Interactive MIP-awareness SPG Sampling Technique

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Abstract: - Cardiovascular disease (CVD) is one of the leading causes of death and health killer. Health monitoring based Sphygmogram (SPG) intelligent analysis is a promising alternative for CVD pre-diagnosis. Unfortunately for a mobile SPG intelligent analyzer user arm's any movement or incorrect posture (MIP) would distort SPG morphological feature thus result in failure of further hemodynamic analysis. Hence an interactive MIP-awareness SPG sampling technique through using micro inertial measurement unit (MIMU) and pattern recognition technology to tackle such a problem is proposed and implemented, which is applicable for any wearable sensor application. The MIP recognition technique is elaborated and the relevant database is designed and built for detecting and adjusting user's motion. The testing results show that the time of sampling qualified SPG signal is reduced and accuracy of CVD prognosis is improved.

Key-Words: - CVD; SPG; movement recognition; MIMU

1 Introduction

Cardiovascular disease (CVD) involves the diseases of heart or blood vessels (arteries, capillaries and veins). It is the leading cause of death worldwide [1]. So e-home healthcare aims at the daily health monitoring and the prevention of occurring CVD suddenly. Electrocardiogram (ECG) and Echocardiography signals are not convenient for home usage; instead SPG as a signal noninvasively and easily obtained from the radial artery can reflect the physiological and pathological changes of heart and blood circulation system. Consequently, a mobile e-home healthcare system using pulse sensor to collect SPG signal, giving real-time intelligent analysis for CVD prognosis is researched and developed by this research group [2].

Specifically, the system uses the piezoelectric film pulse sensor to detect SPG signal by wearing it on user's wrist firmly and stably. Based on SPG morphological feature, hemodynamic parameters can be derived and served as input of intelligent analysis to conclude cardiovascular health suggestion [2]. Though this sensor has high sensitivity, wide frequency response range and easy to operate, but it is easily influenced by user's behavior. Any man-made disturbance would distort SPG morphological feature thus result in failure of further hemodynamic analysis. Fig. 1 shows some examples, where (a), (b), (c) represents different distorted morphological feature respectively; actually they are caused by same user's wrist uprising movement. In a word, the absence of recognizing user's movement or incorrect posture (MIP) and lack of man-machine feedback/adjustment makes SPG proper sampling difficult and time consuming.

To tackle such a problem, an interactive MIP-awareness SPG sampling technique through using micro inertial measurement unit (MIMU) and pattern recognition is proposed. The full SPG vs. MIP database with 32 different relevant motions is designed and built, based on which the user's movement or attitude is recognized. Furthermore, the voice prompt function is implemented thus to inform and guide the user to decrease his artificial disturbance efficiently. As survey indicates that no one has ever done the similar research before and there is no any SPG vs. MIP database for reference [3, 4, 5].

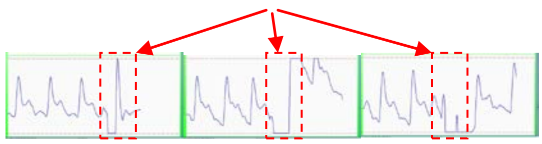

Fig. 1. Different incorrect morphological feature distorted by same user's wrist uprising movement

2 System Overview

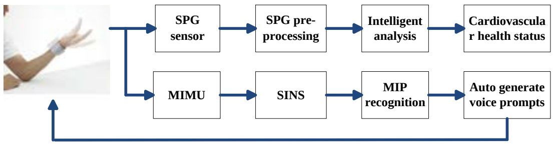

Fig. 2. Function diagram of SPG sampling technique through using MIMU and pattern recognition

Fig. 2 shows the working process of purposed system, in which the MIMU is mounted with the SPG sensor. MIMU can detect the change of attitude information in 3 dimensions individually caused by various MIP. The strapdown inertial navigation system (SINS) is responsible for computing attitude angle values which are used as parameters to estimate the motion type in later MIP recognition part. Finally the voice prompts are generated according to recognized MIP automatically such that to guide the user to correct his MIP in real-time way.

3 MIP Recognition

3.1 SINS

An inertial navigation system (INS) is a navigation aid that uses a computer, accelerometers and gyroscopes to calculate the position, orientation and velocity of a moving object continuously without external references. SINS is INS with sensors strapped to the vehicle that is the SPG sensor in this proposed system. The SINS might be sub-divided further into the following component parts: inertial instrument block; instrument support electronics; coordinate transform; navigation computation; carrier's attitude information, which are shown in Fig. 3 [6].

