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A Preliminary Activity Recognition of WSN Data on Ubiquitous Health Care for Physical Therapy

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***Abstract*—The physical therapy with ubiquitous health care (UHC) for geriatrics training or stroke patients requires continuous and routine rehabilitation during the cure period. The physiatrists are hereby the feedback clinical record to design necessary assistant programs. The successful treatment usually concerns whether the patients follow the therapeutic assignment without interruption. This study hence developed a set of wireless sensor network (WSN) devices including the accelerometer and gyroscope to measure the essential movement of human body. At this initial stage, the sensor data of static and dynamic postures for lying, sitting, standing, walking, and running were calibrated by the fuzzy algorithm with an overall accuracy rate of 99.33%. The approach may support for monitoring patient's remedy process at home for ubiquitous health care of physical therapy.**

Keywords-UHC; WSN; Accelerometer, Gyroscope; Activity Recognition

I. Introduction

The motion detection is one of the most important issues of the health care system, particular for monitoring daily activity. Based on the physical therapy and medicine, the stroke patients usually need to continuously and routinely repeat specific motions during the remedy period of the rehabilitation treatment. If the physiatrists can acquire the rehabilitation records of patients during the cure process through the ubiquitous health care (or u-healthcare) with ambulatory measurement, it is helpful to design necessary assistant programs. The activity recognition hence can be a potential technique to achieve this scope.

The regular postures of human beings essentially include lying, sitting, standing, and so on. According to different circumstance, these activities can be caught and recognized by appropriate algorithms [1]. In general, the methods of image [2] and non-image [3][4] processing are the most popular categories to monitor the postures and motions of human body. However, as considering the privacy of people, the cost of equipments, and convenience in an open environment, it is more reasonable to adopt the modern technology for the u-healthcare. The concept of u-healthcare is extended from the homecare personal area network that provides intelligent monitoring with ad hoc network. With the multi-tier telemedicine system due to the wireless body area network, the real-time analysis of sensors' data was performed by computer-assisted rehabilitation. Thus the ambulatory monitoring was available to generate warnings on the user's state, level of activity, and environmental conditions [5].

In the past decade, the wireless sensor network (WSN) has been widely spread out for different types of healthcare. It detects various vital signals such as blood pressure, impulse, motion as well as variation of home environment [6][7]. Many studies approved this technique on a variety of home healthcare systems since it provides wearable, portable, and mobile functionalities for usage to ubiquitously combine patients' healthcare information with clinical data in hospital [8]. For this approach to the physiotherapy and rehabilitation, it is helpful to measure patients' motions by creating a pattern library of WSN data for activity recognition.

In this study, we developed the wearable sensor by integrating the accelerometer and the gyroscope with the WSN devices to detect the signals of body movements. The preliminary measurement was designed by locating the sensors on the chest and the left thigh to transport data. The fuzzy algorithm was applied for advanced data recognition.

II. WSN Device Design

One of the primary tasks of the u-healthcare for physical therapy is assisting physiatrists to record patients' rehabilitation data continuously for tracking their essential motions during the cure period. It usually includes lying, sitting, standing, walking, and running which imply the spatial movement of specific body part. A gyroscope is a device for measuring orientation, based on the principles of conservation of angular momentum. With modern operating procedures of micro-electro-mechanical system (MEMS), the microchip-packaged gyroscope is found in consumer electronic devices to detect any orientation sensitively. In the other hand, an accelerometer is to measure proper acceleration that is experienced relative to freefall. Its single- and multi-axis models are available to detect magnitude and direction of the acceleration as a vector quantity. Therefore, by integrating the WSN technique for data transportation, both of the MEMS devices could make the ambulatory measurement possible to approve the u-healthcare for physical therapy.

The proposed WSN sensors are designed by remodeling the MEMS modules of the accelerometer and gyroscope with the WSN mote and antenna to transport the signals. The practical devices in this study include (1) a battery-powered mote shown in Fig 1(a), which supports embedded micro control unit (MCU) and radio frequency (RF) for processing and delivering the sensed signals; (2) a triaxial accelerometer and a biaxial gyroscope shown in Fig 1(b), which can detect kinetic acceleration and angular velocity, respectively; and, in addition, a flash memory card which can temporarily store the sensed data. The models of devices are listed in Table 1.

