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A Remote Drip Infusion Monitoring System Employing Bluetooth

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***Abstract*— We have developed a remote drip infusion monitoring system for use in hospitals. The system consists of several infusion monitoring devices and a central monitor. The infusion monitoring device employing a Bluetooth module can detect the drip infusion rate and an empty infusion solution bag, and then these data are sent to the central monitor placed at the nurses' station via the Bluetooth. The central monitor receives the data from several infusion monitoring devices and then displays graphically them. Therefore, the developed system can monitor intensively the drip infusion situation of the several patients at the nurses' station.**

I. Introduction

Infusion solution drips are used in hospitals and care facilities. Management of the infusion rate is important to infusion therapy. The infusion rate is detected by a drop counter attached to the drip chamber [1-5]. The nurses monitor the infusion rate every one hour or 30 minutes.

In this study, we have developed a remote drip infusion monitoring system employing Bluetooth. The system consists of several infusion monitoring devices and a central monitor computer. Each of the infusion monitoring devices monitor the count of drops, the infusion rate and the state of drip: dripping, stopping and finished (bag emptied). These data are sent to the central monitor. The central monitor receives the data from several infusion monitoring devices. These data are displayed graphically on the central monitor. Therefore, the developed system can monitor intensively the infusion situation of the several patients at the nurses' station.

II. System Description

The drip infusion remote monitoring system is shown in Fig. 1. The system consists of several infusion monitoring devices and one central monitor. Each of the infusion monitoring devices is attached to one infusion set. The infusion monitoring device monitors the count of drops, the infusion rate and the state of drip. The infusion monitoring device sends these drip data to the central monitor via Bluetooth when it requests the data. Then each of the data is calculated and graphically displayed on the central monitor. A personal computer is used as the central monitor, and its operating system is Windows XP. The central monitor program was written using Visual Studio 2010, in Visual C#.

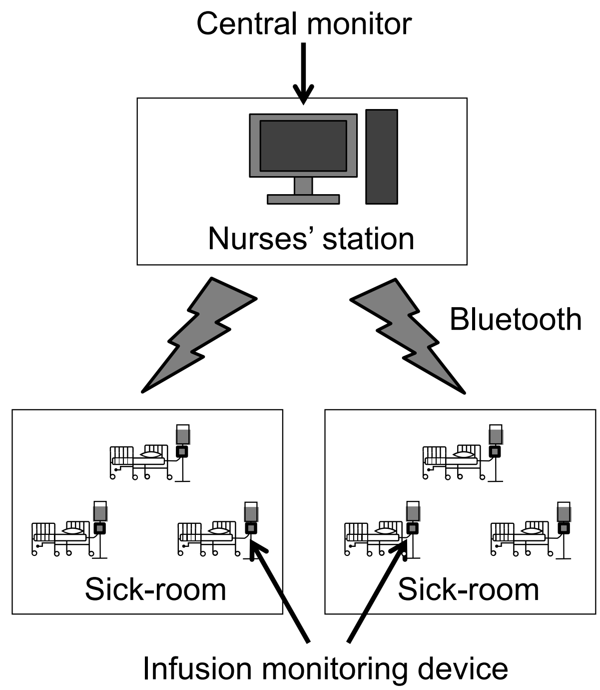

Figure 1. The remote drip infusion monitoring system.

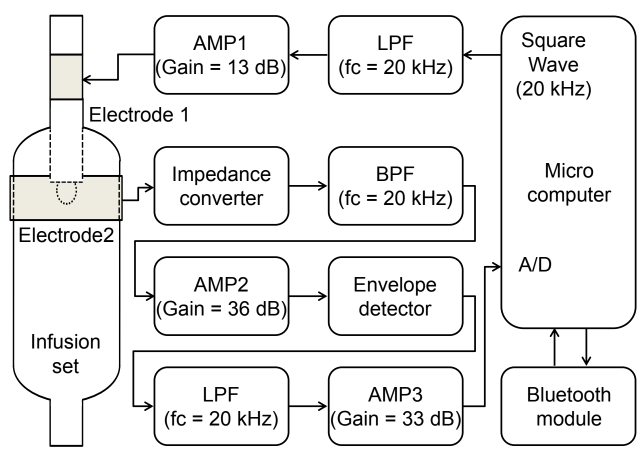

Figure 2. The block diagram of the infusion monitoring device.