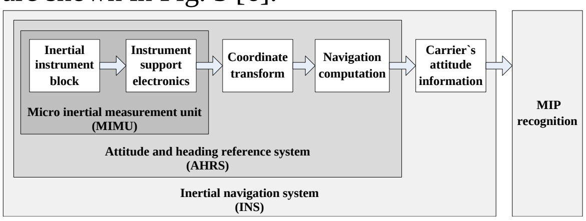

Fig. 3. Components and function diagram of SINS

Concretely, MIMU module applied here integrates GY-29-ADXL345 accelerometer, L3G4200D gyroscope and LSM303DLH compasses together (Fig. 4 (a)); the coordinate transform converts the fixed geographic coordinate system (x_p, y_p, z_p) to the moving carrier's coordinate system (x_p, y_p, z_p). It is supposed that the carrier's coordinate system rotates the angle (θ, γ, ψ) to geographic coordinate system. Then a transition matrix $\mathbf{C}_p^b$ is obtained as (1):

$$\mathbf{C}_p^b = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$= \begin{bmatrix} \cos\gamma\cos\psi + \sin\gamma\sin\theta\sin\psi & -\cos\gamma\sin\psi + \sin\gamma\sin\theta\cos\psi & -\sin\gamma\cos\theta \\ \cos\theta\sin\psi & \cos\theta\cos\psi & \sin\theta \\ \sin\gamma\cos\psi - \cos\gamma\sin\theta\sin\psi & -\sin\gamma\sin\psi - \cos\gamma\sin\theta\cos\psi & \cos\gamma\cos\theta \end{bmatrix}$$

Here, the coordinate system always maintains as rectangular coordinate system during the rotation. So $\mathbf{C}_p^b$ is an orthogonal matrix and has feature as shown in (2):

$$\left(\mathbf{C}_p^b\right)^{-1} = \mathbf{C}_b^p = \left(\mathbf{C}_p^b\right)^T \quad (2)$$

After navigation computation by solving Eq. (2), the carrier's attitude information is derived as three attitude angles relative to the local horizontal plane: roll, pitch and yaw (θ, γ, ψ) [7].

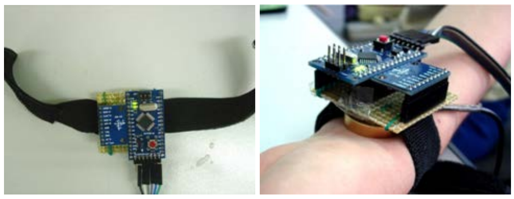

Fig. 4. (a) Diagram of MIMU; (b) Operation of MIMU-mounted SPG sampling

3.2 MIP Database

During the signal acquisition, the factor most affecting SPG morphological feature has been found, that is, the left forearm movement. And other possible factors include waist twist, head movement, chest movement and legs posture. An impact factor (IF) is given here to describe varying degrees of how each MIP influences SPG morphological feature, which is set from low influence to high as 0 to 1.0. 32 kinds of MIP are summed up, which can be classified into three groups: movement, incorrect posture and incorrect posture with movement as listed on Table 1.

Seven volunteers with different ages ranging from 22 to 30, five females and two males, participated in this data collection. They are required to wear the MIMU-mounted piezoelectric film SPG sensor (Fig. 4 (b)), perform above mentioned 32 kinds of MIP and run SPG intelligent analysis system normally. Each kind of MIP should be repeated 10 times lasting about 30 seconds. Correspondingly, attitude information derived from

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SINS is recorded as basis for later carrying MIP recognition.

3.3 MIP Recognition

As aforementioned the MIMU is composed of 3 sensors. The attitude information set of MIMU for MIP recognition is defined by concatenating the accelerometer signal (A_x, A_y, A_z), gyroscope signal (G_x, G_y, G_z), and attitude angle (P_x, P_y, P_z) as $\mathbf{I} = \begin{bmatrix} A_x & A_y & A_z & G_x & G_y & G_z & P_x & P_y & P_z \end{bmatrix}^T$. Supposing there are n volunteers' data, the attitude information for each incorrect posture recognition is represented as matrix **F**

$$\mathbf{F} = \begin{bmatrix} A_{x1} & A_{y1} & A_{z1} & G_{x1} & G_{y1} & G_{z1} & P_{x1} & P_{y1} & P_{z1} \\ A_{x2} & A_{y2} & & \cdots & & \cdots & & P_{y2} & P_{z2} \\ \vdots & \vdots & & & & & & \vdots & \vdots \\ A_{xn} & A_{yn} & A_{zn} & G_{yn} & G_{yn} & G_{yn} & P_{xn} & P_{yn} & P_{zn} \end{bmatrix} \quad (3)$$

