embedded sensors. In the wireless sensing network of Figure 2, it also collects the information of local environment through fire-related sensors. The computing node in the garment analyzes the collected information in a short time and relays the status data to the mobile station through a ZIGBEE network for team monitoring and cooperation.

Second, the mobile station provides an agent monitoring for the firefighting team in the fire field. It can combine information collected by each firefighter and evaluate the danger level of the fire field. If the condition of the fire field was so harsh that the firefighting action should be aborted, an emergency message will be sent to all the wearers of the firefighting garments. In the opposite, if one of the garments reports that its wearer was not in a good physiological state or, even worse, unconscious, the mobile station will send a message to call him back or send the rescue team. What's more, all of the data and message will be uploaded to the cloud via 4G network.

Third, as a central monitoring node, the rescue command center finally downloads the data of sensors and emergency messages that provided by the firefighting garments and mobile station. After that, it performs a long-term analysis to improve firefighting strategy in order to increase efficiency of firefighting action and safety level of firefighters. In addition, it can also offer a backup service for the mobile station.

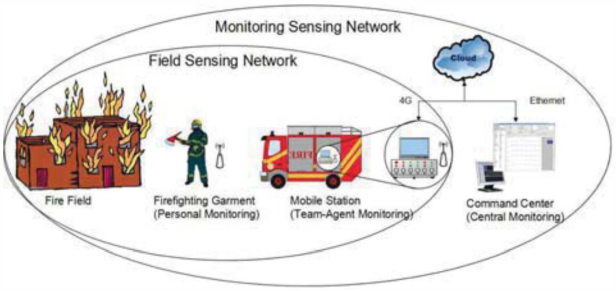

Figure 2 The structure of the monitoring sensing network

4 System analysis and evaluation

In the data analysis, the physical activity, body's posture and heart rate of the firefighters are three main parameters for determining the physiological state of the firefighters.

First, by embedding the three-axis accelerometer sensor into the garments, we can get the accelerated speed of the firefighters' movements in real time. Then the value

of 'G' will represent the level of the firefighters' activities. The higher the 'G' is, the more strenuously the firefighters move. Based on previous action, we can determine the G_{max} and G_{min} that represent the highest level and static level of the firefighters' activities respectively. Unfortunately, only one parameter is not enough in the evaluation of the firefighters' physiological state. For example, if the value of 'G' is higher than G_{max}, it is apparently that the firefighter is moving quick and will be exhausted in short time, but if the 'G' is lower than G_{min} which means the firefighter is in a static state, we can not distinguish resting from unconscious except we know his body is standing or lying.

Second, with the accelerometer sensor, three vectors, X, Y and Z, that represent the accelerated speed of the firefighters in three directions will be obtained. Then we can find θ which is an angle between the firefighter's body and the ground as shown in Figure 3.

$$\theta = \tan^{-1} \frac{|Z|}{\sqrt{|X|^2 + |Y|^2}}, \quad (1)$$

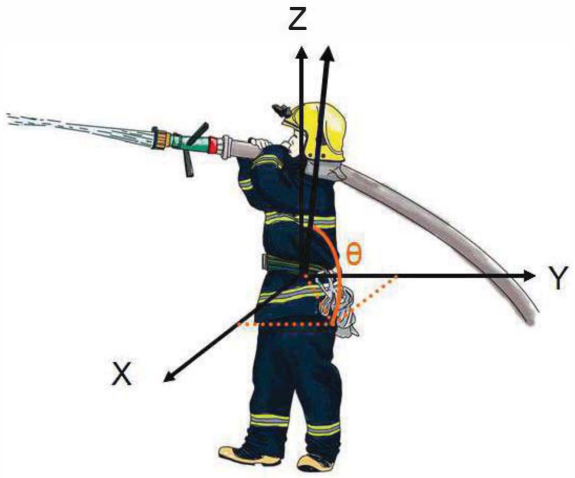

Figure 3 Angle between the firefighter's body and the ground

Normally, the θ should be between 60° and 90°. If it's lower than 30 degree for a long time, it means that the firefighter is lying on the ground and might be unconscious.

Third, the heart rate of the wearer can also be collected by the heart-beat sensor. And two critical values, R_{max} and R_{min}, can be determined through analysis of the previous data. The R_{max} means the highest heart rate that the firefighter can keep his strength to carry on the firefighting action. The R_{min} means the wearer's heart rate is lower than the normal level and might be injured.

Combined with the three parameters, we can use the two-dimensional diagram to evaluate the physiological state of the firefighter. As shown in Figure 4, the whole range of the data are classified into nine sections by four values, G_{max}, G_{min}, R_{max} and R_{min}.

Section 1 and 4 means the firefighter move normally with lower heart rate, it might caused by unstable connection between the heart rate sensor and the skin. The rescue commander needs to make a radio contact with the firefighter in order to confirm his physical state and his environment. Section 2 means that the firefighter is in strenuous activity and might need rest soon. If the firefighter is in section 3, 6 and 9, it means that the wearer is moving strenuously and in the danger of been exhausted unless resting immediately. Section 5 is a normal area and in most of the time during the firefighting action, the activity level and heart rate of the firefighters should be kept in this section. Section 7 means the wearer is not moving with lower heart rate, which is not optimistic. He might be unconscious and injured. If radio contact is not responded, a rescue team should be sent in no time. Section 8 is a challenging one which means the wearer is static but have normal heart rate. In order to distinguish unconsciousness from resting, we have to use the third parameter θ. If the wearer is lying instead of standing, he might be in the danger of unconsciousness.

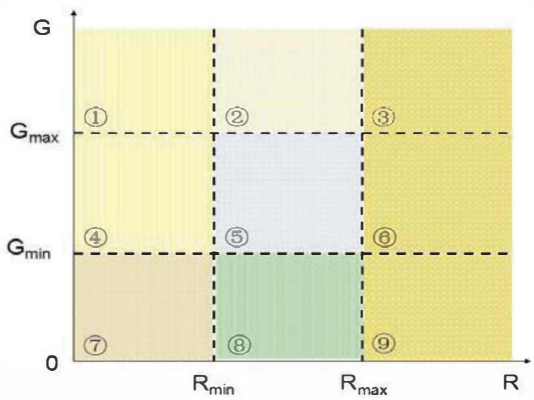

Figure 4 two-dimensional diagram for evaluating the physiological state of the firefighter

5 Conclusion

This paper proposed a wearable intelligent firefighting garment to monitor the firefighter's physiological state and environmental information. In addition, it proposed a method to evaluate the firefighter's physiological state and predict dangers.

Firefighter injuries remain a significant and preventable public health problem, and this garment is one approach that with strong implementation has the potential to reduce the risk of injury. Our future research will be applied to the specific application areas by extending the results of this study, and will build a more practical model for evaluating the firefighter's physiological state.

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