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A Wearable ECG-Recording System for Arrhythmia Monitoring Using a Wireless Communication

Ashwag Al Kheilewi[1], Malak N Al Otaibi[2*], Maram Al Jabry[3] and Fadwa Al Amoudi[4]

*[*1]King Abdullah International Medical Research Center, KAIMRC, Riyadh, Saudi Arabia*

[2]Clinical Performance Monitoring Office, King Fahad Medical City, Riyadh, Saudi Arabia

[3]Ministry of Health, Riyadh, Saudi Arabia

[4]Prince Mohammed Bin Abdul-Aziz Hospital, Riyadh, Saudi Arabia.

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ABSTRACT

Background: The system composed of a wearable patch equipped with a biomedical sensor placed on the patient skin for Electrocardiogram (ECG) monitoring and arrhythmia detection. This patch is connected to Hand Held Device (HHD), which received the transmission through a Bluetooth wireless link to be analysed in it and temporary saved. Finally, the recorded ECG will be transmitted to the healthcare provider on the other end who is tracking the patient's cardiac rhythm disorders whenever abnormal ECG is detected and will be alerted in order to follow up with the patient accordingly.

Method: The wearable ECG system functions by placing a small patch with biosensor into the patient's skin, this sensor is equipped with two electrical points that have the automatic capability of detecting any arrhythmia as an ECG signal and transmits it to the HHD wirelessly via Bluetooth. Using a wireless Internet as well as the DSL connection, The HHD sends the received recorded transmission with an alert to the healthcare server for storing and analyzing the signals. The physician can access the patient ECG recorded via a client-server web application system in the healthcare center. The physician will diagnose and evaluate the situation regarding the patient's condition for taking the necessary actions.

Results: Several previous types of research that employed the wireless ECG approach had proven that the use of the biomedical sensor system is soothing and useful. Our proposed system if worked as planned will benefit the patient with the cardiovascular disorder.

Conclusion: The system discussed in this paper demonstrates a practical approach, which allows the patients who are wearing wireless ECG devices to enjoy their daily activities without feeling its presence. Patients will appreciate a protection sensation at the same time and increased the level of confidence via this technique, which helps to minimize the risk of having a heart attack by early detecting it.

Keywords: Home monitoring, Wireless ECG patch, Body sensor, Long-term monitoring, ECG, Tele-home

INTRODUCTION

Wearable Health Monitoring Systems (WHMS) capability enabled healthcare providers to change the way healthcare services delivered. Monitoring patients in their personal environment improve patient life quality. It helps to concentrate on the early detection of health issues before it is even happening and contributed in avoiding unnecessary hospitalizations. And for that, Hence, WHMS became favorable among researchers and in the health industry during the last years [1]. WHMS allow patients to maintain and monitor their health conditions and get instant help from their healthcare providers using affordable technologies.

According to the World Health Organization report released in 2017, cardiovascular disease (CVD) is associated with substantial morbidity. It becomes the reason for 45% of all Non-communicable diseases (NCD)

Corresponding author: Malak N Al Otaibi, Clinical Performance Monitoring officer, King Fahad Medical City, Riyadh, Saudi Arabia, E-mail: malak.naif@gmail.com

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worldwide death, which accounts for 17.7 million people in 2015 (World Health Organization, 2017). Thus, the sudden cardiac arrest is also referred to as "a silent killer" as sudden death is often the first manifestation of cardiovascular disease. For this reason, ECG monitoring becomes one of the most vital signs that healthcare providers are eager to early detect in the present day [2]. As a result of extensive studies and research, conjointly with the rapid growth of wireless infrastructure in many countries open doors for disclosing new medical tools and applications that increase the interest in wearable telemedicine monitoring systems. Particularly, when these systems have proven it's competence by not interfering with the patient's daily activities [3].

Healthcare providers are fully aware of the necessity of monitoring patient with cardiac arrhythmias. Since the 80s, stakeholders in the healthcare domain were enthusiastic to adopt new technology that facilitates the 24 h electrocardiographic (ECG) monitoring process, which was achieved with the (Holter) monitor at that time, regardless of its limitations.

However, with the technological evolution and advancement in the IT and medical field domain have made it possible to overcome the challenges with the traditional Holter recorders which improved the quality of life and healthcare services. Suave Lobodzinski and Laks [4] had discussed an updated generation of the cardiac arrhythmias monitoring using a wearable long-term 14 day patch attached on the patient skin for ECG monitoring providing maximum convenience with the mobility of the patient due to its wireless communication ability.

Lin et al. [5] provided a novel system that can be used for inpatients, outpatients as well as monitoring normal people. They used a three-lead wireless ECG device, a Java-based expert system application and a web-based monitoring platform to meet these objectives and detect the atrial fibrillation (AF), the most common cardiac arrhythmia with average accuracy, sensitivity and positive predictive performance were 94%, 94.56% and 99.39%.