Practically the movement recognition method differs from incorrect posture recognition slightly. So another matrix $\mathbf{F}_{\text{var}}$ is defined for movement recognition to represent the variation of attitude information as:

$$\mathbf{F}_{\text{var}} = \begin{bmatrix} \Delta A_{x1} & \Delta A_{y1} & \Delta A_{z1} & \Delta G_{x1} & \Delta G_{y1} & \Delta G_{z1} & \Delta P_{x1} & \Delta P_{y1} & \Delta P_{z1} \\ \Delta A_{x2} & \Delta A_{y2} & & \cdots & & \cdots & & \Delta P_{y2} & \Delta P_{z2} \\ \vdots & \vdots & & & & & & \vdots & \vdots \\ \Delta A_{xn} & \Delta A_{yn} & \Delta A_{zn} & \Delta G_{yn} & \Delta G_{yn} & \Delta G_{yn} & \Delta P_{xn} & \Delta P_{yn} & \Delta P_{zn} \end{bmatrix} \quad (4)$$

where $\Delta A_{x1} = \left| A'_{x1} - A_{x1} \right|$, A'_{x1} is the output obtained at the next sampling time after A_{x1}.

For each kind of MIP, *Accord* is a variant that is designed as the recognition accordance and marked with subscript 1 and 2 to indicate their magnitude order in identification. The derivation of *Accord* is self-explained in following pseudocode shown on Fig. 5. It is noteworthy that for incorrect posture recognition the **F** is applied to obtain *Accord* while for movement recognition the $\mathbf{F}_{\text{var}}$ is utilized.

```
for i := 1 to n
do P_i = arg max F_{i,j}    // find the value of j for which F_{i,j} attains
                            // its largest value and j is assigned to P_i
switch (P_i)
{
case 1: T_1++               // T_x is a counter to mark P_i
case 2: T_2++
⋮
case 9: T_9++               // P_i ∈ (1,9)
}
if T_x > n/2
Accord_1 = I_x              // I_x is assigned to Accord_1
else if
for x := 1 to 9
do x = arg max T_x          // find the value of x for which T_x attains its
                            largest value
Accord_2 = I_x              // I_x is assigned to Accord_2
```

Fig. 5. Pseudocode for explaining meaning of *Accord*

The flowchart of MIP recognition is illustrated in Fig. 6. As to the incorrect posture recognition, the predefined range for estimating *Accord* is computed based on MIP database. As to the movement recognition, a state-switch condition is set empirically at the beginning. If the user's state changes from stillness to movement; the attitude angle (P_x, P_y, P_z) value will vary correspondingly. Due to measurement error of MIMU the threshold is set larger than the estimated maximum measurement error and the pre-defined values are shown inside of block "State-switch" on Fig. 6. After finding the predefined range for each MIP's *Accord*, for each new-coming motion the corresponding attitude information set **I** is analyzed element by element to check if any one falls within any specific range then to decide which type of MIP this motion is finally.

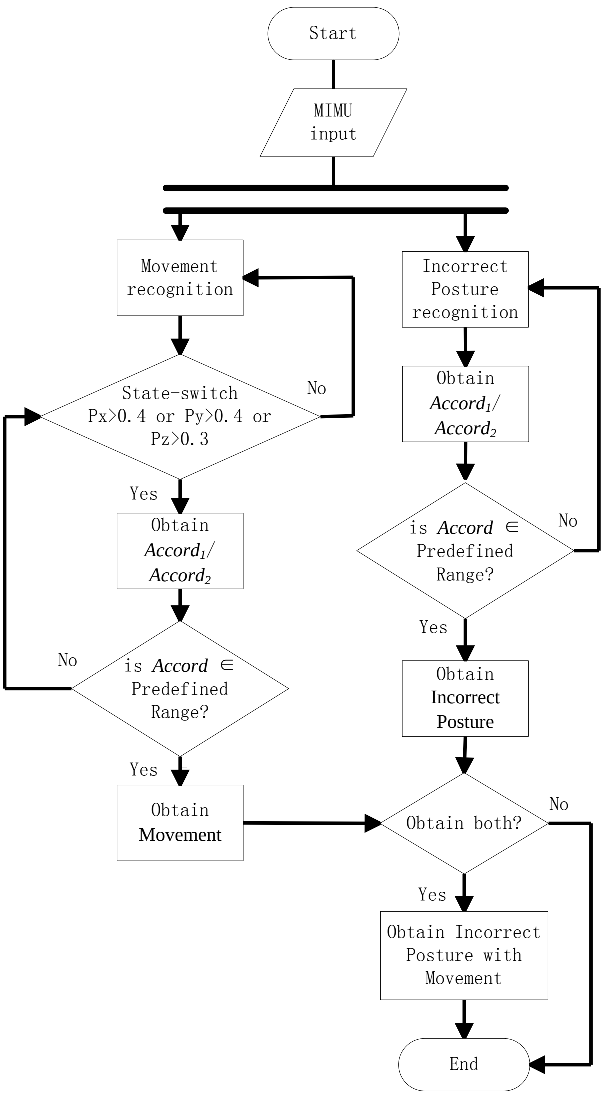

Fig. 6. Flowchart of MIP recognition

4 Test Result

To evaluate the proposed MIP recognition technique, a test is conducted by asking another 5 volunteers to randomly make any movement or set themselves in incorrect posture, which should be in scope of 32 kinds of MIP in the database. Each volunteer is required to perform one MIP for 5 times, consequently there are totally 25 records for each MIP. The recognition results are listed in Table 1, in which each specific MIP with its SPG IF is also presented. Particularly, the *Accord* and its corresponding range are expressed in the recognition accordance column. The recognition accuracy is hereby defined as the ratio of cases successfully recognized to the total records.

