Design of an IoT-Based Mountaineering Team Management Device Using Kalman Filter Algorithm

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Abstract

The heart rate and body temperature for the mountaineering user is very import to detect their life risk factor. Amidst the emergence of wearable and Internet of Things (IoT) devices, exercise- and leisure-related wearable devices have exhibited the most growth in popularity. While many exercise-related wearable devices are available, few have been designed for group interactions. This paper proposes an IoT-based mountaineering team management device to effectively assist mountaineering guides in leading mountaineering teams. The device can monitor the real-time physiological status and coordinate of each team member, and uploads the information to the cloud service platform via the fourth-generation (4G) mobile Internet. We used an unscented Kalman filter (UKF) to reduce the data influence of motion since the user's heartbeat and temperature are unstable during the motion of mountaineering. When an abnormal event occurs, the device allows the guide to immediately acquire the real-time information of each member. If accidents occur or team members become lost, the device enables quickly locating the lost members. Additionally, the device can be used to make announcements to all team members. The proposed device can immediately and effectively assist mountaineering guides managing mountaineering teams, thereby improving mountaineering safety.

Keywords: Wearable device, IoT, Mountaineering team management, Kalman filter

1 Introduction

Since 2009, wearable devices have been introduced to the consumer electronics market, exhibiting a substantial popularity growth in recent years. Exercise- and leisure-related wearable devices have exhibited the most observable growth, which explains the growing number of studies related to these devices [1-7].

Wearable devices [1-7]: wearable devices for exercising and fitness (e.g., smart watches and heart rate wristbands) can be found worldwide. These devices can conduct various functions for the user, including pulse monitoring, calorie expenditure calculation, and exercise distance and speed recording. Numerous firms have produced original wearable device brands. Examples are shown in Figure 1.

Figure 1. Types of wearable devices

The Internet of Things (IoT): IoT is considered the third information revolution, following the prevalent uses of computers and the Internet. In general, the IoT involves a wireless network. Because each person has 1000-1500 devices installed around them on average, the worldwide IoT may possibly consist of 500-1000

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trillion devices. Everyone can theoretically use electronic labels to connect physical objects to the network, enabling users to locate object positions and conduct centralized management and control [8-13]. Additionally, data collected from each device can be gathered to form big data. These data can be used in numerous areas, including the transportation and logistics, health care, smart environment (i.e., house, office, and factory), and private and public domains; demonstrating extensive market potential [14-18]. [26] proposed a novel wearable thermoelectric generator (TEG) device for powering electronics by harvesting human body heat. [27] study involving rehabilitation therapy based on swimming exercises was performed.

This paper proposes an IoT-based mountaineering team management device designed to effectively assist mountaineering guides in leading mountaineering teams (Figure 2). Our proposed system is characterized by an IoT architecture based on multiple people. It different from the IoT devices on the market and it can be managed by a team of multi-person. Through the network connection between the devices, one-to-many communication can be performed to achieve the purpose of multi-person team management based on the IoT. Figure 3 is a schematic diagram of the system communication in the team management mode. In the other hand, our proposed system is difference to the smartphone. The smart phone can not provide the precise heart rate and also can not provide the user's body temperature. Our proposed system is according to the life risk factor to detect the mountaineering physiology. The device enables guides to monitor the real-time physiological status and coordinates of team members. When team members are lost or in danger, the device can quickly locate their positions. Additionally, the device can be used to make announcements to all team members. We constructed the device using IoT concepts, linking it to cloud servers through fourth-generation (4G) mobile Internet. Data are processed by cloud servers, enabling monitoring of mountaineering team status. Our proposed system will store the map in our memory system when not accessing the map data through cloud. When the user is in disconnect situation, our proposed system can provide the correct location by GPS signal.