TABLE I. THE MODELS OF WSN SENSOR DEVICES

Device Module	Model No.	Manufacturer
MCU	MSP430	Texas Industry Co.
RF	CC2420	Texas Industry Co.
Mote	Tmote Mini	Moteive Inc.
Triaxial Accelerometer	ADXL330	Analog Device Co.
Biaxial Gyroscope	IDG500	InvenSense Inc.

Herein, the adopted accelerometer can detect acceleration within the range of ±3.6g with error in ±0.3% while it supports 350mA of current with sensitivity in 300mV/g for 3V of output voltage, in which g is the gravity(=9.81m/sec^2). As the sensor works, the mote reads and transfers analog signals as analog-to-digital conversion (ADC) counts before writing into the transportable packet.

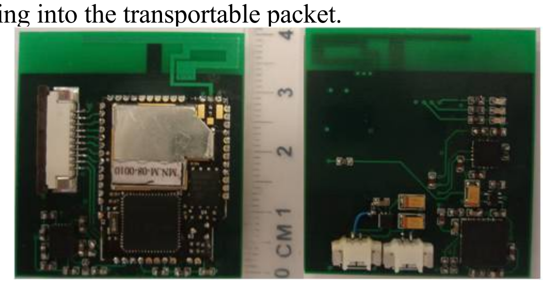

Figure 1. (a) WSN mote, (b) Accelerometer and gyroscope modules

III. MEASUREMENT METHOD

In this study, we implemented two sets of WSN sensors for measuring desired body motions. As shown in Fig 2, the sensor A and B are fixed at the chest and the left thigh, respectively, in which the forward or backward direction is defined as z axis while the up-down and right-left directions represent x and y axes, respectively. Herein, several features are extracted for each of the six data streams (x, y, and z acceleration, x, y, and z angular speed).

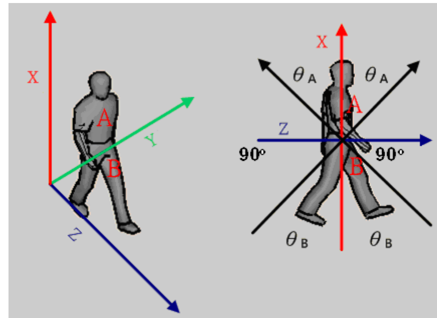

Figure 2. Location of the sensors at body and relationship of tilt angles

A. Feature Extraction

(1) Acceleration: includes g_x, g_y, and g_z acceleration amplitude in gravity of *x*-, *y*-, and *z*-axis, respectively.
(2) Angular velocity: involves angular velocities of *x*-, *y*-, and *z*-axis, respectively.
(3) Tilt angle: represents the angle between *x* and *z* components of the acceleration vector (g_x, g_y, g_z) in gravity can be calculated by $\theta=\tan^{-1}(g_z/g_x)(180/\pi)$.
(4) Mean value: determines the average value (μ) of the number (n) of acceleration components (x_i) in gravity during one second.
(5) Standard Deviation: performs the probability density function (PDF) of probability versus ADC count of the sensed data. The data distribution returns random variables since a range of output voltage might be mapped to the same gravity component as a more-to-one relationship. The PDF can be carried out by

$$\sigma = \left\{ \frac{1}{n} \sum_{i=1}^{n} (x_i - \mu)^2 \right\}^{\frac{1}{2}} \quad (1)$$

Therefore, this feature includes σ_X, σ_Y, and σ_Z that represent the standard deviation of acceleration in gravity x, y, and z-axis, respectively.

B. Evaluation of Acceleration

The WSN data of acceleration components sent by the sensors must be calibrated before the device is worn for measuring individual body posture. We hence evaluated these components due to lying, sitting, standing, walking, and running through an initial test.

C. Application of Fuzzy Algorithm

In this study, we apply the fuzzy algorithm to calibrate measured data. During the procedure, the acceleration per second was firstly classified into fuzzy sets and became the input feature of fuzzy system. Then, after fuzzification, we induced the fuzzy rules with the activity recognition pattern library. Consequently, with defuzzification, we could obtain the output of static postures or dynamic motions and store in the database.

IV. WSN Data Calibration and Activity Recognition

According to the sensed data, we extract the reasonable input features like μ_{Z_B}, σ_{Y_B}, θ_A, θ_B and ω_{X_B} as well as the desired output postures (e.g., lying, sitting and standing) and motions (e.g., walking and running).