Figure 2 shows the block diagram of the infusion monitoring device. The infusion monitoring device consists of two electrodes, a microcomputer (PIC18F4525, Microchip), two low pass filters, a band pass filter, a high pass filter, an impedance converter, three amplifiers, an envelope detector and a Bluetooth module (RN-41, Roving Networks). The 20

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kHz square wave is generated by the microcomputer and the wave is converted to a sinusoidal wave by the 20 kHz low pass filter. The converted wave is amplified by the AMP1 to 3.0 $V_{p\text{-}p}$ and inputted to the electrode 1. The voltage at the electrode 2 is detected by impedance converter. The detected signal passes through a band pass filter of 20 kHz to remove a noise. The signal which passed the band-pass filter, it is amplified 36db by AMP2 and it can demodulate by the envelope detector. The envelope detector demodulates the signal modulated due to the growth and fall of each infusion drop. The demodulated signal is interfered by other electrical devices and the signal is fed into the 16 Hz low-pass filter to eliminate the noises. The filter output is amplified the 33 dB by AMP3 and digitized by a 10-bit A/D converter in microcomputer. The microcomputer counts drops, calculates the infusion rate and judges the state of drip. The detected data are sent by the Bluetooth module using the SPP (Serial Port Profile).

Figure 3 shows the infusion monitoring device flow chart. The infusion monitoring device starts detecting drops, calculating the infusion rate and judging the state of drip after start-up. The infusion rate is obtained by calculating the interval between two drops. When the request from the central monitor is received then the infusion monitoring device sends these data.

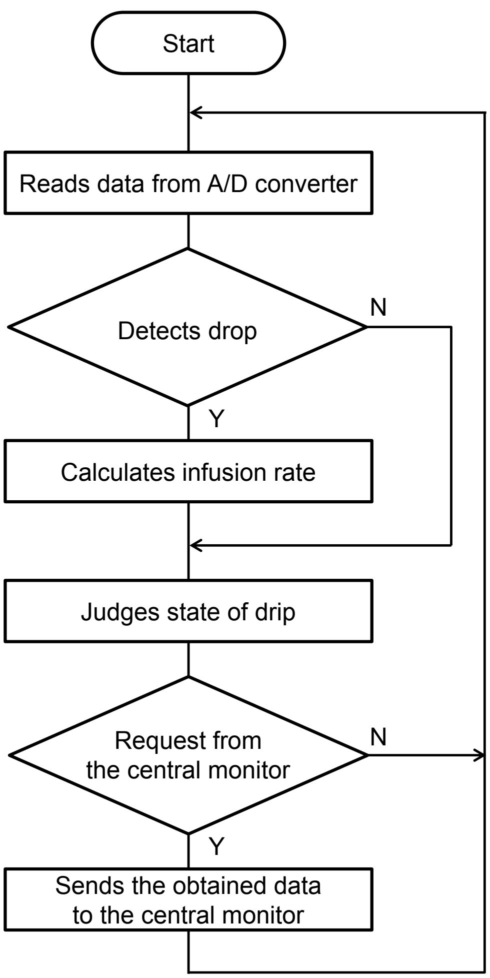


Figure 3. A flow chart of the infusion monitoring device.

The packet format of drip data is shown in table I. The drip data includes the device number, the infusion rate, the drop counts, the elapsed time and the state of drip. The "Device number" is the number assigned to each of the devices. It is represented by 1 byte. The maximum number is 255. The "Infusion rate" means the rate of infusion per unit of time. It is represented by 2 bytes. The maximum number is 65535. The "Drop counts" show the number of drops since the start of dripping. It is represented by 4 bytes. The maximum number is 4294967295. The "Elapsed time" is the period of time (seconds) that has passed since the infusion started. It is represented by 4 bytes. The "State of drip" indicates one of the following three states of drip; dripping, stopping and finished.

TABLE I. THE PACKET FORMAT OF DRIP DATA

Device Number	**Infusion rate**	**Drop counts**	**Elapsed time**	**State of drip**
1 Byte	2 Bytes	4 Bytes	4 Bytes	1 Byte

Figure 4 shows a flow of data transmission between the infusion monitoring device and the central monitor. At first, the central monitor sends the transmission-start request to the infusion monitoring device. After the infusion monitoring device replies to the request, then the device and the central monitor data transmission are established and start the data transmission. After that, the central monitor sends a request for the drip data. When the infusion monitoring device received the request, it sends the data. After updating the screen, the central monitor sends a request for ending transmission to the infusion monitoring device.

