International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-1, October, 2019

Intravenous (IV) Monitoring and Refilling System

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Abstract: Intravenous (I.V.) Monitoring and Refilling System is a system for monitoring I.V. therapy and notifying abnormal drip rate and refilling of the I.V. bag. The system has a portable receiver device (for the nurse/nurse station) and a transmitter device (for the patient). The study uses Radio Frequency (RF) medium. RF module was used for transmitting and receiving of the current status data of the monitoring and notifying system. The system has also fiber optic sensors for detecting and counting the drip rate of the I.V. bag. The control panel of the system is placed on the transmitter (patient side). The main objective of the monitoring system is to process an accurate I.V. therapy, prevent the possible backflow of the blood by stopping the I.V. set attached to the system. It makes the I.V. therapy setup fast and easy allowing more time for nurses to perform duties other than monitoring the IV therapy of patients assigned to them. System test results show that transmission delay is not evident in closed area and can transmit accurately without delay up to 70 meters. A 100% detection rates were also recorded for different drip rates and percent IV bag content. Comparing the operating frequency of the I.V. monitoring and refilling system to other medical equipment, the RF module used in the system has an operating frequency that is unique among all the technologies and equipment that may be present in a hospital or clinical setting. The system can also cut down the cost of such medical equipment by 72% if compared to the infusion pump available in the market.

Keywords: Electronic monitoring, fiber optic sensor, intravenous refilling system, micro controlled drip rate.

I. INTRODUCTION

One of the great human potentials in medicine is the use of technology. However, in the third world countries, where technology and medicine are of outmost need, the cost of medical equipment has become out of reach due to its cost. One of the recent technologies being developed is the intravenous infusion therapy in different medical applications (for diseases). Intravenous (IV) therapy is the infusion of liquid substances directly into a vein [1]. These liquid substances include: nutritional formulas [1], blood [1], and drug treatment solutions [2]. In the Philippines, gravity infusion therapy is commonly used. Most hospitals in the Philippines, even in Level 3 and 4 hospitals monitored the therapy manually by regularly going to the patient's room. Moreover, not only the drip rate is monitored, but also the contents of the infusion bag or bottle. Currently, there are two ways to regulate the amount and rate of fluids given during intravenous therapy; the manual regulation and the pump [3].

Revised Manuscript Received on October 30, 2019.
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In the manual regulation; the rate of fluid dripping from a bag into an IV can be regulated through a manual technique. A nurse or other caregiver increases or decreases the pressure that a clamp puts on the IV tube to either slow or accelerate the rate of flow. The caregiver can count the number of drops per minute to make sure the rate of flow is correct, and adjust as needed. On the other hand, the rate can also be modulated with an electric pump. The caregiver programs the pump to deliver the desired amount of fluid into the IV at the correct rate. Whether done manually or with a pump, IVs must be checked regularly to ensure the patient is receiving the correct amount of fluid [3].

Modern technology in medicine is almost out of reach in hospitals in developing countries specifically the Philippines. Moreover, local public hospitals have deficiency in medical aids (nurses/caregivers) due to low salary grade. Hence, few nurses are in public/community hospitals subjected to 2:59 or 2:64 of nurse to patient ratio [4]. As a result, monitoring these patients is done as quickly as possible to accommodate all patients assigned to them. One of the very critical treatments to be monitored is the intravenous therapy. IV Drip rate should be as much as possible accurate to obtain the best expected treatment to patients. Due to lack of medical staff, monitoring the drip rate and the contents of the IV bag is time intensive.

The whole process of intravenous infusion cannot be monitored unless there is a special caregiver and the reason is that patient maybe frail, narcosis or medical personnel are busy elsewhere. It not only increases the nursing labor but also is not conducive to the integrated management of ward.

Although the IV therapy is an effective curing technique, some treatments like blood transfusion may take hours for completion. For a long time, continuous monitoring of tube for air bubble detection by any nurse or medical practitioner is practically infeasible. Some of the causes of complications that can endangered the patient's life are; failure to remove air from IV tubing, allowing solution bags to run dry, disconnecting IV tubing, manufacturing faulty IV tube, etc. [5]. Infiltration of medications during infusion therapy results in complications ranging from erythema and pain to tissue necrosis requiring amputation. At present, visual inspection by the clinical staff is the primary means for detecting IV infiltration. Recently, researches were carried out to develop workable systems for automatically monitoring and real - time control of intravenous drip in order to reduce the frequent intervention of medical personnel [6-8]. The subsequent literature imparts important information for the advancement of the proposed study.

