Vital Signs Evaluation of Human Behaviour via an Autonomous Body Area Network System

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Abstract. Enhancing Quality of Life (QOL) has long been an explicit and implicit goal for individuals, nations, and the world. QOL involves diverse multidimensional factors spanning wealth, physical health, social well-being, and international relationships. This study presents a definition of QOL combining the measurement of health-related QOL with an autonomous Body Area Network System (BANs). A method of evaluating vital signs is performed and linked to physical intensity assistance in exercise. Specifically, BAN acts as a supportive system which can assist a user in monitoring his or her body’s parameters, providing real-time feedbacks and dynamically sharing information from any location to one or more users.

1. Introduction
Quality of Life (QOL) is a perceived quality which includes all aspects in individual’s daily life. The understanding, measurement and evaluation of human’s vital signs and their applications are essential in order to prevent any potentially life-threatening complications, which may reduce one’s QOL [1]. An autonomous Body Area Network System (BAN) is comprised of wireless interconnected light-weighted wearable sensors, which provide sensing, monitoring, and processing of human vital signs. Heart Rate (HR), Spontaneous Oxygen Saturation (SpO2), and ambient temperature have been studied under varying daily conditions in order to detect the characteristics of human body behaviors. In physical intensity assistance applications, the relationship between heart rate and exercise intensity has been analyzed in order to achieve an appropriate amount of planned exercise intensity among users. Development of BAN also provides audio-graphical interface feedback as well as real-time information sharing to remote users.

2. System Construction
2.1 Construction of Autonomous Body Area Network System
The BAN system (Figure 1) is comprised of Wireless Sensing Nodes (WSN), Hub Node (HUB), Audio Visual Human Interface (AVHI), and host system. The WSN contains several wearable sensor nodes at the ankle, waist, wrist, and shoulder which collect parametric data. The shoulder module in particular consists of physiological sensors which measures data of human vital signs (HR, SpO2), biokinetic sensor which measures acceleration and ambient sensor which measures environment temperature. Data collection for body parameters and vital signs data processing are performed in the PIC of shoulder module, as well as advice command generation based on heart rate variability. Collected data and commands from WSN are sent wirelessly via ZigBee communication to the hub, consisting of a smartphone and receiver board bridging WSN to AVHI and host system. Command
translations are performed in the PIC of hub receiver, then sent to the smartphone’s internal storage via Universal Serial Bus (USB). This internal storage acts as a platform for data interchange, providing data fusion based on the needs of further application (refer section 2.2). Using Bluetooth 4.0 communication, data transmission from hub node to AVHI takes place. AVHI, a smart glass from Vuzix, will decode the commands receive within the system, providing users with a real time advice feedback through audio-visual interface. Additionally, the BAN system interacts with host system, enabling real time data access at remote locations via cloud communication. Use of this interactive closed system in physical intensity assistance enables the user to autonomously receive advice for their current body behaviours, thus increasing users’ awareness about their physical conditions in daily life.

2.2 Data Interchange in Autonomous Body Area Network System

Data interchange for autonomous BAN (Figure 2) takes place in the hub module, consisting of a transceiver board and smartphone which interconnect the sub systems of WSN, host system, and AVHI feedback systems. Each sub systems are using different types of data format for each parametric data on order to avoid any data congestion or confusion.

The receiver (Application 0), which uses ZigBee wireless communication, receives all data from the WSN and sends it to the internal storage of a smartphone (Application 1) to be stored for further data fusion with other applications. Here, we use Sony Xperia™ Z3 compact, which runs on Android 4.4 “KitKat” operating system.

The internal storage of the smartphone is arranged in five folders based on their usages, which can be easily accessed by other applications. Abundance receive data from WSN are converted and saved into CSV files in Data_Collection folder with every minute folder renewal. Besides, the WSN of the shoulder module sends commands in a state of urgency to the Postbox_to_AVHI folders, which enables immediate feedback to user whenever vital signs change or show abnormality (Application 2).

Additionally, using cloud communication, the HUB is interconnected with host system (Application 3), which will display data and files into computer based interface for remote monitoring. Parametric data from Data_Collection folder are copied to Postbox_to_HS for telemetric usage. Application 3 enables third user of BAN, such as home doctor or family members to request data remotely if they want to know more about WSN user’s conditions. Here, the command from host system are saved in the Postbox_to_WSN folder.

Lastly, data of smartphone’s condition such as battery conditions, internal storage availability and used internal storage are saved in the Hub_Status folder. This folder is automatically copied to the Postbox_to_HS folder for telemetric data monitoring [2]-[5].

Figure 1. Autonomous Body Area Network System
In order to achieve a maximum health benefits, human is advisable to perform exercises at medium level of intensity [6]. One of the BAN application enables user to manage exercise intensity at their desired level, keeping heart rate at targeted range of threshold, thus ensuring a pleasant and good quality of physical exercise.