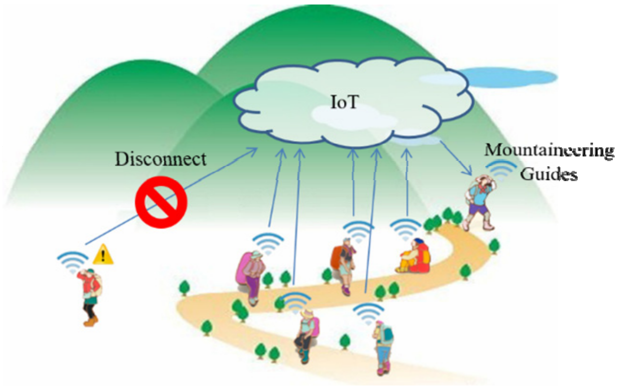


Figure 2. Mountaineering team management device concept

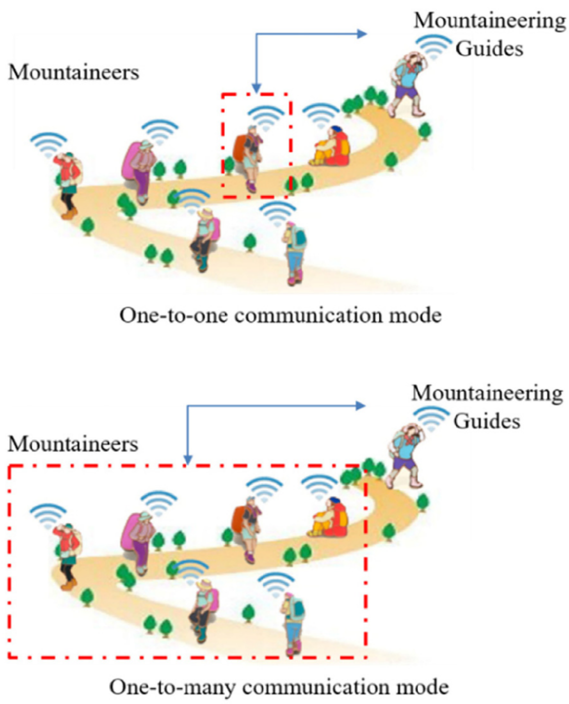


Figure 3. System communication in the team management mode

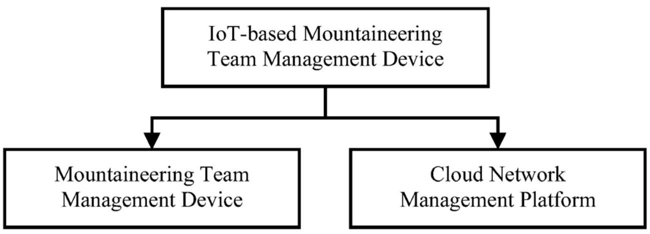


Figure 4. System framework

2 System Design

The system consists of two parts; the mountaineering team management device and the cloud network management platform (Figure 4). The mountaineering team management device measures the physiological statuses of team members and uploads their data to the cloud network management platform using the 4G mobile Internet.

2.1 Mountaineering Team Management Device

The proposed mountaineering team management device includes a central processing module, GPS module, temperature sensor module, heart rate sensor module, MP3 module, and wireless transmission module (Figure 5). When the device is disconnected the cloud to make sure the system working, our system had chosen these sensors for detecting the physiology signal. The central processing module integrates data from all other modules and uploads it the cloud network management platform. If the device determines a team member is in danger or receives commands from the guide, the MP3 module plays the corresponding warning alarm. Extensive description of each module is provided in the following text.

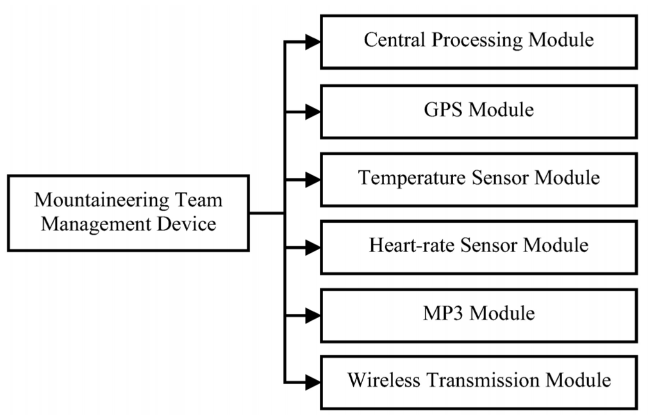


Figure 5. Mountaineering team management device framework

2.1.1 Central Processing Module

In addition to the Arduino Mini microcontroller board, the central processing module (LinkIt Smart 7688 Duo module [7]) features a built-in Wi-Fi module, Mini-SD memory card module, and 1G CPU. Our system is running on Linux and the hardware device is developed with Arduino. Linux is the supporting operating system for the Wi-Fi module, which was coded using Node.js.