Although IV therapy is an effective curing technique, it was detected that it also has some complications. In 2012, [9] proposed an air embolism protection system to save lives in case air bubble gets introduced into the tube. The proposed system monitors the IV tube for possible bubble insertion, detects it, indicates emergency and blocks fluid flow to protect entrance of the air bubble into the human body.

Hence, wireless monitoring of IV therapy is an effort to save lives by preventing the aforementioned bedside errors. The objective of this study is to help nurses in monitoring IV therapy, and also to help patient to receive proper and more accurate IV fluids. More so, it is designed to provide remote monitoring of IV drop rate and alarming the nurse at the nurse's station that the IV bag has drip rate alteration or is near empty. Thus, preventing back flow or clogging of veins due to empty IV bag. It also aims to provide a refilling system that enables the second IV bag after the first bag is detected to be empty o near empty.

This study is a great benefit to the society since it is used for patients undergoing IV therapy and is optimized for portability. Through this, the attention in sanitary centers is more efficient and immediate, as the observation of the state of the container of the IV bag will not need human supervision and monitoring. Real-time monitoring and infusion and alarm can be achieved by the system. It can greatly enhance the intelligence of infusion, reduce the labor intensity of caregiver and strengthen the integrated management of ward. In addition, the biggest advantage of this system is that circuit is simple, the anti- interference ability is strong, and the cost is low. It can solve the problem that community hospital medical staff is small, diagnostic levels is low and medical facilities is poor to some extent.

The study focus is to monitor drop rate of the I.V. that will ensure a continuous medication of the patient. The signal that indicates error to the IV line, IV bag, and drop rate will be sent to the remote device which is carried by the nurse is limited only to 100 meters because of the RF device used. The operating frequency of the device is 433 MHz. Interference caused by the device to other medical equipment will also be included in this study. The project will be used exclusively by nurses on duty.

II. PROJECT DESCRIPTION

The system is divided into two parts; first is the monitoring section (patient side) consisting of PIC16F877A, a 20x4 LCD dot matrix display, a 3x4 LCD keypad, fiber optics, fiber optic sensor, relays, solenoid and a 433 MHz frequency RF module (transmitter). All the data gathered will be automatically transmit to the receiver (nurse side) and all the variables and status will be displayed in the LCD. These include the input drip rate set by the nurse, the time left for the IV bag before it gets empty, the number of drops per minute, and the status of the drip rate; if it is in normal or in error state.

The nurse must attach the cannula (IV set) with an IV needle to the IV bag. The IV set (cannula) must then be installed to the solenoid on the top of the system and then pull the solenoid. The solenoid actuator has a 5V input voltage. It is an example of electromechanical transducer, which transforms an input electric signal into a motion. The solenoid is responsible in maintaining and controlling the drop rate of the IV bag. It will stop any flow on both directions and it will prevent the occurrence of back flow/ clogging of veins due to empty IV bag.

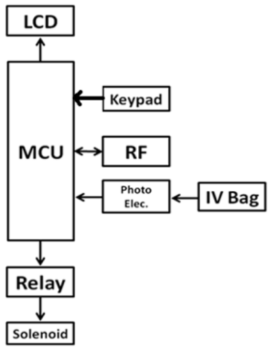

Figure 1. Block Diagram of the Transmitter (patient side)

The fiber optic sensor must be placed to the drip chamber of the I.V. bag. The fiber optic sensor is a 12-24 VDC+/- 10% power supply with 40mA maximum current. It is used for detecting the drop rate. The fiber optic sensor tries to detect a variation in the tension level in the photoelectric cell, produced by the deflection of the beam of light generated by the passage of the drop. The study of dripping detection techniques has determined that the beam of light used for the sensor is the optical one. The passage of the drop turns aside the beam and the light intensity that arrives at the photo transistor decreases, so a small fall of tension takes place.

The microprocessor module is the core of the system. It receives the dripping signal and determines if the intravenous infusion system is dripping or not. The microprocessor also controls the battery level of the device. The microprocessor also controls the radio communication; in such way that the first routine it must do is configuring the radio, which means, to choose the correct frequency, the correct power and so on.

Another process is to check the information of the received signals, and to send the corresponding message to the receiver.

When any air bubble gets introduced in the tube due to an empty IV bag, there is an abrupt change in the received signal and it will be detected by the MCU; the next step is to block the flow through the solenoid and alert the medical staff. The MCU in the main board is a PIC16F877A; a 40 pin 8 bit CMOS flash operating at a speed up to 20MHz. It has a 8kx 14 bit word flash memory (for program), 368x8 bytes RAM (for data), 256x8 bytes EEPROM (for data) and 2-5V operating voltage.

The second system consists of the PIC, LCD display, buzzer and RF module (Receiver). All the data transmitted by the system at patient side will automatically receive by the system. Alarm will trigger if the status of the drop rate is in error state or in its critical state.