3.1 Methodology

Relationship between HR variability and exercise intensity are defined by Karvonen Formula as in equation 1, which is employed in order to determine heart rate threshold ranges and indexes of heart rate trend in generating advices.

\[
El[\%] = \frac{HR - HR_{\min}}{HR_{\max} - HR_{\min}} \times 100
\]

Here, \(HR_{\min}\) represents heart rate in rest, while \(HR_{\max}\) represents heart rate during performing the heaviest exercise. As the \(HR_{\max}\) cannot be measured directly, it can be calculated by using \(HR_{\max} = 220 - \text{Age}\) formula. Employment of Karvonen Formula enables exercise intensity to be classified into four groups as shown in the table below.

| Exercise Intensity [%] | Exercise Level   |
|-----------------------|------------------|
| 20-40                 | Light            |
| 40-60                 | Medium           |
| 70-85                 | Stressed         |
| 85-100                | Heavy            |

Thresholds values are determine by the value of lowest and highest heart rate during certain exercise intensity. For example, when exercise intensity is assigned to medium level, minimum threshold value [Thr_Min] is the heart rate that corresponds to 40%, while maximum threshold value [Thr_Max] is corresponds to 60% of intensity. The targeted heart rate zone while performing physical exercise will be between the minimum and maximum threshold range. Table 2 shows the relation between heart rate existence and indexes of heart rate trend in advice generation.
Table 2. Relation between heart rate existence and indexes of trend

| Heart rate existence | Trend   | HR Difference = Trend | HR Difference < Trend | HR Difference >= Trend |
|----------------------|---------|-----------------------|-----------------------|------------------------|
| HR <= Thr_Min        |         |                       |                       | KEEP PACE              |
| Thr_Min < HR < Thr_Max|        |                       |                       | KEEP PACE              |
| HR >= Thr_Max        |         |                       |                       | PACE DOWN              |
| HR > 180             |         |                       |                       | STOP EXERCISE          |

Here, heart rate existence ranges are divided into four types: [HR <= Thr_Min], [Thr_Min < HR < Thr_Max], [HR >= Thr_Max], [HR > 180]. A method of comparing the value of heart rate difference and trend is performed. Here, trend means change of heart rate. The maximum trend calculation of data acquisition for heart rate is three seconds. Heart rate trend are classified into three types: falling or flat, mild and steep trend with indexes of [HR Difference = Trend], [HR Difference < Trend] and [HR Difference >= Trend] respectively.

In this application, advice is generated autonomously when heart rate is out of threshold range and is refreshed every 25 seconds, enabling the user to remain aware about their exercise pace. The effectiveness of this system is evaluated by the percentage of heart rate in threshold range as shown in equation 2.

\[
\text{Percentage of heart rate in thr} \% = \frac{\text{Total HR data in thr}}{\text{Total HR data in running period}} \times 100
\]  

(2)

Here, a higher percentage of heart rate in threshold range indicates a good quality of running.

3.2 Experiment Method

Experiment is conducted on the treadmill. Two healthy male students with normal heart rate reading were chosen as the subjects with medium level of exercise intensity (40% to 60%).

| Subject | Age | Sex | Normal Heart Rate [bpm] | Height [cm] |
|---------|-----|-----|-------------------------|-------------|
| A       | 23  | Male| 73                      | 172.3       |
| B       | 24  | Male| 74                      | 173.0       |

In order to prove the effectiveness of this TBAN system, experiment was conducted under two condition, non-advice running and advice running. Experiment schedules are as follows. Running without advice; A minute of rest, 10 minutes of free running without advice, and 5 minutes of rest. Running with advice; A minute of rest, 10 minutes of running with advice and 5 minutes of rest. Total time for each experiment is 16 minutes.

3.3 Experiment Results

Effectiveness of this system is shown by the comparison of percentage of heart rate in threshold range of advised running and non-advised running. For running with advices, type of advices feedback to the users are present as the coloured background of the graph where grey for pace up, green for keep pace and red for pace down respectively.

Figure 3 shows the comparison results of running for subject A. By using Karvonen Formula, the threshold ranges for the subject A with normal heart rate reading of 73[bpm] was between 122[bpm] and 147[bpm]. When running without advice, percentage of heart rate at threshold was 6.7%, with heart rate value was mostly over the threshold range, compared to running with advice, which increased this value to 45.9%.
Figure 3. Comparison of non-advice and advice running for subject A

Figure 4 shows the comparison results of running for subject B. The threshold ranges for subject B with normal heart rate reading of 74[bpm] was between 122[bpm] and 147[bpm]. When running without advice, percentage of heart rate at threshold was 15.17%, compared to running with advice, which increased this value to 82.15%.

These results indicate a positive relationship between percentage of heart rate at the threshold and advice given by the system, ensuring users better-quality exercise. In other words, the application of physical intensity management in exercise is actualized.

3.4 Remote Health Care Monitoring

Host system is capable in accumulating and storing all receive data within the system. The collected data from WSN can be viewed in real time, where parametric data are saved in every seconds and integrated into computer-display interface for easier remote data monitoring. Figure 5 shows the example of interface view for advice running of subject B.
Figure 5 shows the home view of host system interface, where current location of user’s Global Positioning System (GPS), smartphone status, battery condition, hub node status and weather data are displayed. Figure 5(b) shows the user’s interface view during advice running of subject B, where elapsed time, running speed, running distance, heart rate and SpO2 graphs, heart rate in threshold percentage data and advice command are displayed. The evaluated data of heart rate, SpO2 and threshold range are displayed in two types of graphs; every minute graph display and total time graph display. Renewal of graph in every minute enables the user of host system to monitor the vital signs changes in detail. Coloured background of the graphs shows the advice that is feedback to the subject. Besides, data storage in the host system enables user to review or track their body parametric data after exercising.

4. Conclusion
This paper has supported the use of autonomous BAN in daily life as a contributor to a higher QOL. In physical intensity management, as irregular pattern or over limit of exercises may cause unwanted illness, the employment of this system enables the user to perform exercises at a targeted exercise intensity, therefore ensuring both pleasant and safe exercise. BAN acts as a supportive system which provides dynamic Human Interface (HI) and remote data access via host system, which is useful for remote health monitoring. In a conclusion, this system may become the basis of efforts to prevent potentially life-threatening diseases, helping user to achieve an optimal health status, as well as improving users’ general QOL.

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