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# Developing Trends in Cardiac Monitoring Systems

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**Abstract** – Increasing cardiac diseases is one of the major issues in the world; hence a review about the state-of-art technologies in cardiac monitoring has been presented. The paper provides a brief summary about the developments so far in three main factors of the device i.e. sensors used, the system design and the algorithm implemented in the design. It also gives us an idea about the possible future scope in this area.

**Keywords -** Cardiac monitor, body worn unit, base station

## I. INTRODUCTION

Cardiovascular disease (CVD) like heart disease and stroke remains the leading cause of death around the world. According to a survey conducted by WHO, around 17.3 million people died of heart diseases, representing 30% of the global deaths in 2008[15]. And it has been estimated that, by 2030 the heart disease rate might increase to 23.3 million of the total population [9,15]. Most of these CVDs could be prevented if some method of pre-monitoring and pre-diagnostics could be provided. In particular, early detection of abnormalities in the function of the heart, called arrhythmias, can help in averting the problem to a great extent.

In order to address the above said reasons, Norman J. Holter invented cardiac monitor in 1949[11]. The cardiac monitor are devices that record and display the electrical and pressure waveforms of the cardiovascular system for measurement and treatment, up to 48 hours duration. Clinical use of these devices started in the early 1960s [11]. After the invention of telemedicine, cardiac monitors which could transmit data in real time were developed. Today mobile PDA systems are used as cardiac monitors [8]. 3G internet, Wi-Fi and Bluetooth devices are used to transmit the data in real time [8][9]. This paper provides a detail description of the inventions done in cardiac monitoring field.

The paper is divided into three sections. The first section lists out the important units in cardiac monitors and the latest inventions. The second section gives us the possible future scope in this area. The third section concludes the discussion in this paper.

## II. CADRDIAC MONITORS

The basic principle of Cardiac monitors is to acquire ECG from the patient, perform some basic signal processing operations on them (filtering the ECG, classifying arrhythmias, etc..) and then transmit them to the physicians clinic wirelessly for further analysis. The basic

components of the monitor in order to perform all the above said functions are

- Sensors / Electrodes to sense and acquire ECG.
- Body worn unit with transmitters to transmit ECG acquired.
- Base station unit to receive the transmitted ECG.

The implementation of these components is as shown in Fig. 1.

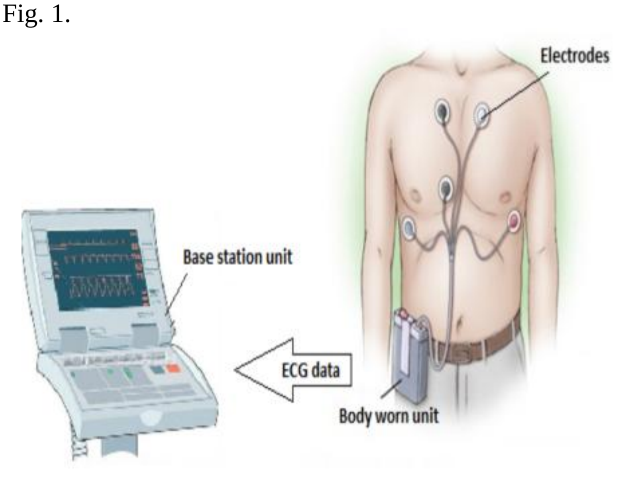


Figure 1 : Cardiac monitoring system

### A. *Electrodes And Sensors Design*

Disposable electrodes are the most widely used electrodes. They are Ag or AgCl electrode, which consist of base lining material, conductive gel, and electrode buckle. The base lining material uses the nonwoven fabric, the breathable paper, cotton or PE and foam with medical hypoallergenic adhesive. They have average AC

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Impedance of ≤2KΩ and DC offset voltage of ≤100mV [21]. Fig. 2 shows a disposable electrode.

Figure 2 : Disposable electrodes

Richard R. Fletcher et.al. in 2010 [12], presented a new type of non-contact sensor for use in ambulatory cardiac monitoring. The sensor operation is based on a microwave Doppler technique; however, instead of detecting the heart activity from a distance, the sensor is placed on the patient's chest over the clothing. The basic components and the principal for the working of a sensor based on Doppler technique is as shown in the Fig. 3.