2.1.2 GPS Module

The VK2828U7G5LF GPS module features a high-accuracy antenna with 2.5-m horizontal error. It is capable of receiving signals from up to six satellites. In addition to locating coordinates, the module can measure altitude and determine the standard time of the region. The module also features a built-in gyroscope capable of measuring movement direction, velocity, and acceleration.

2.1.3 Temperature Sensor Module

The MLX90614 infrared thermometer is a highly accurate noncontact temperature sensor module used to measure the current target temperature.

2.1.4 Heart Rate Sensor Module

Pulse Sensor is a photoelectric reflective sensor used for pulse measurement. The recorded pulse signals are transferred to Arduino, which then converts the signals into numerical data and calculates the pulse rate.

2.1.5 MP3 Module

The MP3 module (DFPlayer Mini) supports a 48-KHz sampling rate, features 30 different volume levels, and plays MP3, WAV, and WMA audio files. Its main function is to enable Arduino to play audio files.

2.1.6 Wireless Transmission Module

The wireless transmission module was built into the LinkIt Smart 7688 Duo. Our system adopted the 4G communication, but the development board (Linkit) does not support 4G protocol but support wifi protocol. Therefore, our system must connect from the Linkit to smartphone to communicate with the cloud server shown in Figure 6. By using a mobile Wi-Fi connection, the data can be uploaded to the cloud service platform and displayed on a smart device.

Figure 6. Wi-Fi to 4G process

The aforementioned modules were integrated into arm wearable devices worn by the mountaineering team. The team management device recorded and uploaded real-time team member information to the cloud management platform, allowing the guide to monitor the coordinate and physiological status of each team member and to adjust the team's progress as necessary (Figure 7).

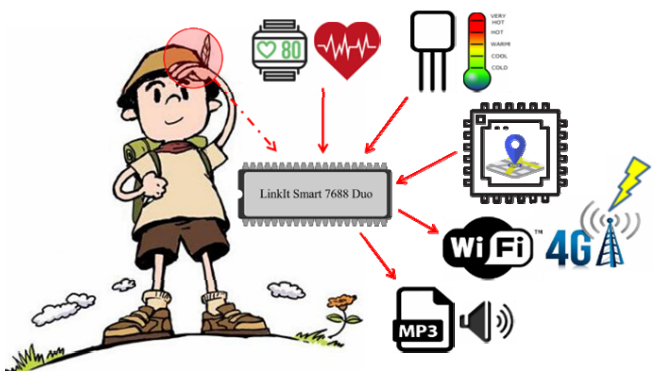


Figure 7. Mountaineering team management device

2.2 Cloud Network Management Platform

The MediaTek Cloud Sandbox (MCS) provides data and device management for developing commercialized wearable and IoT devices [19]. The MCS is allowed the data backup in the disconnected the cloud. The MCS application website is compatible with Android and iOS systems. Figure 8 displays the graphical interfaces on various platforms for the gathered information, which is collected from the devices using a specialized API. The MCS website can also remotely command wearable and IoT devices.

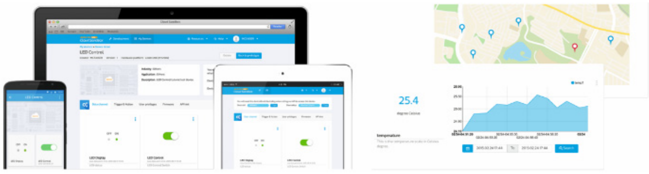


Figure 8. Different operating systems of MCS [19]

3 Data Estimation

Because the Wi-Fi signal is not stable in the mountain climbing, we must predict the user's singal in our cloud server to avoid the dangerous situation. Therefore, the predict algorithm must be developed. Since the user's heartbeat and temperature are unstable during mountaineering, we used an unscented Kalman filter (UKF) whose parameters are varied to reduce the influence of motion. The UKF is an extension of the traditional Kalman filter for the estimation of nonlinear systems that attempt to remove some of the shortcomings of the extended Kalman filter (EKF) in the estimation of nonlinear systems. For parameter estimation, the EKF can be used, because the computation time of the UKF is greater than the computation time of the EKF. However, because there are no limitations with regard to computation time and it has been shown that the UKF outperforms the EKF in numerous examples, the UKF was chosen for parameter estimation. More detailed discussion of the UKF can be found in [20-22]. The UKF uses deterministic sampling to approximate the state distribution. The unscented transformation uses a set of sample or sigma points that are determined from the a priori mean and covariance of the state. The sigma points are propagated through the nonlinear system. The posterior mean and covariance are then calculated from the propagated sigma points. Parameter estimation equations for the UKF are similar to the state estimation.

