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m-Health 환경에서 효율적인 생체 데이터 전송 및 보관을 위한 방안

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Solution for Efficient Vital Data Transmission and Storing in m-Health Environment

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요 약 세계적으로 정부 재정에 상당한 영향을 주고 있는 보건의료 비용 문제를 해결하기 위해 m-Health가 등장하였다. 그러나 최근 저조한 m-Health의 결과물들은 m-Health 서비스 개혁의 필요성으로 이어졌다. 따라서 본 논문의 목적은 이와 같은 일환으로 m-Health 환경에서 효율적인 생체 데이터 전송 및 보관을 위한 방안을 제시하는 것이다. 연구방법으로는 생체 데이터를 효율적으로 전송 및 보관할 수 있는 시스템 및 알고리즘을 개발하였다. 분석 결과로 제시하는 솔루션의 효율성을 평가하기 위하여 전송되는 데이터의 압축률을 비교 평가하였다. 그 결과 본 논문의 압축률은 30.4배였다. 본 연구가 제시하는 시스템은 향후 m-Health에서 생체 정보를 모니터링 하는 시스템을 구축하도록 기여할 것으로 전망된다.

주제어 : m-Health, 융복합, 생체 데이터 전송, 생체 데이터 보관, 압축률

Abstract In order to tackle healthcare expenditure problems that affects a crucial part of government finances world-wide, m-Health emerged as a solution. However, recent poor outcomes of m-Health led to the need for reform in m-Health services. Therefore the purpose of this research is to propose a solution for efficient vital data transmission and storing in m-Health environment as part of such initiative. Methods included development of an efficient system and algorithm for vital data. For results, the compression ratio of the proposed solution was compared and evaluated. Results showed a compression ratio of 30.4. The proposed system is envisioned to contribute to the future vital data monitoring system in m-Health.

Key Words : m-Health, convergence, vital data transmission, vital data storing, compression ratio

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1. Introduction

On the globe, total healthcare expenditure is said to be approximately 4.2 trillion dollars. The average expenditure to healthcare among OECD(Organization for Economic Cooperation and Development)consists an average of 10% of their GDP[1]. Unfortunately, this mass amount of expense is not evenly distributed among healthcare beneficiaries. The top 16% “haves” share over 89% of health spending, whereas the rest of the 84% share the remaining 11%[2]. This is when m-Health emerged to face the challenges of unfair distribution of healthcare expenses on the planet. Curated by numerous global health related institutions, m-Health was applied mainly in the developing world with commentators on the industry suggesting m-Health to grow up to 60 billion dollars in market size[3].

However, as a result of the past few years of implementation, m-Health service is facing poor performance and low health outcomes[4]. m-Health have mainly been applied in developing countries such as Africa, South America for disease interventions such as malaria, maternal care and AIDS[5, 6], but with somewhat disappointing outcomes.

A couple among the many reasons why the adoption of m-Health have been unsuccessful is due to technical problems and patient preferences problems[2]. The technical problem is that m-Health relied mostly on text messaging follow ups for healthcare delivery. Considering the state-of-the-art level technologies that is being developed in the field of medical information systems such as maternity monitoring system[7], infusion pump monitoring system[8], emergency management information system[9], spectrometer system[10], and ECG data transmission system[11, 12], simple text messaging services are hardly thought to be high-tech. Patient preference problems refer to m-Health’s lack of providing important services that truly meet the patients’ needs.

For m-Health to be revitalized once again to reach the scope of success that many have expected, it needs a state-of-the-art technology service that is simultaneously critical to the patients’ needs. Efficient ECG(Electrocardiogram) transmission and storing solution in m-Health environment that this research proposes could be a solution for such problems. This is because this research overcomes the technical problems in current services in m-Health which heavily relied on text messaging follow-ups. Second, since ECG is considered as the most basic and at the same time the most vital data that indicates the patients’ health, monitoring of such services can be seen as something crucial to healthcare users.

However, in order to provide ECG monitoring service, the solution must support two important points: a capacious network environment, and a capacious storage system. This is because the total amount of ECG becomes astronomical when it is accumulated by time. The key solution to supporting the two points is to compress ECG data. When highly compressed, ECG data could be efficiently sent throughout the network and also could be efficiently stored due to its reduced size. That is why after the presentation of the ECG monitoring service, its efficiency in terms of compression ratio will be evaluated.

