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Intensive/High Care Unit System for Long-Term Monitoring of Heart Rate Variability

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ABSTRACT

Real-time instantaneous vital sign monitoring systems help medical staff in the intensive/high care unit to monitor a patient's condition, but the data are usually discharged and not stored. This vital sign data may exhibit trends that could be useful information for the medical staff to estimate a patient's prognosis. However, to make an accurate estimation, a large amount of data should be acquired and analyzed; therefore, long-term trend monitoring systems and analyses are required to provide better medical treatment. This study aims to develop a centralized long-term monitoring system for heart rate variability of a patient undergoing treatment in the intensive/high care unit. The long-term monitoring system for heart rate variability was examined in the laboratory. It was capable of acquiring and storing vital sign data from two clients running simultaneously. The server system received the data and performed a real-time analysis before presenting the results as a long-term trend, thus enabling the medical staff to observe and monitor the heart rate variability trends in patients. In conclusion, a long-term monitoring system for heart rate variability in intensive/high care unit patient has been developed that can retrieve, store, and analyze vital sign data from more than one patient to track changes in their condition.

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1. INTRODUCTION

The intensive/high care unit (ICU/HCU) is a specially staffed, equipped, and separate section of a hospital dedicated to the observation, care, and treatment of patients with life-threatening or potentially life-threatening diseases, injuries, or complications [1]. Intensive care in the ICU/HCU requires medical staff that can respond to a patient's condition as quickly as possible to prevent adverse events. The units are also equipped with complete biological equipment to directly observe the condition of a vital organ. Current patient monitoring systems provide instantaneous information on the patients' vital signs such as heart rate, blood pressure, oxygen saturation, body temperature, and respiration rate, and inform the medical staff if a vital sign value exceeds the tolerated ranged. Long-term observation using the patient monitoring system is helpful for the medical staff, but it only provides an alarm that notifies the medical staff that the patient needs an assistant and/or help; it does not provide complete information on the patient's condition.

In some cases, an adverse event occurs in which a medication fails to revive the patient's stable condition; thus, the prediction and prevention of such events are required. Rather than providing only an instantaneous value, long-term monitoring should review trends in the collected data. Heart rate variability (HRV) extracted from an electrocardiogram (ECG) provides valuable information on the body's condition, especially on the balance of the sympathetic and parasympathetic nervous systems [2]. Fortunately, ECG is required in ICU/HCU basic care [3], and the long-term observation of HRV in the ICU/HCU is possible.

However, the current patient monitoring system does not have this functionality. In this study, a long-term monitoring system for HRV in ICU/HCU patients is proposed.

2. RESEARCH METHOD

The development of the biomedical signal analysis software and plotting software has been previously proposed [4], [5], [6], [7], [8], and [9]. They all provide a reasonably convenient way to analyze and represent their results; however, they do not perform real-time and long-term analyses and result representation. In this study, the proposed system is installed together with the bedside monitoring system in the ICU/HCU. The bedside monitor records an ECG, which is then sent to the server computer through LAN after being converted to a digital signal by A/D converter. All ECG data from all bedside monitors will be preprocessed on the server computer. The HRV data, extracted from the ECG, were recorded and saved on the server computer for analysis. Along with the HRV data, the results from real-time HRV analysis processing are also saved. All long-term analysis results can be recalled for further analysis by the medical staff. The detailed system design and architecture are shown in Fig. 1.