Kalman Filter has been the subject of extensive application and research, especially in the autonomous navigation and guided navigation areas. The Kalman Filter performs well in practice and attractive in theory because it can minimize the variance of the estimation error [23]. The small computational requirements, recursively properties, and status as optimal estimator are the great success of the Kalman Filter [24]. In this study, the UKF is designed to reduce the noise on the sensors of the user's heartbeat and temperature.

3.1 Input Vector, Process and Measurement Model

The input vector x of the Kalman filter is the user's heartbeat and temperature which are recorded by our proposed device. The process model predicts the evolution of the state vector:

$$x_{k+1} = x_k + \gamma(x_k - x_{k-1}) + w_k \quad \textbf{(1)}$$

$$= q \cdot I_{3\times3} \quad \textbf{(2)}$$

where x_k is the processed state in time k and w represents the process noise with covariance matrix Q. The measurement model relates the measured value z to the value of the state vector x.

$$z = H(x) = [z_{heartbeat} \quad z_{temperature}]^T = R \cdot x + v \quad \textbf{(3)}$$

$$R = \begin{bmatrix} r_{heartbeat} \cdot I_{3\times3} & 0_{3\times3} \\ 0_{3\times3} & r_{temperature} \cdot I_{3\times3} \end{bmatrix} \quad \textbf{(4)}$$

where v represents the sensor noise with covariance matrix R. The output noise is assumed to be uncorrelated between the two sensors and between the different axes.

3.2 Prediction

The first step in the Kalman filter is the prediction, which is based upon (1). Since this is actually a linear equation, no sigma points have to be calculated yet.

$$\hat{x}_k^- = \hat{x}_k^+ + \gamma(\hat{x}_{k-1}^+ - \hat{x}_{k-2}^+) \quad \textbf{(5)}$$

$$P_k^- = P_k^+ + Q \quad \textbf{(6)}$$

3.3 Compute Sigma Points

Before the correction can be executed, sigma points must be computed from the mean and square root decomposition of the covariance of the a priori estimate.

$$x_k = [\hat{x}_k^-, \hat{x}_k^- + \eta\sqrt{P_k^-}, \hat{x}_k^- - \eta\sqrt{P_k^-}] \quad \textbf{(7)}$$

where $\eta = \sqrt{n+\lambda}$ is the state dimension, and λ determines the spread of the sigma points.

3.4 Measurement Prediction

From the computed Sigma Points, a prediction of the measurement can be made based on (3). The measurement mean $z_{\bar{k}}$ and the measurement covariance P_{x_k} are calculated based on the statistics of the expected measurements as follows.

$$Z_k = H(X_k) \quad \textbf{(8)}$$

$$Z_k^- = \sum_{i=0}^{2n} W_i^{(m)} Z_{i,k} \quad \textbf{(9)}$$

$$P_{x_k} = \sum_{i=0}^{2n} W_i^{(c)} (Z_{i,k} - z_k^-)^2 \quad \textbf{(10)}$$

$$P_{x_k z_k} = \sum_{i=0}^{2n} W_i^{(c)} (X_{i,k} - x_k^-)(Z_{i,k} - z_k^-)^T \quad (11)$$

where $P_{x_k z_k}$ is the cross-correlation covariance and the weights $W_i^{(m)}$ and $W_i^{(c)}$ are calculated as follows.

$$W_i^{(m)} = W_i^{(c)} = \begin{cases} \lambda / n + \lambda, & i = 0 \\ \lambda / 2(n+\lambda), & i = 1...2n \end{cases} \quad (12)$$

3.5 Correction

This is where the actual measured data comes into play and the posteriori estimate is calculated.