TABLE I. MIP DATABASE

No.	Groups	Category of movement or incorrect posture			SPG IF	Recognition Accordance	Accuracy (%)
1	moving	Left forearm	Parallel to the ground	Forward-backward	0.6	Py > 50	80
2				up-down	0.8	(Px >20) || (Gz > 500)	96
3				left-right	0.8	(Gz >500)	92
4				wrist-twist	1.0	Gy >500	100
5		upper body	waist	twist	0.2	not explicit	20
6		lower body	left leg	left-right	0.1	not explicit	12
7			right leg		0.1	not explicit	12
8	incorrect postures	Left forearm	Lay naturally to the ground		0.6	Ay - 100 > 0	100
9			lay down 45 degree to the ground		0.4	0 < Ay && Ay < 150	96
10			up-lift 45 degree to the ground		0.4	-220 < Ay && Ay < -150	96
11			up-lift vertical to the ground		0.6	-220 - Ay > 0	100
12		lower body	One leg cross the other		0.2	not explicit	8
13	incorrect postures with movement	Left forearm	Lay naturally to the ground	Forward-backward	0.9	Py > 50	92
14				up-down	1.0	(Px >20) || (Gz > 500) && Ay - 100 > 0	100
15				left-right	1.0	(Gz >500) && Ay - 100 > 0	96
16				wrist-twist	1.0	Gy >500 && Ay - 100 > 0	100
17			lay down 45 degree to the ground	Forward-backward	0.8	Py > 50	88
18				up-down	1.0	(Px >20) || (Gz > 500) && 0 < Ay && Ay < 150	100
19				left-right	1.0	(Gz >500) && 0 < Ay && Ay < 150	96
20				wrist-twist	1.0	Gy >500 && 0 < Ay && Ay < 150	100
21			up-lift 45 degree to the ground	Forward-backward	0.8	Py > 50	88
22				up-down	1.0	(Px >20) || (Gz > 500) && -220 < Ay && Ay < -150	100
23				left-right	1.0	(Gz >500) && -220 < Ay && Ay < -150	96
24				wrist-twist	1.0	Gy >500 && -220 < Ay && Ay < -150	100
25			up-lift vertical to the ground	Forward-backward	0.9	Py > 50	92
26				up-down	1.0	(Px >20) || (Gz > 500) && -220 - Ay > 0	100
27				left-right	1.0	(Gz >500) && -220 - Ay > 0	96
28				wrist-twist	1.0	Gy >500 && -220 - Ay > 0	100
29		upper body	head	movement	0.1	not explicit	8
30			chest	movement	0.3	not explicit	28
31		lower body	left leg	up-down	0.2	not explicit	12
32			right leg		0.2	not explicit	12

It shows poor performance in recognizing 8 kinds of MIP, such as lower body movement and head movement. It is because this method is sensitive to MIP occurring at left forearm where the MIMU located. While the MIP occurs at those parts of body that is far away from left forearm, the collected attitude information is not strong enough to characterize this MIP. This limitation can be remedied by adding more MIMU at different parts of body such as leg or head. It is noteworthy that the SPG IF related to those MIP is so low that it is acceptable to ignore its influential effect. Weighing the pros and cons, the current recognition performance by applying one MIMU is enough for sampling qualifying SPG.

Through successful MIP recognition and voice prompt to decrease user's MIP, SPG sampling time is shortened. Another test conducted to contrast the operation time before and after using the proposed SPG sampling technique shows that for untrained volunteers the time can be shorten about one third averagely.

5 Conclusion

An innovative technique for fast sampling qualified SPG signal is proposed and presented. It integrates MIMU hardware platform and intellectual technology to detect the motion automatically then eliminate the user's disturbance with high efficiency by voice prompt. Technically speaking, the recognition is based on the foundation of digging out recognition accordance and its range from the constructed MIP database. The computation of *Accord* and the recognition process are well illustrated. The test to evaluate recognition accuracy of each MIP has been authenticated and the global performance of the proposed technique is outstanding. Consequently, this interactive MIP-awareness technique is proved to be effective and potential in fast sampling qualified SPG signal and useful for other mobile applications.

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