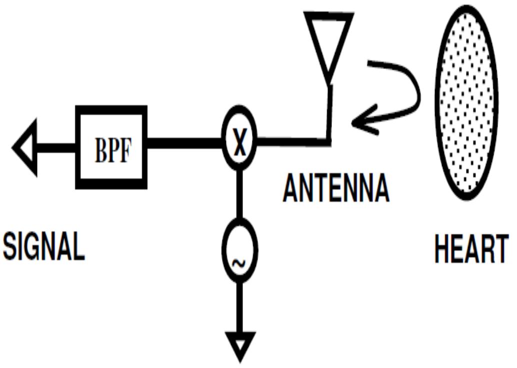


Figure 3: Block diagram of a Doppler radar sensor

The advantages of these microwave sensors include small size, light weight, low power, low-cost, and the ability to operate through clothing [3].
Long Yan et. al. in 2011[16], designed a low power highly sensitive Thoracic Impedance Variance (TIV) and Electrocardiogram (ECG) monitoring SoC and implemented into a poultice-like plaster sensor for wearable cardiac monitoring. 0.1Ω TIV detection was made possible with a sensitivity of 3.17 V/Ω and SNR>40 dB. With 25 adhesive screen-printed fabric electrodes, detection of TIV and ECG at 16 different sites of the heart was made possible, allowing optimal detection sites to be configured to accommodate different user dependencies.
Chae Young Lim et al. in 2013 [20] designed fabric electrodes. The overall organization of such a wearable system is shown in Fig. 4. Initial placement of the conductive fabric electrode is on the chest in a bi-polar electrode configuration based on the measured potential difference. Placement in a modified bipolar configuration was determined by comparing the signal obtained from the placing electrodes at standard locations and the signal obtained from Ag/AgCl electrodes placed in the standard limb lead configuration. Table 1 shows the list of sensors.

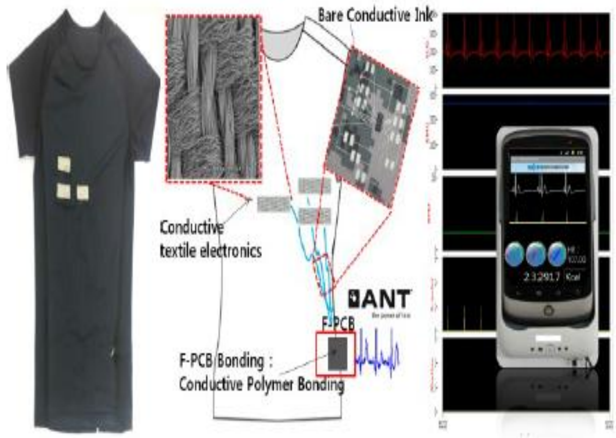


Figure 4: Organization of wearable electrode system

TABLE 1 SENSORS

| **Electrode type** | **Material** | **Current/Voltage Consumption** | **SNR** |
|---|---|---|---|
| Disposable Electrodes | AG-AgCl | <=100mV | 666.66 |
| Non-contact sensor Electrodes | PCB with a microwave circuit | 30mA | 50dB |
| Thoracic Impedance Variance (TIV) and Electrocardiogram (ECG) monitoring SoC | poultice-like plaster sensor | 3.17V/Ω | >40dB |
| Fabric Electrodes | AgCu | 20mV | 110dB |

B. *System Design*

P. N. Kizakevich et al. in 1988 [2] developed a personal monitor comprising of ECG recording and impedance cardiography in a wearable and untethered unit. This personal monitor was a small, battery powered device for acquiring and processing number of ensemble averaged ECG and dZ/ dt waveforms. Since the instrument is battery powered, subjects could move freely while monitoring. The duration of data acquisition was programmable, ranging from 3 to 24 hours.

Hanh Le et al. in 2010 [13] designed an electronic cardiac monitor, the overview of such a system is as shown in the Fig. 6. An ECG Sensor is connected to a PDA, which acts as a local server to forward the signal to a centralized server. Data from the biosensors could be visualized, monitored and transmitted to a central health server for further review. The system was provided with a provision for both in-home monitoring, as well as mobile monitoring and was able to generate multiple alerts based

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on the patient's condition. The system was developed using C# on the Windows Mobile platform. An Alive Technologies ECG Bluetooth sensor and a HTC p4350 running Windows Mobile 6 OS were used for implementation of the system.


Figure 6: Overview of the electronic cardiac monitor

Yongwon Jang et al. in 2012 [17] developed a patch type embedded cardiac monitoring system with dual microprocessor for arrhythmia detection in heart disease patients. It detected arrhythmias such as PVC (Premature Ventricular Contraction), pause, ventricular fibrillation, and tachy/bradycardia. The overall system was composed of a main module including a dual processor and a Bluetooth telecommunication module. The processing module has two 16-bit microprocessors which communicates with each other through SPI (Serial Peripheral Interface). The dual processor concept was used to increase the processing capacity and minimize power consumption. Whenever an arrhythmia occurred, the system sent an alarm sign to the user's terminal device (i.e. smartphone) through Bluetooth connection. The user's device, smartphone, then displayed the monitoring status and result through its display, and sent this situation to the caregiver's device or system through 3G network. The system architecture of this device is shown in Fig. 7.