In section 2, some related works that are needed to understand the proposed solution are presented. In section 3, the proposed ECG transmission and storing solution in m-Health environment is presented, followed by section 4 which shows the efficiency evaluation results of the proposed solution. Conclusions, limitations and future research is discussed in section 5.

2. Related Works

2.1 m-Health Initiative & Related Research

m-Health(Mobile Health), also written as mHealth, is a term where healthcare services are supported by mobile devices such as mobile-healthcare emergency system[13], m-Health system[14], mobile collaborative medical display system[15], and M-HELP system[16]. Mobile phones, laptop computers, and tablets are some examples of these mobile devices. m-Health is deemed as a new domain of public health research with yet a short history by means to leverage health outcomes. m-health covers a diverse range of IT(Information Technology) applied health services such as enhancing access to health information, improving the distribution of routine and emergency health services, supporting and streamlining data collection and surveillance, or providing diagnostic services[17].

As an effort to overcome the conventional method of text messaging follow-ups, there have been some researches attempting to attach ECG monitoring services to m-Health. Sannino et al[18] proposed an easy-to-use, cheap mobile-based approach to detect and monitor obstructive sleep apnea episodes in real-time.

Another research developed a wearable efficient tele-cardiology system called “WE-CARE” for early warning and prevention of cardiovascular disease risks in real time[19]. According to the research, WE-CARE is designed to work 24/7 online for m-Health applications. Core objective was to get a system light-loading technology to enable m-Health with a benchmarked ECG anomaly recognition rate to overcome the overload issue of mass amount of ECG data.

2.2 ECG Monitoring System& Related Researches

ECG monitoring system is a system where the service users’ ECG data is transmitted, at most times in real-time, to the clinical doctor in order to monitor the users’ health status. In a typical ECG monitoring system scenario, wearable ECG sensors are attached to the user to send the sensed ECG data via wired or wireless network to a mobile processing device. The mobile processing device then sends the data to the center server which manages the destination of the data. Center server can choose to send the data to the medical specialist, to send the data to the data history server, or to return feedback to the user.

ECG monitoring system applied health information system were a number of times developed in our prior researches. Such researches include a highly reliable emergency management information system that secures ECG transmission network between physicians and ambulances[9].

Efficient ECG monitoring scenario was applied to u-Healthcare(Ubiquitous Healthcare) environment[11], medical information systems[12], and IoT environment[20].

2.3 Digital Signal Compression & De-noising

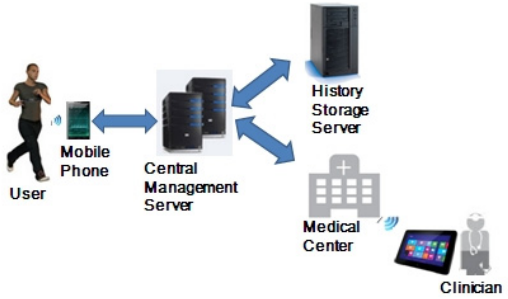
In a stream of digital signals, there is bound to be redundancy in the signal data. The core notion of digital signal compression is to remove the redundancy to ultimately reduce the overall data size. There are many different algorithm approaches to achieve this goal, and among them Huffman coding and LZW (Lempel-Ziv Welch) coding are the most widely used even to this day. Huffman coding is a probability coding method which sets the code size according to the probabilities of individual data symbols[21]. LZW is a dictionary coding method, which is a variant of the algorithm developed by Lempel and Ziv[22, 23].

Realistically, it is impossible to assume a digital signal without noise. For example, an ECG signal is no exception. In most cases when sensing ECG from patients or users, signals contain noises coming inside and outside of the body. Especially in a scenario when ECG signals are obtained by wearable ECG sensors, curbing the fluctuation of signal baseline and preventing signal distortion are uneasy tasks. Traditional transform techniques can be applied to ECG signals such as fourier transform, cosine transform and wavelet transform[24]. Wavelet based ECG transformation methods have been proved to perform well in prior researches[25], which overcomes the limitations in the conventional fourier transform.

3. System Overview

3.1 Overall Solution Architecture

The overall solution architecture of the proposed ECG monitoring system in m-Health environment is shown in [Fig. 1].



[Fig. 1] ECG Monitoring System in m-Health Environment

Wearable ECG sensor leads are attached to the user in order to gain ECG data, which is transmitted to their mobile phones via wireless network. Recent advances in technology have already enabled sensing and sending of ECG signals to the dedicated user's mobile phones such as Google Watch.