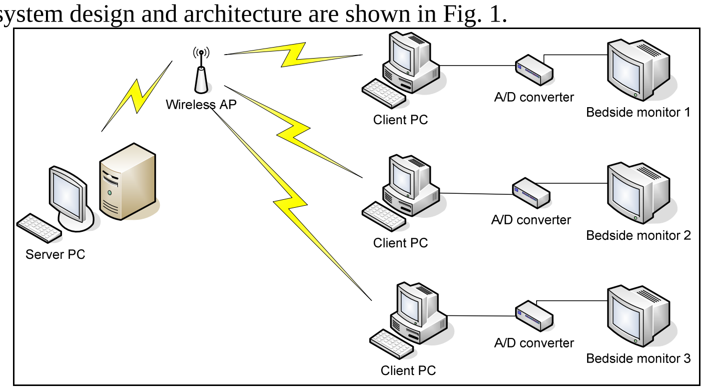

Figure 1. System design and architecture

2.1. ECG Data Retrieval Method

To retrieve the vital sign data, in this case an ECG, from the bedside monitor, a small retrieval program was developed. The bedside monitor outputs analog data, which are later converted into digital data by an A/D converter. Fig. 2 shows the A/D converter used by this system. These digital data were sent to the server computer by a client program installed on the client computer.

Figure 2. A/D converter used by the system

2.2. Monitoring System Development

The server computer is used by the medical staff to review the results. The software for data processing, analysis, and reporting was developed from scratch using MATLAB [10]. Various HRV analyses were performed, including time-domain analysis [11], frequency-domain analysis [11], nonlinear analysis [12], [13], and PUCK analysis. The server PC has a touch-screen display, which enables the medical staff to intuitively interact with the monitoring software.

2.3. Testing and Implementation

The software was tested in a laboratory environment, with two subjects using it simultaneously. The subjects maintained a seated position with a one-channel ECG recorder applied to their body following the standard limb lead II with 12 leads ECG measurement. Following laboratory testing, the software was implemented in the ICU/HCU in the hospital. To connect the server and client computers together, a secured wireless router with a hidden SSID was installed. The server computer was located in a separate room from the ICU/HCU room, which is a wide room with many beds separated by curtains or room separators.

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3. RESULTS AND ANALYSIS

The result of this research is a long-term monitoring system for HRV in ICU/HCU patients. The monitoring software was developed using MATLAB and compiled using the MATLAB compiler toolbox [4] to allow it to run in a stand-alone state on a computer installed in the hospital; the computer had a wide-screen monitor with touch-screen capability. Because this monitoring software was designed for retrieving and processing data from multiple clients, a parallel computing toolbox was employed to speed up the process. Laptop computers were installed as the client, and they were connected to an A/D converter and ECG recorder. The client computer and server computer were connected through a wireless LAN network.

The client software, which reads the data that is received from the A/D converter and then sent to the server computer, was installed on the client computer. To connect the client and the server, the server IP address should be set in the client software. The client software user interface is shown on the left-hand side of Fig. 3.

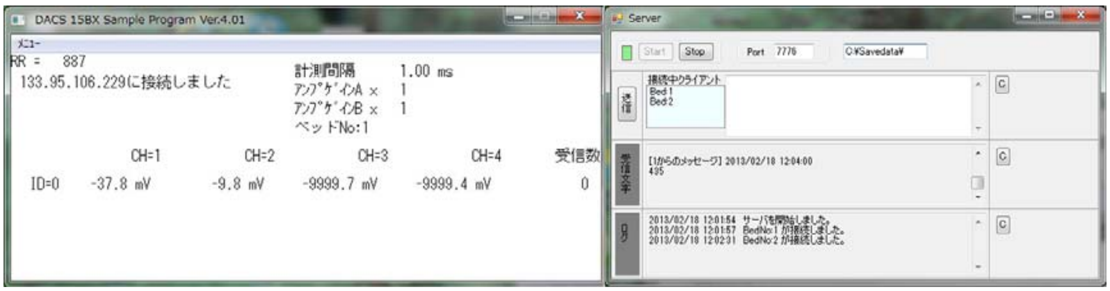

Figure 3. **Left**: Client program. **Right**: Server program

Once the client program is run, the server program can be executed. First, the file directory where the file is saved, which should be accessible to the monitoring software, should be initiated. The created filenames include the bed number and the current date of recording. When the date changes, the program automatically creates a new file. This procedure prevents file size overflow and increases the speed of reading large files. The server program is shown on the right-hand side of Fig. 3.