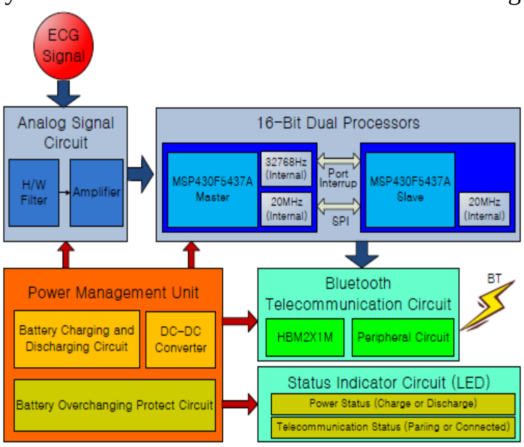


Figure 7: Architecture of dual microprocessor based cardiac monitor

Keunjoo Kwon et al. in 2013 [19] developed a remote cardiac monitoring system for preventive care. The system was composed of physiological measuring devices, mobile gateways, PoC devices, and a monitoring server. The overview of the remote cardiac monitoring system is shown in Fig. 8. The application had two communication modules running concurrently i.e IEEE 11073 protocol stack and HTTP (Hyper-text Transfer Protocol) stack. The application contained user interfaces which helped patients connect measuring devices to mobile gateways and describe their symptoms which could be sent to the server. The PoC Devices were tablet PCs with Android OS which were carried by physicians. An application was running on the device to receive alert messages from the server and to notify physicians. Preventive care was developed by designing a decision support system with personalized parameters and an algorithm to predict forthcoming paroxysmal atrial fibrillations. The proposed prediction algorithm showed 87.5% accuracy.

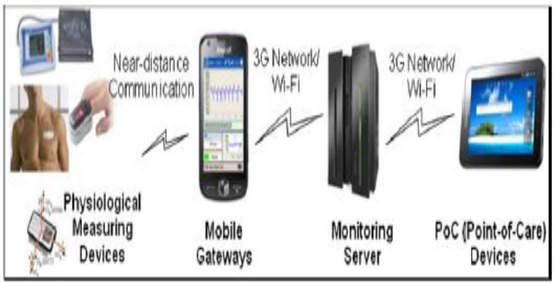


Figure 8: Overview of remote cardiac monitoring system

C. *Algorithms*

I˜naki Romero et al. designed low power beat detection algorithm in ambulatory cardiac monitor in 2009 [10]. The algorithm evaluated ECG data of 3 seconds length. Then the peak detection was performed in the CWT-modulus maxima domain as the maximum value within the 3-seconds window. To avoid noise being selected as the peak, a threshold ($th_{new}$) was computed recursively by using a weighted sum of the previous threshold ($th_{old}$) and the newly calculated threshold ($th_{current}$) as in Fig. 9.

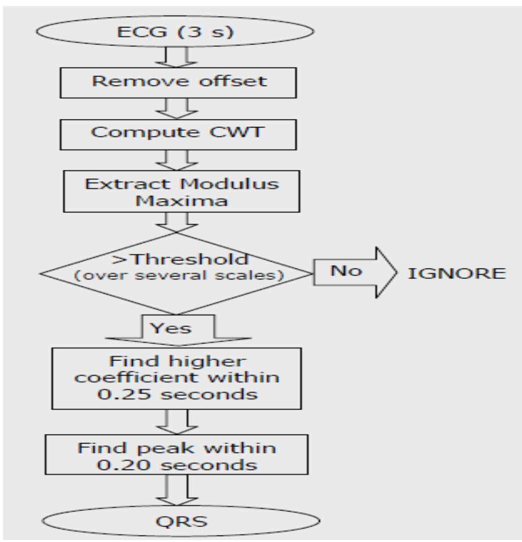


Figure 9: Scheme of the Beat Detection CWT algorithm.

