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Development of the Irregular Pulse Detection Method in Daily Life using Wearable Photoplethysmographic Sensor

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Abstract— **We developed an arrhythmic pulse detection algorithm from photoplethysmography (PPG) measured in daily life using a wearable PPG sensor, in order to provide a simpler device than a Holter electrocardiograph (ECG). However, PPG is very sensitive to artifacts in daily life, e.g. body movement.**

First, we analyzed the correlation between the ECG and the PPG measured at the same time when the arrhythmic heartbeat occurred in daily life. Using the correlation characteristics, we developed a detection algorithm of the arrhythmic pulse to distinguish the artifacts ascribable to body movement and evaluated its accuracy. The algorithm detects pulse-to-pulse interval (PPI) and pulse amplitude by a beat to distinguish between irregular PPI by arrhythmic pulse and that by the artifact.

I. Introduction

ARRYTHEMIA is closely related to various cardiovascular diseases, including lethal ones, such as ventricular fibrillation, that can cause of sudden death. So it is important to detect and diagnose it early. In particular, real-time alert and diagnostic services for arrhythmia in daily life are required that apply recent developments in IT to provide preventive healthcare.

In conventional clinical practice, electrocardiography (ECG) at hospital is used for diagnosis of arrhythmia. However, as the irregular heartbeat caused by arrhythmia does not necessarily occur during examination at hospital, it is necessary to measure ECG in daily life. A Holter ECG is a small device for measuring one or two channels of an ECG during 24 hours in daily life. The patient suspected of having arrhythmia can be diagnosed using the Holter ECG. There are some works concerning auto detection of the arrhythmia from Holter ECG [5][6]. However, since it is necessary to attach some electrodes to the patient's chest in the case of the Holter ECG, it is troublesome to check arrhythmia using a Holter ECG for preventive healthcare in daily life. Therefore, development of a heart rate monitor that is simpler and easier to use than the Holter ECG is desirable.

Such a heart rate monitor would also be useful for checking the change of a physical condition of an artificial dialysis patient during dialysis and to check the stress condition of a normal person by autonomic analysis of the heart rate variability.

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In this study, we use a PPG sensor, which is a simpler device than the Holter ECG. Using the PPG sensor, our goal is to detect the arrhythmic pulse with the same accuracy as the arrhythmic heartbeat is detected by the Holter ECG. First, we analyzed the correlation between the ECG measurement and the PPG measurement performed at the same time when the arrhythmic heartbeat occurred. Using the correlation characteristics, we developed a detection algorithm of the arrhythmic pulse for premature beat and evaluated its accuracy. PPG is more sensitive to body movement than ECG. The algorithm reduces the influence of the body movement.

II. Photoplethysmography of Irregular Heartbeat

There are 8 kinds of arrhythmia according to the Minnesota code that is widely used in the clinical field [1]. Since atrial or junctional premature beat (8-1-1), ventricular premature beat (8-1-2), atrial fibrillation / atrial flutter (8-3), supraventricular tachycardia intermittent (8-4-2), sick sinus syndrome (sinoatrial arrest, sinoatrial block) (8-5), sinus tachycardia(8-7), and sinus bradycardia(8-8) are detectable on the basis of RR intervals, they are the target of this study. Pulse-to-pulse interval (PPI) by PPG can be considered the same as R-R interval (RRI) by ECG provided the subject's physiological state is static.

However, in the case of RRIs with irregular intervals brought about by these 8 kinds of arrhythmia, pulse amplitude of the PPG varies. When the irregular interval is shorter than the normal interval, the amplitude of the irregular pulse is smaller than that of the normal pulse. This is because the duration of ventricular diastole is shorter owing to the shorter RRI, causing blood volume congested in the left ventricle to decrease, and consequently, stroke volume to decrease. In contrast, when the irregular interval is longer than the normal interval, the amplitude of the irregular pulse is larger than that of the normal pulse [4].

In developing the irregular pulse detection algorithm, it is necessary to consider the change of the pulse amplitude owing to the irregular pulse.

III. Data Acquisition

For confirmation of the characteristics of the PPG of irregular pulse described above, we measured ECG and PPG simultaneously for a person suspected to have arrhythmia.

A. Devices

We used a polygraph system (Polymate AP1124, TEAC Corp., Japan) for measuring ECG, the sampling frequency of the ECG is 200Hz. We also used a prototype of a wearable sensor that is wrist-watch style and has a reflective PPG sensor (wavelength of 525 nm) in the sensor head worn on the finger for measuring pulse wave and 3-axis acceleration sensor (H34C, Hitachi, -3 to +3G) in the sensor body for measuring body movement (Fig.1)[2][3]. The sampling frequency of the PPG is 64Hz. The clock between ECG and the wearable sensor were synchronized.