While the server program writes the data obtained from client in real time, the monitoring system reads the file, performs the analysis process, and creates a file to store the result. In contrast to the data file written in CSV, the analysis results file was written in a MATLAB data file. At the same time, the monitoring system shows the plot of several analysis results for one selected bed. The graphical user interface (GUI) of the monitoring system is shown in Fig. 4.

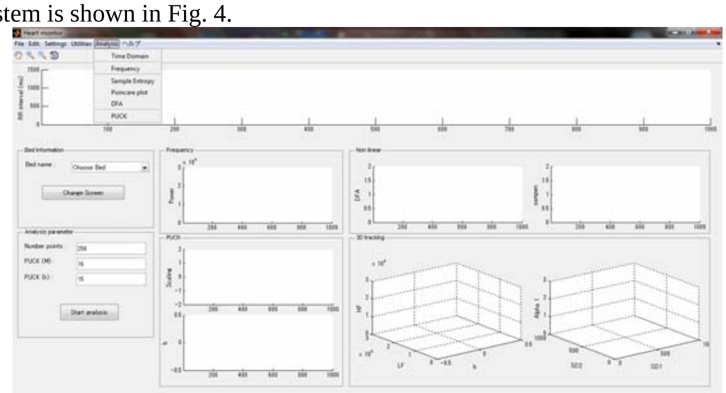

Figure 4. Monitoring system GUI

3.1. Laboratory Experiment

In the laboratory experiment, the monitoring software system could serve two client computers that ran simultaneously. The client computer retrieves the biological signal data from two subjects by using the ECG recorder and A/D converter. The software shows the various HRV analysis results for a single observed bed. In addition, the bed can be changed to show the HRV results for different beds. The HRV parameter results were plotted in a time-varying graph so that the long-term change of each parameter can be observed. Once the server computer's hard disk drive is full, the data should be backed up on a separate disk space using a high-speed 120 GB solid-state drive. Fig. 5 shows a plot of the analysis results for two different subjects. The analysis process runs concurrently while the plot is created by selecting the bed number in the

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left-hand bed information drop down menu. This experiment was performed to ensure that the program was running properly and ready for the next step in the research objectives.

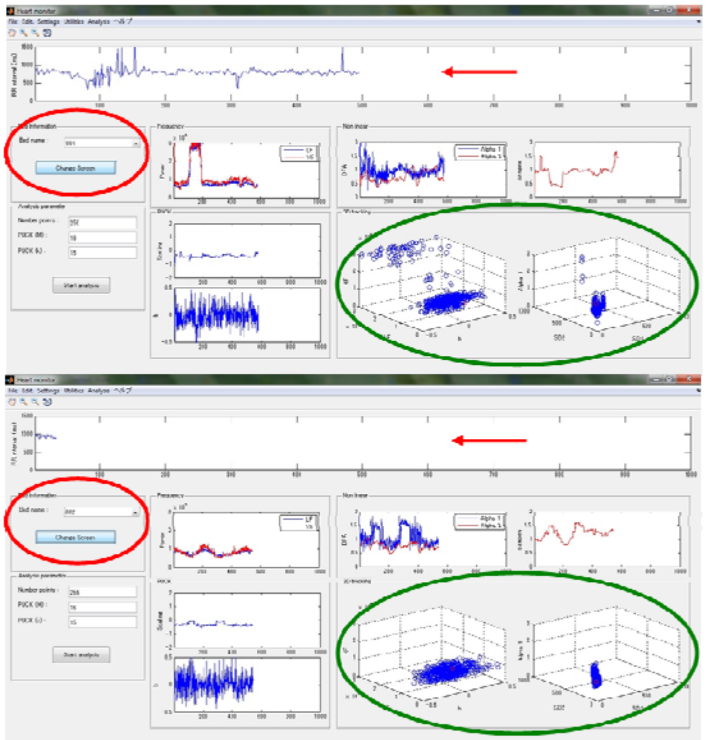

Figure 5. Analysis result plots for subjects 1 (top) and 2 (bottom). The red circle shows the software feature for changing the plot to the selected bed. The green circle shows the three-dimensional plots for observing the trajectory of the indicated parameter change. The red arrows indicates the plot of HRV data