$$K = P_{x_k z_k} (P_{x_k} + R)^{-1} \quad (13)$$

$$\hat{x}_k^+ = \hat{x}_k^- + K(z - z_k^-) \quad (14)$$

$$P_k^{\mp} = P_k^- - (P_{z_k} + R) K^T \quad (15)$$

3.6 Postfilter

Finally, the posteriori estimate is low pass filtered.

$$\hat{x}_k^+ = \alpha \hat{x}_{k-1}^+ + (1-\alpha) \hat{x}_k^+ \quad (16)$$

4 Experimental Results

In this paper, there are two parts of the experiment. The system device is the implement of the hardware and the system test is the experimental results of the hardware. The detailed descriptions are as follows.

4.1 System Device

The proposed mountaineering team management device is shown in Figure 9. It includes a central processing module, GPS module, temperature sensor module, heart rate sensor module, MP3 module, and wireless transmission module. If the device determines a team member is in danger or receives commands from the guide, the MP3 module plays the corresponding warning alarm. In additional, there are 7 audio commands in the management device, shown in Table 1, and the mountaineering guides will transmit the corresponding audio command to the team members through the MP3 module of the management device.

When the heartbeat and temperature are in an abnormal state, the system will determine that the user has an abnormality and immediately notify the mountaineering guide. In the abnormal state determination of the heartbeat, the system uses the heart rate to determine the abnormal state of the user. The target heart rate of the user is calculated as follows.

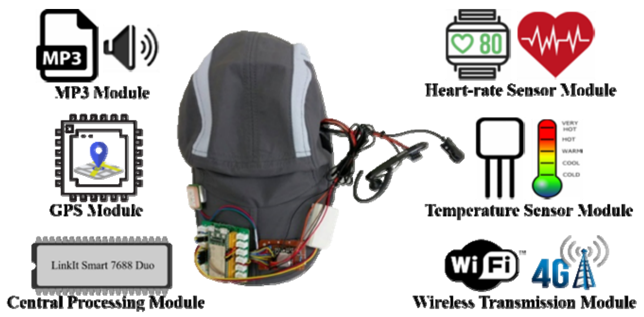


Figure 9. The proposed mountaineering team management device

Table 1. The audio commands in management device

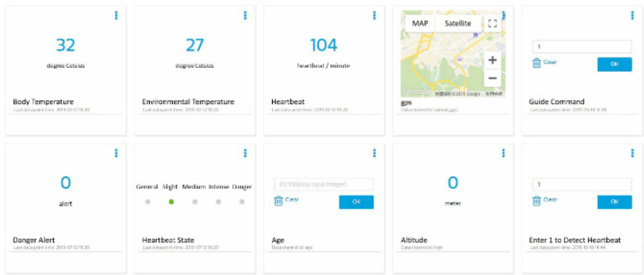
#	Command
1.	Gathering. Please report to the guide.
2.	Detecting abnormal physical condition. Please confirm that you are OK.
3.	If the device has any problems, please report to the guide.
4.	Slippery road ahead. Please proceed with caution.
5.	About to leave the group. Please keep up.
6.	Setting up camp ahead.
7.	Approaching a river. Please prepare for river crossing.

$$T(M, R) = R + E(M - R) \quad (17)$$

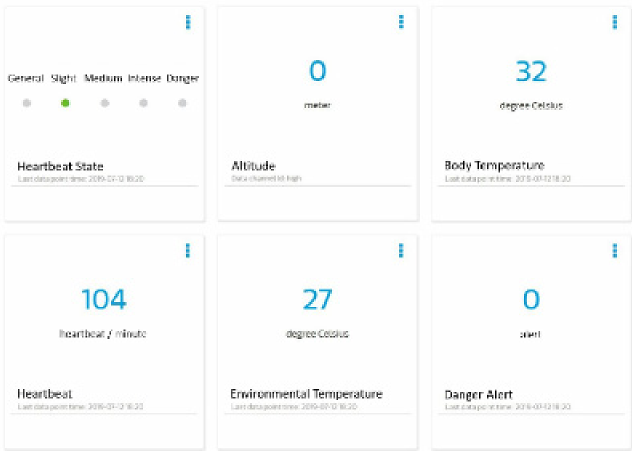
$$M(x) = 220 - x \quad (18)$$

where R is the resting heart rate, M is the maximum heart rate, S is the exercise intensity, and x is the age of the user. The age predicted maximum heart rate equation was developed by Dr. William Haskell and Dr. Samuel Fox in 1970 [25]. They wanted to examine how strenuously heart patients could exercise. Using heart rate data from other research studies, they plotted the average maximum heart rates onto a graph and estimated a linear best fit which came out to 215.4(0.9147). The 220-age formula was the closest estimate to their findings.