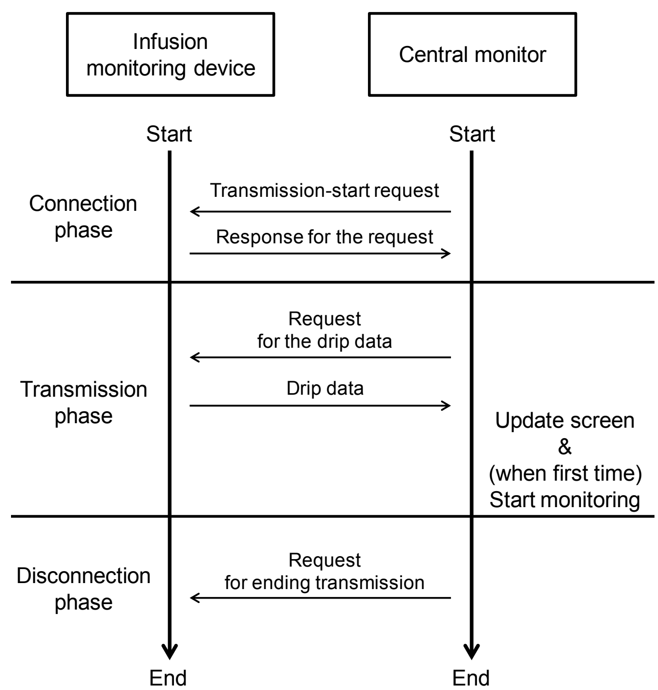


Figure 4. A flow of data transmission between the infusion monitoring device and the central monitor.

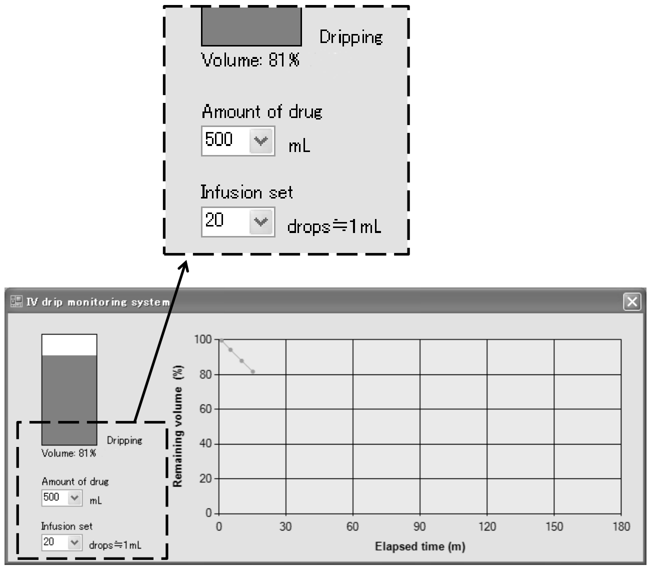


Figure 5. Remaining infusion volume displayed on the central monitor.

Figure 5 shows remaining infusion volume displayed on the central monitor. It shows some information such as the state of drip, the remaining volume and the remaining time. The remaining volume is indicated on the left-hand side of the screen. As the infusion proceeds, the bar diminishes. The bar's color changes from blue through green through yellow to red with the remaining volume. They mean 3/4, 1/2, 1/2 to 1/4, and under 1/4 remaining, respectively. The percentage of the remaining volume is shown as numbers below the bar. And the type of infusion set and the amount of drug can be selected by an operator. The state of drip is displayed on the right side of the bar: dripping, stopping, finished. A line graph is shown on the right side of the screen and visually represents the remaining volume with the time. The X axis represents the elapsed time as minutes and the Y axis represents the remaining volume as percentage points. The central monitor sends requests to the infusion monitoring devices at specific time intervals. The infusion monitoring device sends the current drip data instead of the difference data, so that even an outside possibility of data transmission failure may not affect the accuracy of monitoring.

III. Results & Discussion

In order to evaluate the system, an experiment was performed in a laboratory instead of the hospital. Measurements were performed with an infusion set (20 drops/mL, JMS) and electrolytic solution (KN No.1, Otsuka Pharmaceutical). The infusion solution volume is 500 mL. These were set to a drip stand with the infusion monitoring device. The infusion rate was set at 150 drops/minute and the infusion set was carried around the floor.

The experiment result is shown in Fig. 6. The drip data was updated every 5 minutes. When the drip infusion stopped, then the data was updated every 2.5 minutes. The experiment was performed for 80 minutes, and drip infusion was stopped for 10 minutes during experiment. The remaining volume decreased in most straight line from 0 minute to 35 minutes. When the drip infusion was stopped from 35 minutes to 45 minutes, the remaining volume was updated every 2.5 minutes and did not change. After that, the remaining volume decreased from 45 minutes to 80 minutes.