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Zhen Xing-Zang et al. in 2010 [14] developed a Real-Time Algorithm for a Mobile Cardiac Monitoring System to Detect Life- Threatening Arrhythmias. In the detection process of the algorithm, 14 initial features were extracted from the detail coefficients d3 at level 3 and d4 at level 4 of the Haar wavelet transform. Finally, four features were selected to generate fuzzy rules using Non-overlap Area Distribution Measurement based on the neural fuzzy network. The performance results demonstrate the proposed algorithm's effectiveness and efficiency with 92% accuracy and 93% sensitivity.

Beatrice Arvinti et al. in 2012 [18] presented a wavelet based algorithm using biorthogonal mother wavelets. Many other algorithms have been developed for cardiac monitors based on, Zero-Crossing [5], Signal Derivatives [1], Digital Filters [4], Filter Banks [7], Neural Networks [6] and Wavelet Analysis [3], [8].

## III. INSTITUTIONAL RESEARCHES ON CARDIAC MONITORS

Indian Institute of Technology, Mumbai (in 2002), India, under the aegis of Tata Consultancy Services developed a wearable electrocardiogram system known as the 'Silicon Locket'. The device could store, record and download patients ECG onto a personal computer, transmit it to a central server and alert the doctors through SMS about the patients abnormal heart.[22]

Georgia Institute of Technology in January 2006 developed "CardioMEMS", pioneered a new breed of testing devices to monitor heart patients, combining wireless communications technology with microelectromechanical systems (MEMS) fabrication.[25]

Researchers at the Interuniversity Micro-Electronic Centre (IMEC), Netherlands, in December 2007 developed an flexible stick-on device, a variation of a Holter monitor. The new device just sticks onto the patient's chest and wirelessly sends electrical signals detected from the heart to a credit-card-like receiver.[23]

Yu M. Chi et.al., at University of California , San Diego developed a wireless non-contact cardiac and neural monitoring in 2009. It was a wireless biopotential instrumentation system using non-contact capacitive electrodes that operates without skin contact.[26]

M. K. Delono et.al., at Microsystems Technology Laboratories, MIT, Cambridge in 2013 developed an experimental cardiac monitor for long-term data acquisition and analysis. [24]

## IV. COMMERTIALLY AVAILABLE PRODUCTS

Many leading companies across the world have been developing/manufacturing various types of cardiac systems. 'DigiTrak XT Holter Monitor' is a holter monitoring system by Philips[27]. Similarly 'MARS Ambulatory ECG system' is by GE Healthcare[28]; 'evo' by Spacelabs; 'Clikholter' by Cardioline and so on[29].

## V. PATENTS AWARDED

Barry M. Yomtov et.al., were awarded patent by InControl, Inc., Redmond, Wash., on May 2, 1995 for developing a cardiac monitor which was fully implantable beneath the skin of the patient to monitor the heart rate variability.[31]

William J. Luczyk et al. were awarded patent by Marquette Electronics, Inc., on Oct. 10, 1995 for developing a "Cardiac Monitoring and Diagnostic system". The system included a acquisition module for acquiring the plurality of analog cardiac signals through leads connected to predetermined positions in the body and for converting the signals into 12standardised ECG lead signals.[33]

William J. Sanders was awarded patent by ITH, Inc., on Aug 22, 1989 doe developing a "Cardiac Probe Enabling Use of Personal Computer for Monitoring Activity or the like".[34]

Gary N. Mills et.al., were awarded patent by Instomedix, Inc., Hillsboro, Oreg, on March 25, 1997 for developing a "High Functional Density Cardiac Monitoring system for Captured Windowed ECG Data". It was a compact, light weight wrist-worn cardiac data and event monitor having dry skin electrodes integral with the monitor's housing.[32]

APPLE was awarded patents by the US Patent and Trademark office (USPTO) on December 25, 2013 for "seamlessly embedded heart rate monitor".The described device would incorporate several leads used to detect a user's heart rate transmitted from the user's skin through the electronic device housing to the leads.[30]

## VI. FUTURE SCOPE

The studies developed until now reveal that there are cardiac ambulatory devices which record the ECG of the patients and classify them. But there is no means to correlate the patient's activities (in day to day life) with the problems occurring in the ECG. This is being performed manually i.e. the patient is asked to note down the activities that he performs during the monitoring period. Hence it can be automated. This can be done by acquiring the patients EEG simultaneously and classifying them to reveal human activities; and correlating it to the ECG at that time instant. This can help the physician to perform more accurate diagnosis which can go a long way in averting tragedies.

## VII. CONCLUSION

The purpose of this study was to provide a review about the existing technologies in the field of cardiac monitoring devices. Hence a literature survey has been done and a brief idea about the technologies developed in this domain has been projected. In addition to the existing technologies, a novel idea about the future scope in this area has also been provided.

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