The system uses MCS as the cloud network management platform. First, the website is connected to the device. Next, the response values of each module are defined, and the activation conditions are set. The warning alarm activates when a mountaineer is lost or has poor physiological status. In the other hand, the locator signal of the GPS is connected with Google Maps. The real-time data of the mountaineering process are uploaded to the cloud platform. The mountaineer and guide can see this information in the cloud platform, shown in Figure 10, but personal privacy information will not be seen by the guide. By analyzing the recorded data (i.e., data on the condition of the mountaineering team and physiological status of each mountaineer), the guide can gain valuable insights. Additionally, mountaineers can utilize the recorded data to adjust their movements and their training in preparation for their next mountaineering activity.

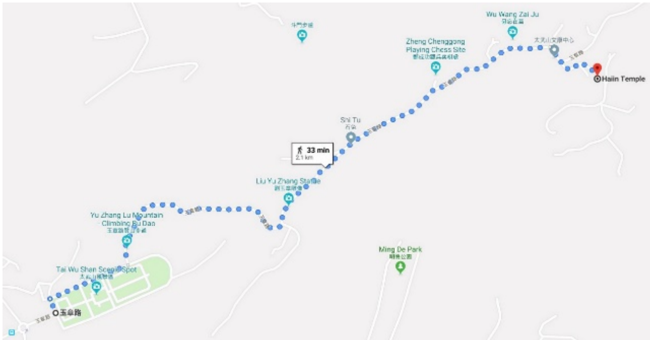


(a) mountaineer's perspective



(b) guide's perspective

Figure 10. MCS interface



(a) google map of the trail

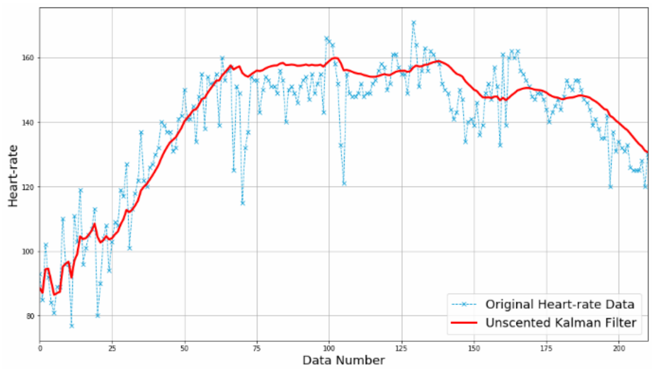
(b) altitude variation of the trail

Figure 11. The hiking trail information in Tai Wu Mountain

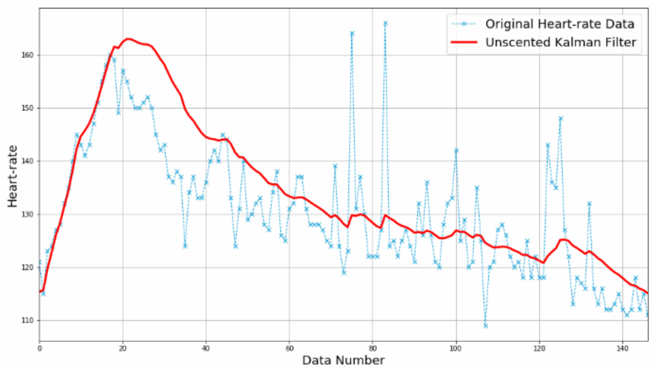
4.2 System Test

In the system test, we chose Tai Wu Mountain in Kinmen as the test location of the system. The total distance and altitude variation of the hiking trail in Tai Wu Mountain is 2.1km and 134m(84m-218m). Figure 11(a) shows the google map of the trail and Figure 11(b) shows a plot of an altitude variation of the trail. We start mountain hiking from the left side of the path and use the system device to record the back and forth information. In this experiment, the subject was a 26-year-old male who spent 33 minutes going up the mountain and 24 minutes down the mountain, taking a total time is 57 minutes.