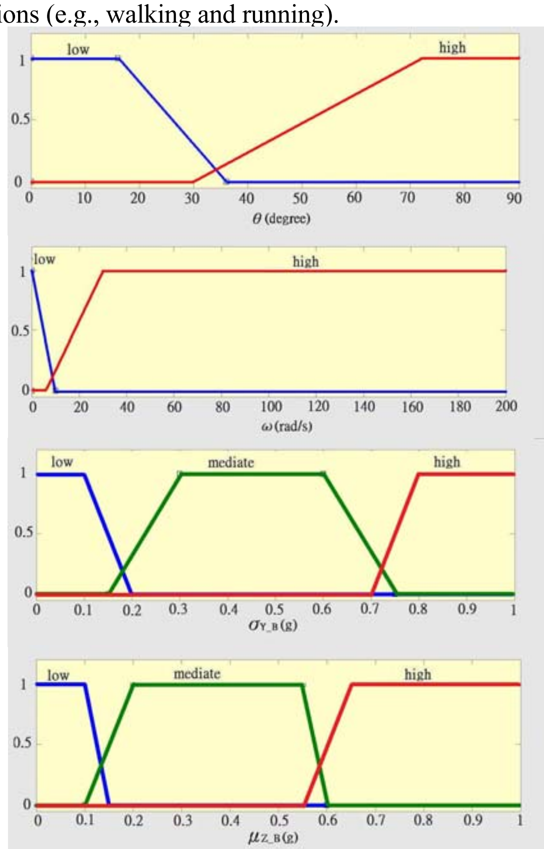

Figure 3. (From up to down) Membership function of (a) tilt angle, (b) angular velocity, (c) the standard varience of the probability density function due to measured acceleration components in gravity, (d) the mean value of measured acceleration components in gravity

A. Fuzzy Rules for Calibration

1) θ_A

The feature θ_A is defined by the angle between *x* and *z* axes and can be detected by the sensor A. Each set of the sensed θ_A data was collected per second to yield Gaussian distribution in which the peak value can be adopted as the input features of the fuzzy system. As shown in Fig 3a, we define two membership functions within the range from 0^o to 36^o as the low-angle and above 36^o as the high-angle.

2) θ_B

The feature θ_B can be detected by the sensor B and follows the same data processing as θ_A. We can regulate the variation between θ_A and θ_B to determine the relative position of the chest and the left thigh and to recognize the postures of lying, sitting, and standing. For example, if the initial angles of θ_A and θ_B are identical to 0 as "standing," then the condition of (θ_A=0^o and θ_B=90^o) will be "sitting".

3) ω_{X_B}

The feature ω_{X_B} is provided by the gyroscope of the sensor B to judge the static posture or the dynamic motion. According to the practical test, the angular velocity was approaching 0 as steady status, but its absolute value would pass a level (> 10 rad/sec by referring Fig 3b) for the apparent motions. Hence, we can calibrate this rule with fuzzy variables as "the thigh is starting to move".

4) σ_{Y_B}

The dynamic motions such as walking and running can be calibrated by the standard deviation of sway conditions along the *y* direction due to the sensor B. The membership function of σ_{Y_B} is shown in Fig 3c. The motion of changing posture is defined as "in moving" since it could be either "walking" or "running". We use σ_{Y_B} of g_y data distribution as the level "in moving". Herein, the motion is "in moving," "walking," or "running" when σ_{Y_B} is less than 0.2g, between 0.2g and 0.6g, or greater than 0.6g, respectively.

5) μ_{Z_B}

Besides of σ_{Y_B}, we can also consider μ_{Z_B}, which is the mean value of g_z in absolute integer value, to categorize different types of activity recognition. The membership function of μ_{Z_B} is shown in Fig 3d that a variety of ranges present movement levels.

The input features above can calibrate sensed WSN data through the fuzzy system for the output movement. Fig 4 illustrates the membership function of output.