This also includes wrong drip rate and nearly empty state of the IV Bag.

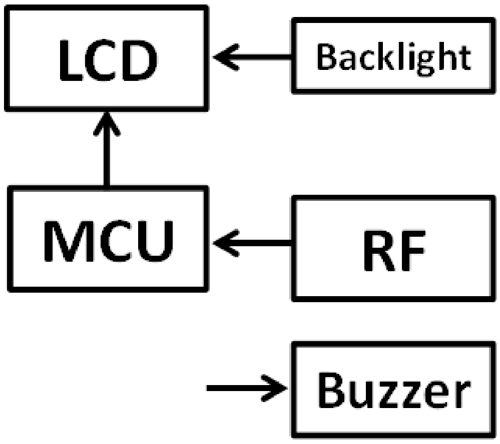

Figure 2. Block Diagram of the Receiver (nurse side)

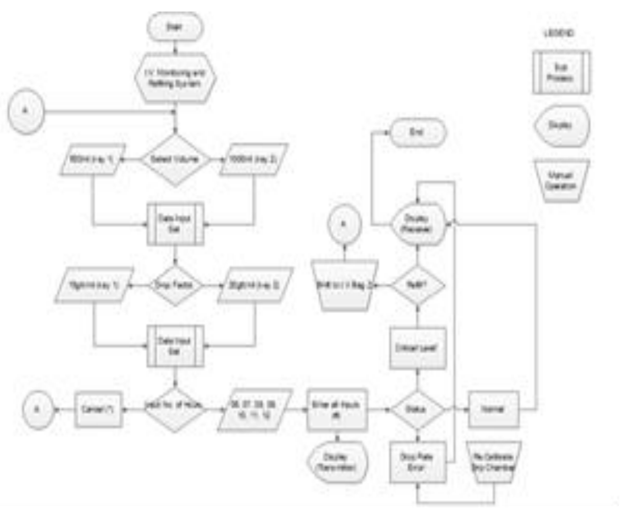

Figure 3. System Flowchart

Figure 3 shows the flow chart of the system. Upon the doctor's prescription, the floor nurse is the one responsible for installing the IV set to the IV bag and input the necessary fluid volume or drop rate prescribed by the doctor. When setting for the required volume, press "1" key for 500ml and press "2" key for 1000ml. When entering for the required gtt. Press "1" key for 15gtt and press "2" key for 20 gtt. Next, the time needed for the IV bag must also be set. Press "0" key and "6" key for 6 hours. Key "0" and "7" for 7 hours, and so on. Lastly, press "#" key to start the monitoring system. The microprocessor module is the core of the system. It receives the dripping signal and determines if the intravenous infusion system is dripping or not. While working normally, i.e., when the drop rate set by the nurse is correct; the RX gets a specific constant signal and it can be examined by the MCU; so the status at the receiver's display is read as "Normal." If the system didn't achieve the drop rate set by the nurse; the status at the receiver's display is read as "Drop rate error," then the MCU will immediately alarm the receiver and the attending nurse must recalibrate the drip chamber. When the IV bag is nearly empty for about one hour, the status displayed is "Critical Level," then the MCU will alarm the receiver and the attending nurse must refill or replace the IV bag immediately. When the IV bag is about to get empty, the solenoid will stop the flow and prevent the occurrence of back flow.

Figure 4. Transmitter System prototype

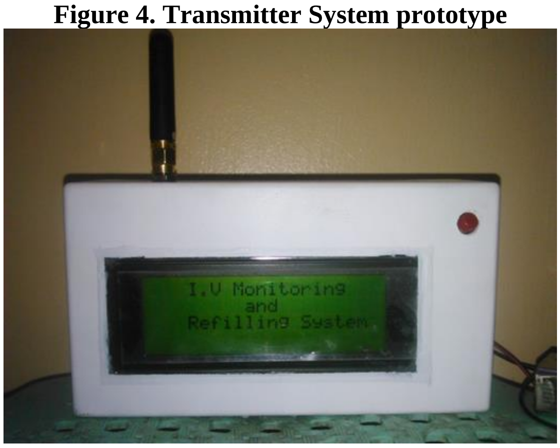

Figure 5. Receiver System prototype

III. METHODOLOGY

A. Frequency Comparison

To ensure the non-interference effect of the prototype to the different medical equipment possibly available in a clinic or hospital, operating frequencies of these equipment were identified. Other wireless communications technologies were also included to expand the comparison. Table 1 confirms that the RF module used in the system has an operating frequency that is unique among all the technologies and equipment presented.

Table 1 Frequencies of different medical equipment and wireless technologies [10-11].