Figure 12 and Figure 13 show the experimental results of the user heart rate and temperature. Figure 12(a) shows that when the user starts mountain hiking, the heart rate will rise rapidly and reach a stable state. Until the road near the end point tends to be gentle and descending, the user can take a rest and lower the heart rate. When going down the mountain, the beginning is a small uphill and the user's heartbeat increased significantly, and then the heart rate gradually decreased with the downhill, shown as Figure 12(b). Figure 13 shows that when beginning the mountain hiking, the user body temperature will gradually drop and reach a steady-state due to sweating. The body temperature during mountain hiking is about 27-30 degrees.

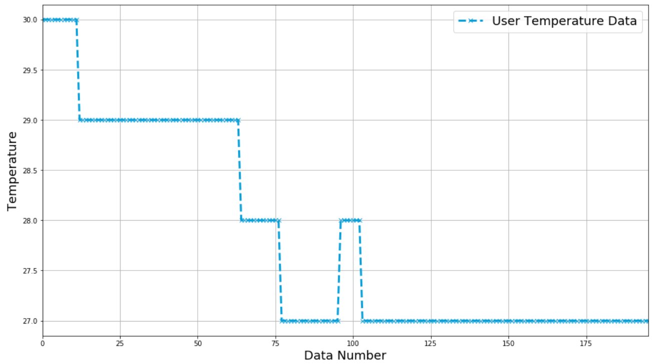


(a) going up the mountain

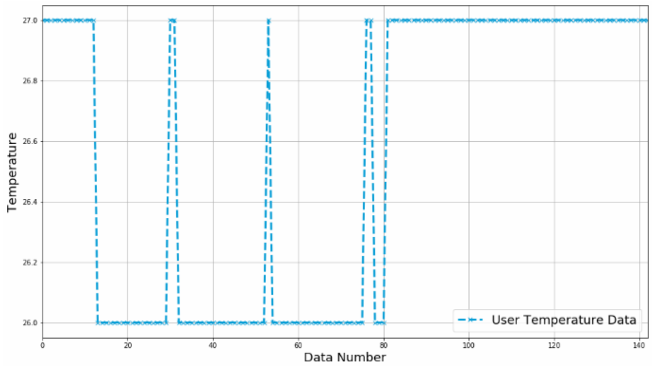


(b) going down the mountain

Figure 12. The user heart rate information of the experimental result



(a) going up the mountain



(b) going down the mountain

Figure 13. The user temperature information of the experimental result

5 Conclusion

This paper proposes an IoT-based mountaineering team management device. The device can connect to a cloud server through 4G Internet and share information regarding team members coordinates, direction, height, and physiological status (i.e., pulse and temperature). Using the device, a guide can monitor the physiological statuses of team members, including whether they are losing body temperature or experiencing irregular pulse rates because of weariness. The device also enables guides to monitor whether team members are keeping up with the mountaineering progress and to adjust the mountaineering speed accordingly. In the other hand, we also proposed an unscented Kalman filter (UKF) to reduce the data influence of motion during mountaineering. The experimental results show the good performance of this proposed algorithm. In summary, the device enables guides to accurately monitor the physiological status of each team member and to make punctual commands, thereby providing guides with an immediate and effective route for assistance. Currently, the 4G mobile network is unstable in Taiwan's mountainous areas, particularly when climbing Taiwan's top 100 peaks. However, simple hiking trails established by local counties are all within Internet coverage range. Our system will store the data when the 4G signal is loss, when the 4G signal appears, the data will be upload to the cloud server. We hope that, in the future, Internet coverage will reach all areas in the world. Multiple global corporations are conducting development in this direction; including Google Project Loon and Facebook Aquila. A future of global IoT technology is within sight. The proposed device could assist mountaineering guides in immediately and effectively managing their teams and facilitate improving safety in mountaineering.

Acknowledgments

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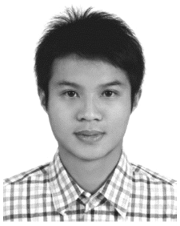

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