Senatore et al. [6] investigated the uses of the transtelephonic (TT) electrocardiographic (ECG) monitoring and compared it with the standard ECG and 24 h Holter recording to detect the incidence of asymptomatic recurrences of atrial fibrillation (AF). They recruited seventy-two of 97 patients who underwent catheter ablation of AF. The researchers succeeded in proofing that long-term TT ECG is better than standard ECG and 24 h Holter recordings in evaluating AF relapses after RCA which results in changing the short-term success of ablation from 86% to 72%.

Piorkowski et al. [7] were interested in doing a comparison between TT ECG every two days and serial 7 day Holter as two methods of follow-up after atrial fibrillation (AF) catheter ablation for the judgment of ablation success. TT ECG and serial 7 day Holter were equally effective to objectively determine long-term success and to detect asymptomatic patients with the success rate for AF was 70%. Regarding the serial 7 day Holter it decreased to 50% and on transtelephonic monitoring to 45%. The purpose of this paper is to provide maximum suitability to the patient during ECG monitoring in their personal environment, especially for prolonged uses. The proposed system also provokes an emergency alarming system when abnormal ECG is detected. This system will be considered as a pilot test for patients living in Saudi Arabia, Riyadh especially for the areas with STC DSL coverage [8].

PROPOSED METHODOLOGY

The wearable ECG system functions by placing a small patch with biosensor into the patient's skin, this sensor is equipped with two electrical points that have the automatic capability of detecting any arrhythmia as an ECG signal and transmits it to the HHD wirelessly via Bluetooth. Using a wireless Internet as well as the DSL connection, HHD sends the received recorded transmission with an alert to the healthcare server for storing and analyzing the signals. The physician can access the patient ECG recorded via a client-server web application system in the healthcare center. The physician will diagnose and evaluate the situation regarding the patient's condition for taking the necessary actions **(Figure 1)**.

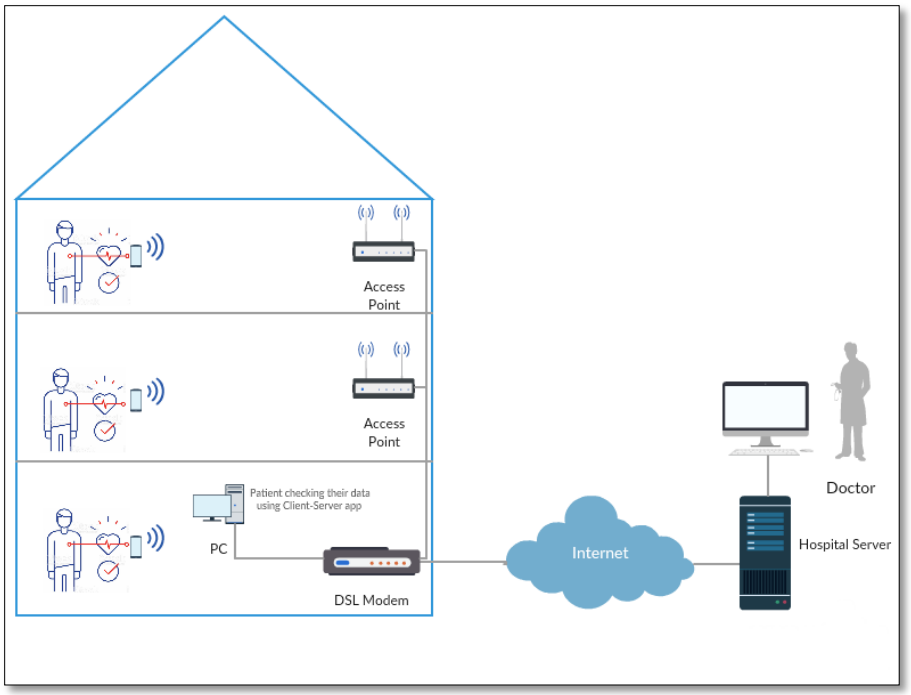

Figure 1. The coverage of wireless network connected with access points' in-patient home.

System configuration and the alternative solutions

- The sensor is placed on the patient' using patch that connects to the HHD via Bluetooth and transmit the signals. This approach allows the patient to be mobile.
- HHD is connected to the internet using STC DSL modem as a primary link. It transmits the ECG signal and the alarm in almost real time. In case of any issue with the STC DSL network, STC 4G connections can be used as an alternative link.
- DSL approach supported by Moron et al., 2012 study [3].
- 4G approaches are supported by Suave Lobodzinski and Laks, 2012 study [11].
- The transmitted data is stored in the healthcare provider server. The physician accesses the ECG records on the server using a web-application interface. Physician PC is then connected to hospital network using a client-server wired local area network LAN with copper cables such as CAT6 as a medium laid out in two types of topology (Star-Mesh) to make sure that this computer will not lose access and the wire won't be affected by electrical interference. This topology is supported by this study [9].
- TCP/IP is used as the protocol.
- The patient can access a private cloud version of the application to check the data. In case of non-function, they might contact the hospital to check the data or an email request or text [10,11].

