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Heart monitoring systems—A review ☆

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ABSTRACT

To diagnose health status of the heart, heart monitoring systems use heart signals produced during each cardiac cycle. Many types of signals are acquired to analyze heart functionality and hence several heart monitoring systems such as phonocardiography, electrocardiography, photoplethysmography and seismocardiography are used in practice. Recently, focus on the at-home monitoring of the heart is increasing for long term monitoring, which minimizes risks associated with the patients diagnosed with cardiovascular diseases. It leads to increasing research interest in portable systems having features such as signal transmission capability, unobtrusiveness, and low power consumption. In this paper we intend to provide a detailed review of recent advancements of such heart monitoring systems. We introduce the heart monitoring system in five modules: (1) body sensors, (2) signal conditioning, (3) analog to digital converter (ADC) and compression, (4) wireless transmission, and (5) analysis and classification. In each module, we provide a brief introduction about the function of the module, recent developments, and their limitation and challenges.

1. Introduction

Worldwide, the number of patients of cardiovascular diseases (CVD) is huge [1]. Mortality caused by CVD in 2008 was 17.3 million which represents 30% of global deaths. In the U.S. alone, 2200 persons lose their life due to CVD each day [2]. According to American Heart Association (AHA) report, the total cost of CVD and stroke in the U.S. for 2008 is estimated to be 298 billion dollar [1]. 80% of the total mortality caused by CVD occur in low and middle-income countries.

These figures indicate need of systems that should be (1) sensitive to detect CVD at early stage, (2) capable of continuous monitoring, (3) light weight for portability, (4) cost effective. Lack of early stage detection and hence delay in medication causes heart diseases to extent at a level where it is difficult to cure [3]. Persons diagnosed with CVD need continuous monitoring of health status of their heart as they are at a higher risk to their lives as compared to the normal persons. According to the Heart Association, people diagnosed with CVD have 4–6 times higher mortality than normal one [4]. Portability of such systems makes it highly useful for elderly patients as this minimizes visits to clinics or hospitals. A cost effective system will emphasis the use of heart monitoring systems in low and middle income countries. Proper diagnosis reduces the mortality caused due to CVD which ensues economic up-lift of the country [5].

Due to the problems mentioned above, a lot of work has been done in development of a diagnostic efficient system [6–10]. Keeping in view that heart monitoring systems would be used in different socio-economic conditions, rural-urban population, and deficiency of availability of cardiac experts [11], recent research is focused towards system features such as cost effective, portability, easy diagnose process, and signal transmission capability. In view of these developments, we propose a review of various work done in this area.

Portable heart monitoring systems are used in two manners, as shown in (Fig. 1), one is on-site and other is off-site. In on-site monitoring, the acquired heart signal is processed on the patient site, without transmitting it to the remote site. While in off-site, the acquired heart signal is transmitted to a remote site using a wireless module. On-site heart monitoring system has advantages in the case of low latency feedback is required or wireless access is not accessible. Furthermore, it eliminates data transmission and hence eliminates the radio power consumption. However, the on-site monitoring has limitation that it has only a set of general diagnosis steps and thus unable to perform a detailed diagnosis. On the other hand, in off-site monitoring, diagnosis is performed at remote location with high computation capable processors and supports input from a cardiologist. This makes it suitable for accurate and detailed diagnosis. It is attractive because of higher processing capability and less power restrictions on such remote computation. Off-site monitoring also reduces the false alarm rate and thus reduces visits to clinics or hospitals. In view of

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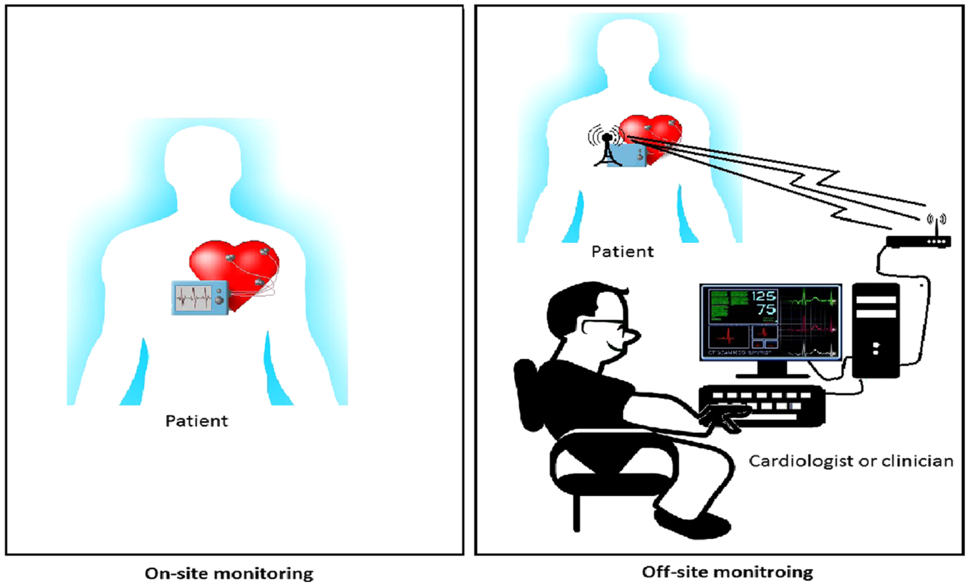