3.2. Implementation in ICU/HCU

This software was then implemented in the ICU/HCU. One bedside monitor was temporarily connected to the system in the early stages of implementation. The client computer was installed at the bedside, next to the patient. The server monitoring system was located in the monitoring room next to the ICU/HCU room. The software setup procedure required the operator to turn on the server computer, execute the server program, and start receiving data from the client. The second step was connecting the specific connector from the bedside monitor to the client computer. Later, the client computer was turned on, and the client program was run. Once the network connection between client and server was connected, the data could be sent to the server computer. At the server computer, the long-term monitoring software was executed, and all the collected data on the server computer were processed by running the analysis procedure. This is illustrated in Fig. 6.

Because the vital sign data are collected on a high-resolution scale, the client–server communication needs a reliable wireless connection. Sometimes, a sudden and unwanted termination occurred during the client–server communication. We believe this communication problem was caused by the glass divider surrounding the ICU/HCU room, which might interfere with the communication line between the client and server systems.

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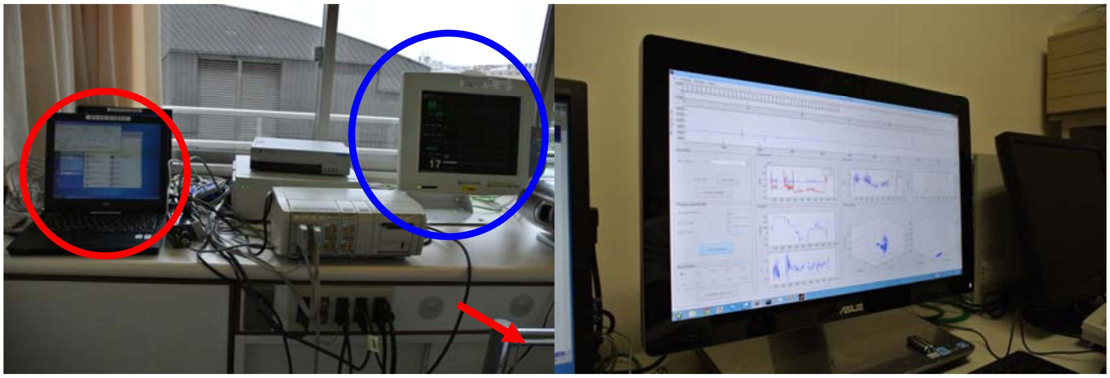

Figure 6. Implementation of system in ICU/HCU. **Left**: The blue circle indicates the bedside monitoring system retrieving vital signs from the patient. The red circle shows the client computer running the client software. The red arrow indicates the patient location. **Right**: The monitoring system server installed in a separate room next to the ICU/HCU showing the HRV result at the same time.

4. CONCLUSIONS

Currently, patient monitoring in the ICU is carried out by observing the patient's body by using a bedside monitoring device. However, it only provides instantaneous and current information on the patient's condition, and no historical data are saved. Unfortunately, this is important information that can be used for estimating the patient's prognosis. In this study, a long-term monitoring system for HRV that can be implemented in the ICU/HCU has been developed. The system can prove to be useful for medical staff in tracking a patient's biological condition on the basis of their HRV measures. Using this system, long-term HRV data of more than one subject/patient can be retrieved and saved to track changes in their condition. The system has worked properly in the laboratory experiment with two subjects. This system also worked in the ICU/HCU and provided a monitoring tool for the medical staff. Future work will examine the use of varying vital sign information, which is expected to increase the accuracy of the prognosis estimation.

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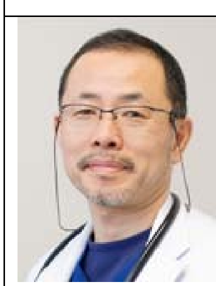

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