As innovation advancement from our side, and in order to assure that the patients HHD will be able to send the single everywhere in their home, we suggest employing this technique with access points. This will help with overcoming the potential of losing the singles while the patient leveling up to different floors due to concrete walls. These access points were then connected to the main DSL modem using wire from the ground floor of the patients' homes to assure having the same speed of the configured modem.

In this approach, we are using the following architecture tools and equipment:

Patients home

- DSL modem
- Access point for each floor, in our example we assume to use two of them
- Biomedical wearable sensor placed on patch
- HHD
- PC to view and monitor the patient's collected details using a web-based interface of the application

Healthcare provider environment

- Server to store the transmitted signals and install the application, which allowed the physician and the patient to view the data. Also, the data will be backed up on other server and will be switch to in case of any issue happening to the primary one.
- LAN network
- PC to view and monitor the patient collected details

EXPECTED RESULTS

Several previous types of research that employed the wireless ECG approach proven the use of the biomedical sensor system which is soothing and useful. Our proposed system if worked as planned will benefit the patient with the cardiovascular disorder. It will have the following functionalities:

- **Wireless:** All type of communications between the patient and the HHD, and the HHD with the DSL modem is performed wirelessly, (Bluetooth/DSL as a primary link or 4G as an alternative link) which offers the patients with more flexibility.
- **Mobility:** The ECG patch is small, light and can operate for an acceptable period.
- **Timely manner:** Near real-time ECG signals are transmitted in seconds, which make it competent. However, with the use of DSL and the small size of the collected data, in our case text this may make it in real-time.
- **Alerting mechanism:** It is used for detecting abnormal ECG signals which alerts the patients and the healthcare providers.

To calculate the approximate time taken to send these data, we used the below formula assuming that that the text file size will be around 500 Kb; and the data rate of STC DSL modem connection is minimum as 200 Kbps.

$$Time\ taken = file\ size / data\ rate$$

$$Time\ taken = 500 * 1024\ byte / 200{,}000 = 2.56\ s$$

*This result only an estimate, there will be an added latency time.

DISCUSSION

As per the system configuration previously mentioned, this paper described a wearable ECG system with almost near real-time monitoring and alarming functionalities. The data collected from the wearable ECG system should be kept private. Moreover, during transmission the data should be encrypted to assure its security and the patient confidentiality. The system gives reliable recordings of medical data as following: First of all, a wave signal sent from the sensor to the HHD device via Bluetooth. Then this wave was converted in the HHD using specific algorithms to be in text format and sent to the server located at the hospital through DSL modem with speed up to 200 kbps and a maximum size up to 500 Kb.

Since the patients will be moving around their home sand to assure the maximum coverage, the configured AP in each floor will maintain the connectivity and strengthen the signal using the same data rate of the DSL modem. This will allow the physician on the other end to access the recoded data of the patient on the server via the hospital LAN and interfere immediately.

This interference of the physician is highly important, there will be a backup server used as a mirror for the primary one in case any thing happened and to avoid the single point of failure of the primary server. However, if the patients were not able to view the application interface this will not be an issue, since viewing the data is not vital for the patients and they can contact the healthcare provider using the phone and inquiry about any details.

As a general recommendation for enhancing the connection and improving the quality of this technique, the patients at their homes needs to pay attention to the surrounding noise that may interfere with the signals like the use of microwaves. Also, they should focus on the availability of mirrors and other furniture or objects that might scatter or sometimes completely prevent the wireless signals. Finally, it would be advisable if they can select different frequency range to be used than the one used with their neighbors to avoid the frequency interference. And not to forget the environmental factors like weather conditions, which can affect the liability of the signals and connection.

At the end, the healthcare provider should make sure to test the sensor from time to time and create a maintenance schedule to examine it or replace it if needed. This will help to avoid any malfunction that might be caused during the use.

CONCLUSION AND FUTURE WORK

In the last few years, many potentials of employing technology were witnessed to enhance the healthcare quality, which result in increasing the patient satisfaction. One of them is the achievement made in developing contactless, mobile ECG sensors. This technique was widely accepted due to its small size, low power consumption and wireless communication functionality.

In conclusion, the system discussed in this paper demonstrates a practical approach, which allows the patients who wear wireless ECG devices to enjoy their daily activities without feeling its presence. Patients will appreciate a protection sensation at the same time and increase the level of confidence via this technique, which helps to minimize the risk of having a heart attack by early detecting it [9]. However, proper clinical trials are

required to verify our hypothesis, it therefore seems reasonable to assume that our ECG-monitoring system will be able to, reliably, detect the occurrences of cardiac arrhythmias and thus contribute in facilitating the healthcare provider' job to able to make correct diagnosis even under situations where the patient is not hospitalized.

The current technological developments in this field can be employed for future improvements specially to enhance both hardware and software designs, which can be useful to obtain more efficiency and accuracy results. Moreover, future models of this system can be utilized to cover different areas of Saudi Arabia.

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