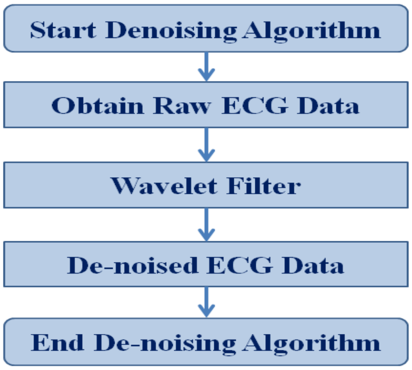
In the mobile phone is installed an application which contains the de-noising algorithm and the compression algorithm, which will be specifically handled in section 3.2. The signal is processed, and then sent to the central management server, which is the core server of the proposed system that administers the destination of the ECG data. Central management servers are expected to be placed in the health institutions that manage overall m-Health project. Central management server can choose to send the data to the history storage server, to the medical center, or to provide feedback to the user.

Basically at all times, the central management server sends all the recorded ECG data into the history storage server. This is where the ECG data that have been processed by our proposed algorithm will be efficiently stored, because data will be significantly compressed.

If the central management server chooses to send the data to the medical center, for example, when an emergency occurs, the ECG data is referred to the clinician. Naturally, the clinician will not be able to read the encoded data, so in the clinician's mobile tablet is installed the same application that was installed in the user's mobile phone which contains the decoding algorithm. Then, the clinician can choose to provide feedback, which will be returned to the user by the central management server.

3.2 The De-noising Algorithm

The proposed de-noising algorithm that is installed in the mobile applications(mobile phones or tablets) will be explained in this section. Simulation was implemented using Matlab and SPSS. The flow chart is shown in [Fig. 2].



[Fig. 2] Flow Chart of De-noising Algirhtm

By initiating the de-noising algorithm, the ECG data sent from the sensor is obtained by the application as digital signal samples(samples must be integers) up to 2^n. The signal samples are then processed through wavelet filter. In the proposed research's wavelet filter, Haar wavelet with coefficients [-1, 1] is used. Refer to specific mathematical equation (1), (2), (3) given x_n is the data sequence of ECG samples, and y_n is the data sequence of filtered ECG samples. a_n and b_n are data sequences needed in the process.

$$a_n = \frac{x_{2n-1} + x_{2n}}{2} \left(1 \le n \le 2^{2n-1}\right) \quad (1)$$

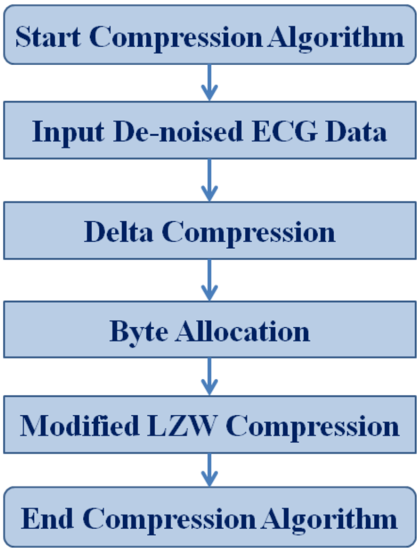
$$b_n = \frac{x_{2n-1} - x_{2n}}{2} \left(2^{2n-1} + 1 \le n \le 2^n\right) \quad (2)$$

$$y_n = \begin{cases} a_n \left(1 \le m \le 2^{m-1}\right) \\ b_n \left(2^{m-1} + 1 \le m \le 2^m\right) \end{cases} \quad (3)$$

Then, threshold values from -10 to 10 was set and sample values within were zeroed. Such effects are expected to cut out the noise included in the ECG signal without distorting much of the signal. Threshold range was set after a number of trial and error. In the last phase of the de-noising algorithm, the de-noised ECG data is obtained. Note that the reconstruction algorithm is the reversed version of the process.

3.3 The Compression Algorithm

The proposed compression algorithm will be explained in this section. Simulation was implemented using Microsoft Visual Studio. Flow chart is shown in [Fig. 3].