B. Procedure

We measured the 2-lead ECG and PPG for three subjects suspected to have arrhythmia during one normal night of sleep. PPG was measured from the index finger. The experimental procedure was explained, and written informed consent was obtained from all subjects.

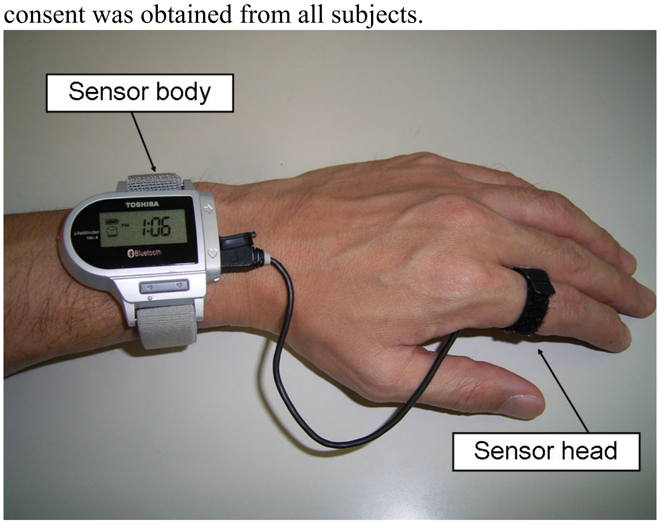

Fig. 1. Wearable photoplethysmographic sensor

IV. RESULTS OF THE DATA AQUISITION

Fig.2 shows the waveform of the irregular pulse of the first subject who has atrial premature beat.

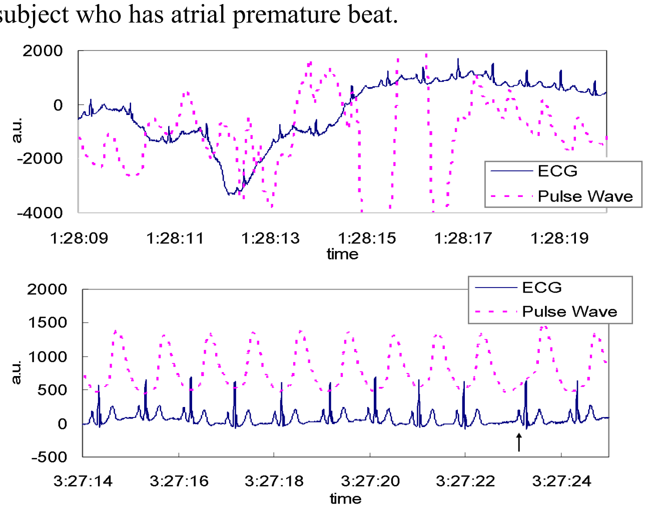

Fig. 2. ECG and PPG waveforms. (upper: during body movement, lower: including irregular heartbeat by atrial premature beat[arrow])

Fig.3 also shows the waveform of the irregular pulse of the second subject who has atrial premature beat.

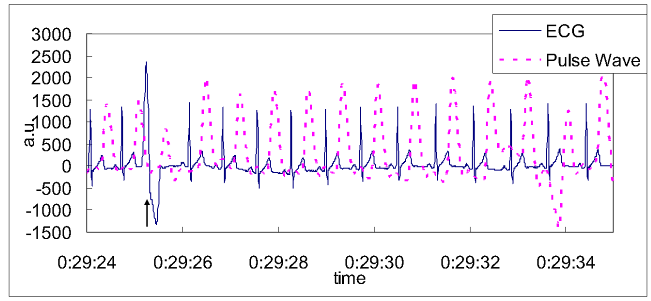

Fig. 3. ECG and PPG waveforms. (including irregular heartbeat by atrial premature beat [arrow])

Fig.4 shows the waveform of the irregular pulse of the third subject who has ventricular premature beat.

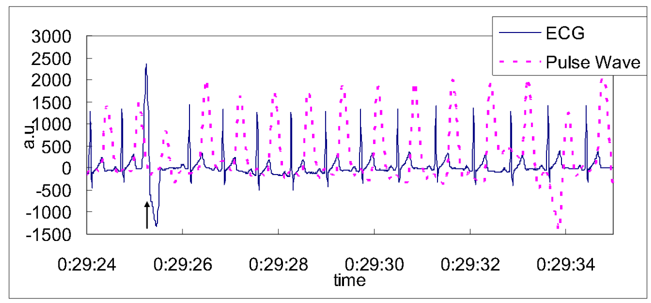

Fig. 4. ECG and PPG waveforms. (including irregular heartbeat by ventricular premature beat [arrow])

There are common characteristics in the three PPG waveforms. The characteristics are the same as the assumption described above. Meanwhile, the baseline of the PPG waveforms during the body movement fluctuates widely.