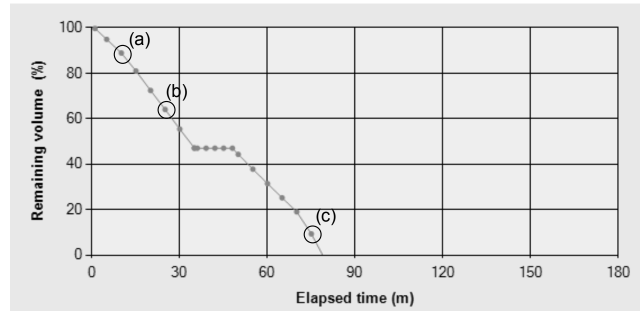
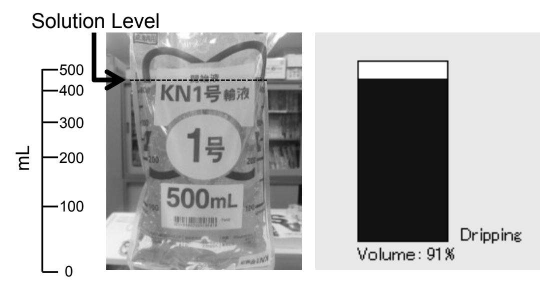
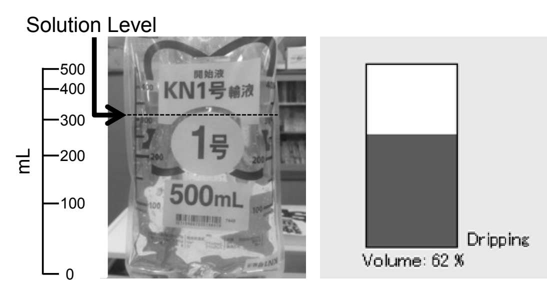


Figure 6. Remaining volume displayed on the central monitor.

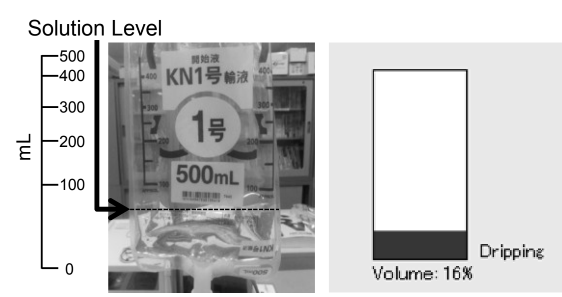
Figure 7 shows the infusion solution bag and the remaining infusion volume bar displayed on the central monitor at various elapsed time. The remaining infusion volume level corresponded to the volume bar.



(a) The elapsed time is 10 minutes.



(b) The elapsed time is 25 minutes.



(c) The elapsed time is 75 minutes.

Figure 7. The infusion bag being used for the experiment and the volume bar of its solution.

The drip infusion monitoring device was moved to five rooms in the same floor for checking the data transmission. Figure 8 show the route of infusion monitoring device moving.

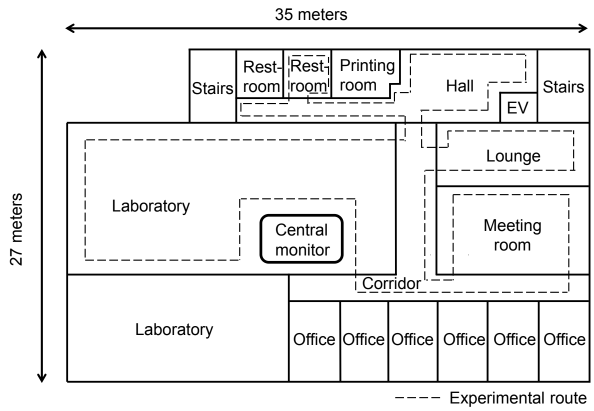


Figure 8. The route of infusion monitoring device moving.

In the floor, there are several walls and doors. However, the data transmission between the drip infusion monitoring device and the central monitor did not disconnect. This result indicated that neither the door nor the wall influenced the data transmission. The transmission range was within 100m. If the system is placed within 100m in Hospital, then the system can monitor the drip infusion situation.

IV. CONCLUSION

The remote drip infusion monitoring system was developed for use in hospitals. The infusion monitoring device, which is attached to the infusion set, detects the drip infusion situation. The central monitor computer receives the data from infusion monitoring devices used by the several patients. These data are displayed graphically on the central monitor placed at nurse station. Therefore, the developed system can monitor intensively the drip infusion situation of the several patients at the nurse station.

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