Fig. 1. Heart monitoring system.

these advantages of off-site monitoring, this paper is intended to provide a detailed review of recent research in the off-site monitoring system.

A typical off-site heart monitoring system consists of five modules as shown in (Fig. 2). The system with first four modules – body sensor, signal conditioning, ADC and compression, and wireless module is situated at the patient site. While the fifth module that is analysis and classification module is situated at remote site which can be any computational device with high computational ability.

Heart monitoring system uses signals produced by heart to diagnose its health status. It extracts diagnostic features from the acquired signal which caries information of heart functionality such as re-polarization, depolarization, and valve movements. Analysis of these features leads to specific health status of heart such as normal, arrhythmic, myocardial infarction, regurgitation, and stenosis. However, extraction of diagnostic features from the heart signal is challenging due to its non-stationary nature and the presence of noises such as muscles movement noise and environment noise in the signal. In this paper, we reviewed recent developments in the area of heart monitoring systems which are portable and have good diagnostic efficiency.

Rest of this paper is organized as follow. Physiology of heart and cardiac cycle in Section 2 and brief introduction about important cardiovascular diseases in Section 3 are given for reader's simplicity. Section 4 describes the recent developments in the body sensors. While different approaches of signal conditioning have been reviewed in Section 5. In Section 6, analog to digital conversion and compression techniques are presented. Section 7 discusses various wireless transmission technologies and Section 8 gives comprehensive review of noise removal algorithms, analysis and classification techniques for heart signals. Conclusion and potential research area have been presented in Section 10 followed by important references.

2. Physiology of heart and cardiac cycle

Since understanding of various components of heart monitoring systems needs knowledge of heart functioning, a relevant physiology of heart is described in this section.

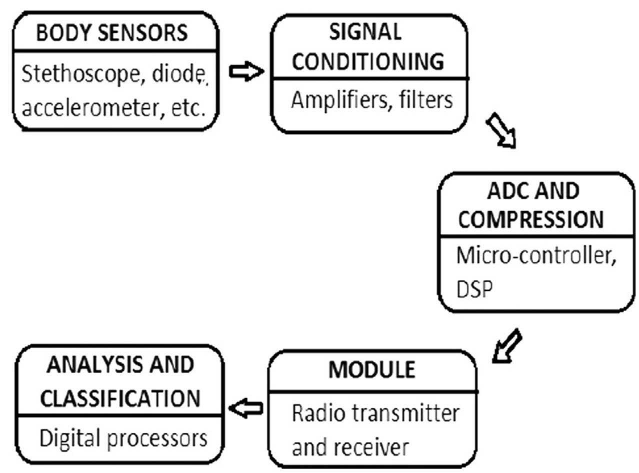

Fig. 2. Off-site heart monitoring system.

Heart is a prominent organ of human body. It supplies replenish oxygen to each part of the body and removes waste of each cell. Physiologically, heart comprises of four chambers named as left and right ventricles and left and right atrium as shown in Fig. 3. There are two atrioventricular valves namely tricuspid valve and mitral valve. As can be seen in Fig. 3, tricuspid valve separates right atrium and right ventricle while mitral valve separates left atrium and left ventricle. Aortic valve and pulmonary valve jointly called as semilunar valves separate left and right ventricles from aorta and pulmonary artery respectively. At rest, each cell of the heart muscle has a negative charge, called the membrane potential. Due to rapid change of membrane potential towards zero, due to influx of positive cations ($Na+$ and $Ca++$), an electrical impulse is generated at sinoatrial node. From sinoatrial node, the impulse spreads over both the atrium and both the ventricles. Presence of the impulse causes the contraction of atrium and ventricles sequentially.

Contraction of both atrium pushes the blood into respective ventricles. Then the impulse spreads all over left and right ventricles which causes the contraction of both the ventricles. This contraction results to closing of both atrioventricular valves and opening of both semilunar valves. During this contraction phase, oxygenated blood from left ventricle flows into the body