V. IRREGULAR PULSE DETECTION ALGORITHM

Using the characteristics described above, we developed an irregular heartbeat detection algorithm. Fig.5 shows the flowchart of the algorithm.

First, pulse trigger point (falling-edge) is detected by finding the crossing point of the internally dividing point between maximum and minimum value of the differential of the pulse wave during the prior 1 second, and then PPI is calculated by getting the interval from the previous pulse trigger point and the present point. Irregular PPI is detected from the change of the PPI. Also, we defined an index AIR (Amplitude / Interval Ratio) to distinguish an irregular pulse and an artifact as follows. AIR for the irregular PPI is calculated.

$$AIR = PulseAmplitude / PPI \quad (1)$$

In the case of an irregular pulse, AIR is almost a constant value. In contrast, in the case of artifact, AIR is varied by an artifact because the artifact does not have regularity.

The set value 1 and 2 were set empirically from measured three subject's data described below.

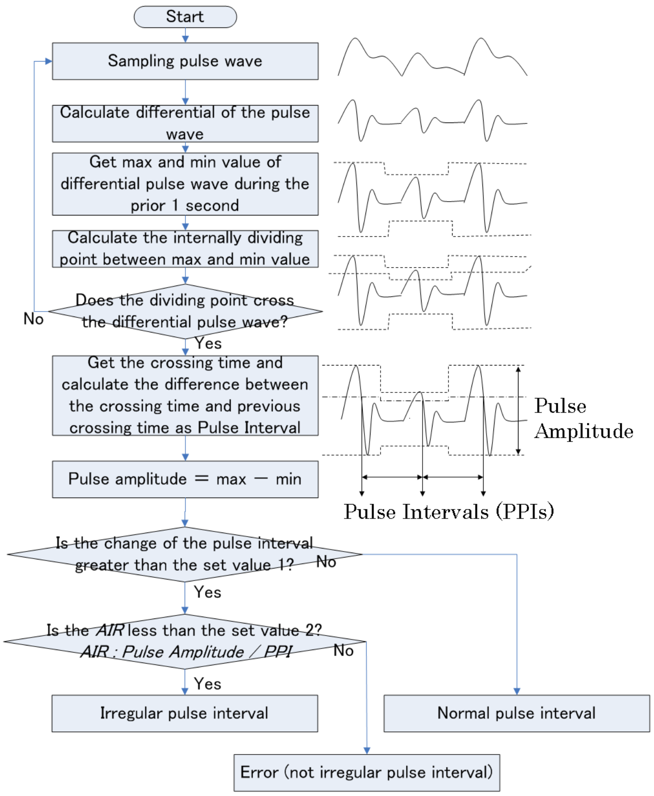

Fig. 5. Flowchart of the irregular heartbeat detection algorithm.

VI. EVALUATION OF THE ALGORITHM

We evaluated the accuracy of this algorithm using sample data. Fig.6 shows the detection result of atrial premature beat data (shown as Fig. 3). Large dot indicates the irregular pulse detection. This result shows that the irregular pulse detected by this algorithm is coincident with the irregular heartbeat detected from ECG. However, short-interval irregular pulse could not be detected because its amplitude was too small to detect pulse trigger.

Fig.7 shows the detection result of body movement data (shown as Fig.2). Large dot indicates the error detection (not irregular heartbeat). This result shows that the irregular heartbeat detection algorithm can discriminate between pulse wave of irregular heartbeat and pulse wave with an artifact (e.g. body movement).

Also, we evaluated the algorithm using all the data gathered in the acquisition described above during sleep. Table 1 shows the detection results for the three subjects.

The number of the artifact detected from the PPG is 47 for the three subjects. Almost artifact case was rolling over during sleep.