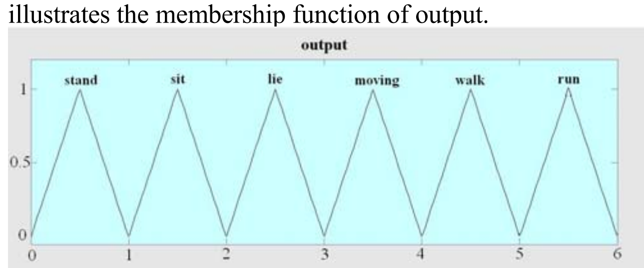

Figure 4. Output of activity recogntion pattern after defuzzification

B. Fuzzification and Defuzzification

The first step of fuzzification is finding the membership function. In this test, as shown on Fig 3a, the θ_A and θ_B can be considered as the low angle if they are in the range between 0^o and 36^o; otherwise they are classified as the high angle that is grater than 36^o. Similarly, the membership function shown in Fig 3b implies a cut for ω_{X_B} to detect the motion is starting. Furthermore, for "walking" and "running", Fig 3c and 3d provide the required membership functions for fuzzification of σ_{Y_B} and μ_{Z_B} to find the criteria. At once the membership functions of input and output features are obtained, the fuzzy rules can be calibrated for the activity recognition pattern.

For defuzzication, the MATLAB toolbox was applied with the discretization technique to carry out the solution.

V. Results

In this study, we recruited three volunteers who wore the developed WSN sensor A and B on the chests and thighs, respectively, to collect sensed data. Then, the movements of static postures and dynamic motions were calibrated through fuzzy algorithm to yield the pattern library of activity recognition. Fig 5 shows the data distribution of acceleration components in gravity corresponding to a variety of movement sensed by the sensor A and B, respectively. The input features including ω_{X_B}, θ_A, θ_B, σ_{Y_B}, and μ_{Z_B} for the fuzzy system were extracted and the output movement for lying, sitting, standing, in moving, walking, and running were finally obtained. By comparing the calibrated data and real motions, we found the good recognition rate as results show in Table 2. In the test, most of test movements were recognized with successful rates approaching 99.33% in average while that of the static postures and dynamic motions were approximately 100% and 98.67%, respectively. These results approved accuracy and stability of the developed devices in this study.

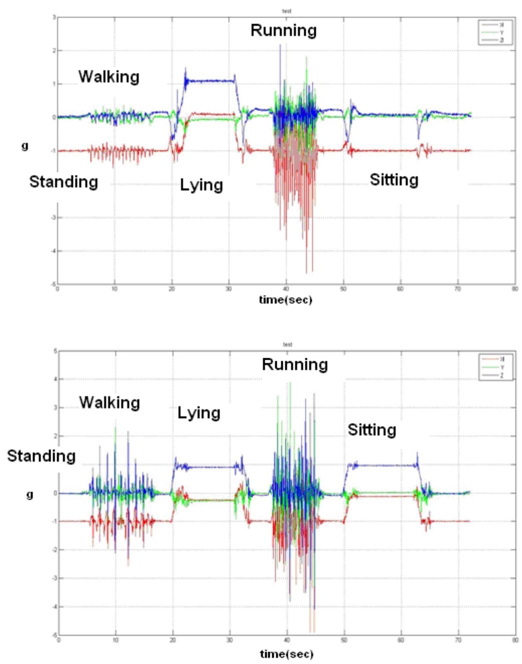

Figure 5. (from up to down) Measured acceleration components in gravity during a period by (a) sensor A and (b) sensor B.

VI. Conclusion Remarks

In this study, we developed the wearable WSN sensor integrated with the accelerometer and gyroscope to detect the signals of body movements including static postures (e.g., lying, sitting, and standing) and dynamic motions (e.g., walking and running). The sensed data could be transported to the backend server via WSN by wearing the sensors on the chest and the left thigh. The fuzzy algorithm was applied for calibrating these data while qualifying the input features involving the tilt angles, the angular velocity, the standard variation and the mean value of acceleration in gravity. With processes of fuzzification and defuzzification, the activity recognition pattern library was created and output movements were obtained. Comparing with the traditional threshold criteria, the proposed algorithm can consider more flexible range with judge rules as recognizing the sensed data. The results performed the successful recognition rate to 99.33% in average and this preliminary study possessed the potential in advanced application on the ubiquitous health care for physical therapy.

Acknowledgment

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TABLE II. THE SUCCESSFUL RATE OF ACTIVITY RECOGNITION TEST

Sample	Standing	Sitting	Lying	In Moving	Walking	Running	Average
Sample 1	*100*	*100*	*100*	*100*	*100*	*100*	*100*
Sample 2	*100*	*100*	*100*	*94*	*94*	*100*	*98*
Sample 3	*100*	*100*	*100*	*100*	*100*	*100*	*100*
Average	*100*	*100*	*100*	*98*	*98*	*100*	*99.33*

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