[Fig. 3] Flow Chart of Compression Algorithm

After de-noising algorithm ends, the compression algorithm initiates. In the compression algorithm is first initiated by the input of the de-noised ECG data. The data samples are then delta computed. Delta computation mathematics are shown in equation (4), given x'_n as the input de-noised data and y'_n as the output of delta computation.

$$y'_n = x'_n - x'_{n-1} \left(y'_1 = x'_1, n \ge 2\right) \quad (4)$$

Next, the delta computed data samples' distribution is analyzed to find sample values within the range of -128 to 127. The sample values within the range of -128 to 127 were changed from default 4 bytes into 1 byte. The reason for this is because value from -128 to 127 can be represented with only one byte. Lastly, the data samples are compressed using dictionary modified LZW compression algorithm. The dictionary size was programmed to be modified to 8096. Through trial and error, the proposed research came to a conclusion that dictionary size of 8096 was most optimal to cover the dictionary indices for ECG data used in this research. Note that the decoding algorithm is the reversed version of the process.

4. Evaluation

4.1 Materials and Method

As ECG sample materials, data were obtained from Physionet[26], that offers free web access to large collections of recorded physiologic signals and related open-source software. Physionet provides reliable physiologic data that have already been verified and used in countless prior researches from Petrolis et al[27], Mirmohamadsadeghi et al[28], Maheshwari et al[29], and Li Q. et al[30]. In this research, MIT-BIH atrial fibrillation database's ECG records were used. A total of 15 ECG record intervals that contain 32768 samples each were randomly chosen. MIT-BIH atrial fibrillation database contains 2 ECG channels, each with a sampling frequency of 250 Hz(Hertz), in other words, with sampling interval of 0.004 second.

For methods, statistical analysis was performed using SPSS. One-way ANOVA(ANalysis Of CovAriance) was implemented to statistically analyze the differences of compression ratio(95% confidence level, null hypothesis: There is no difference between the three groups). Then, average mean error value was calculated to show the error rate.

4.2 Compression Ratio Comparison

Compression ratio comparison will be implemented in this section. The equation of the compression ratio is shown in equation (5). The larger the compression ratio, the better its compression efficiency is.

$$Compression\,Ratio = \frac{Uncompressed\,Size}{Compressed\,Size} \quad (5)$$

In order to prove the compression efficiency of the proposed algorithm, it was compared with Huffman compression algorithm and LZW compression algorithm. This is because these two are the most widely used compression methods today, and have already proven its scientific soundness in previous researches[11, 12, 20, 31]. The results are as follows.

〈Table 1〉 Compression Ratio Comparison to Huffman and LZW(Mean±Standard Deviation)

	Huffman	LZW	Proposed Algorithm	p-value
Compression Ratio	2.24±0.07	3.26±0.03	30.4±0.49	p<0.05

Results in <table 1> shows that the proposed algorithm had the highest compression ratio. The compression ratio of Huffman, LZW, and the proposed algorithm was 2.24, 3.26, and 30.4 respectively. p-value of lower than 0.05 meant that the three compression ratios were statistically different from each other under 95% confidence level.

4.3 Signal Error Evaluation

Signal error evaluation was implemented to check how much error between the raw ECG signal and the reconstructed/decoded ECG signal is. Interval range from 1 to 32768 was randomly selected for evaluation. Signal error evaluation follows the following equation in (6).

$$ASE = \frac{\sum_{n=1}^{32768} |A_n - B_n|}{n} \quad (6)$$

A_n is the data sequence of the raw ECG signal, and B_n is the data sequence of the reconstructed/decoded ECG signal. In this research, the range of n is from 1 to 32768. After computation, the total average signal error value turned out to be 51.3 in our algorithm.

5. Conclusion & Limitations

This research proposed a solution for efficient vital data transmission and storing in m-Health environment. First, an ECG monitoring system that is envisioned to enrich the limited service boundaries that conventional m-Health used to produce mainly using text messaging services was proposed.

Then, an efficient ECG compression algorithm was developed in order to maximize the efficiency of the proposed ECG monitoring system. If ECG data is compressed, the data can be seamlessly transmitted through the network with guaranteed speed. Also, even if network errors occur, it can be restored quickly due to its compressed size. Efficiently compressed ECG data could also allow the history storage server to load more ECG data with less burden.

Limitation of this research is that the proposed ECG transmission algorithm is somewhat lossy. When handling clinical data, minimizing the loss rate of vital signals such as ECG is important, because it may confound the decision of medical professionals. Future research regarding further minimization of the loss rate is needed.

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