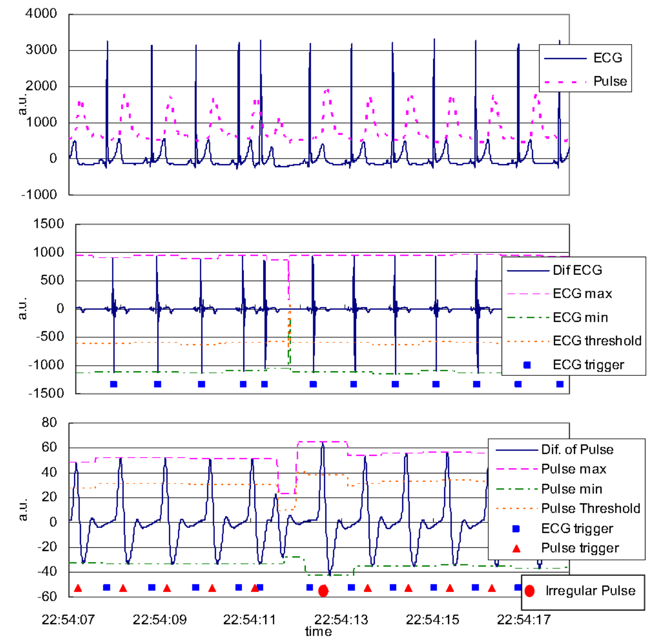

Fig. 6 Results of irregular heartbeat detection (upper: ECG and pulse waveforms; middle: ECG R wave trigger detection to get R-R intervals; Pulse trigger detection to get pulse intervals. DIFF ECG/Pulse means differential of ECG / pulse wave. ECG / Pulse threshold means internally dividing point between maximum and minimum of ECG / pulse waveform.)

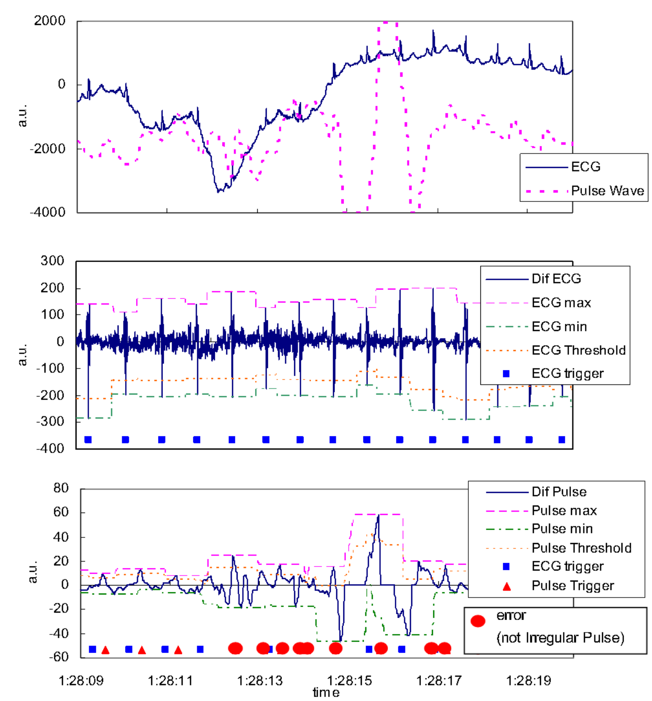

Fig. 7 Results of irregular heartbeat detection from body movement data (upper: ECG and pulse waveforms; middle: ECG R wave trigger detection to get R-R intervals; Pulse trigger detection to get pulse intervals. DIFF ECG/Pulse means differential of ECG / pulse wave. ECG / Pulse threshold means internally dividing point between maximum and minimum of ECG / pulse waveform.)

TABLE I
Irregular heartbeat detection results

		Photoplethysmography		
		Irregular	Normal	Sum
ECG	Irregular	161	15	176
	Normal	123	12214	12337
	Sum	284	12229	12513

Accuracy	0.989
Sensitivity	0.915
Specificity	0.990
False negative rate	0.085
False positive rate	0.433
Positive predictive value	0.567
Negative predictive value	0.999

VII. DISCUSSION

Since, as shown in Table 1, this algorithm has sufficiently high specificity, we confirmed the feasibility of detecting irregular pulse without misdetection of body movement data using the characteristics of the pulse amplitude fluctuation.

Pulse trigger detection of this algorithm uses pulse amplitude of every pulse wave employing constant width time window (1 second width). So, in the case that the fluctuation of the pulse amplitude is large, the pulse trigger cannot be detected. However, this algorithm can detect the irregular pulse of the premature beat robustly using the pattern that the next interval of short interval is longer interval.

The index AIR includes the influence of pulse amplitude fluctuation by respiration and autonomic nervous system. It is necessary to distinguish the irregular pulse from these influences.

VIII. CONCLUSION

We developed an irregular pulse detection algorithm using photoplethysmography. We confirmed the feasibility of detecting irregular pulse without misdetection of body movement data using the characteristics of the pulse amplitude fluctuation. In future work, we intend to apply and evaluate this algorithm for data on various situations in daily life.

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