Medical Equipment and Wireless Technology	Operating Frequency
Ad hoc	2.412 GHz
Anaesthetic Unit W/Vent 2 Vaporiser	4.763 kHz
Bipolar Coagulator	700 to 900 kHz
Bluetooth	2.4 to 2.485 GHz
Colonoscope (With halogen light source)	0.67 to 150 Hz
Computerised Exercise System	2000 Hz
Diathermy unit short wave	15 to 600 Hz
Digital Echocardiography	6 to 8 MHz
ECG Monitor	0.5 to 150 Hz
Echocardiograph with Tee probe	6 to 8 MHz
EEG Machine32 Channel	15, 35, 50, 75, 300, 2000 and 5000 Hz
Fetus heart detector sonic aid	3 MHz
Gastroscope (With halogen light source)	50/60 Hz
GPS	1.57542 GHz (L1 signal) 1.22776 GHz (L2 signal)
Integrated Service Digital Network (ISDN)	80 KHz
Interferential therapy with suction	4000 to 4199 Hz
I.V Monitoring and Refilling System (RF)	433 MHz
Low frequency electrotherapy	3 kHz
Mammography	29 to 60 kHz
Ophthalmic ultrasound	100 kHz
Panoramic X-ray dental	10 MHz
Phaco-machine	200 kHz
Portable ultrasound scanner	3.5MHz
Probes: Electronic convex, Electronic	7.5 MHz
Scaler Ultrasonic	29 kHz
Surgical C-arm	40 kHz
Wi-Fi 802.11a (up to 2Mbps)	2.4 GHz or 5 GHz
Wi-Fi 802.11b (up to 11Mbps)	2.4 GHz
Wi-Fi 802.11g (up to 54Mbps)	2.4 GHz
Wi-Fi 802.11n (up to 600Mbps)	2.4 GHz or 5 GHz
Wi-Fi 802.11ac (up to 1700Mbps)	5 GHz
Wi-Fi 802.11ad (up to 7000Mbps)	60 GHz
WiMAX 802.16/d (up to 1Gbps+)	2.3, 2.5, 2.6, 3.5 GHz
Ultrasonic nebulizer	2.4 MHz
Ultrasound (3 probes): General abdomen OB/GYN	2.5 to 6.0 MHz
Small parts, PV (steered linear)	5.0 to 10.0 MHz
Adult heart (harmonic echo)	2.1 to 3.8 MHz
Ultrasound diagnostic colour Doppler	2 to 11 MHz
Vasscular Doppler	3 MHz and 10 MHz

Vital Sign monitor	100 Hz
X-Ray Film processor tabletop	50/60 Hz
X-ray Film Viewer	50/60 Hz
X-ray radiography system	20 kHz
ZigBee	2.412 GHz
4G TD LTE (up to 1000Mbps+)	3.5 GHz, 3.6 GHz

B. Delay Test

The system was also tested for its frequency range to determine the occurrence of time delay within a specific location of the transmitter to the receiver. The test was divided into two actual field tests: a closed area and in an open area. A three-story building was used for closed area testing. The transmitter was placed in every floor and the receiver was tested in every room of the building. For the open area test, a no obstruction place was selected at line-of-sight. The transmitter was placed in one location and the receiver was tested every 10 meters for 100 meters.

C. Drip Rate Accuracy Test

Drip rate accuracy was tested for 1000 cc and 500 cc IV bags. It was monitored the entire time for any drip abnormalities. The fiber optic sensor identifies the drip signal of the IV. Drip signal is sent to the microcontroller for counting and compared to the set drip rate. If the drip rate deviates from the set value, an alarm is sent to the receiver end at the nurse's station.

IV. RSULTS AND DISCUSSION

All the data gathered were used to determine if there is time delay based on the position of the transmitter and the receiver. As seen in Fig. 6, time delay occurrence was not visible during the testing of the RF frequency. The transmitter can be suitable to be placed in every location of the building and also the receiver can receive in any part of the building.

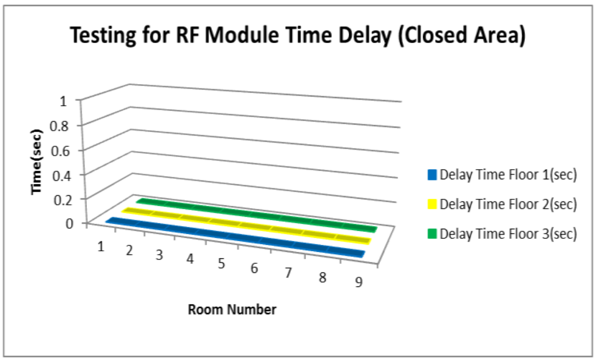

Figure 6. Time delay test results for closed area.

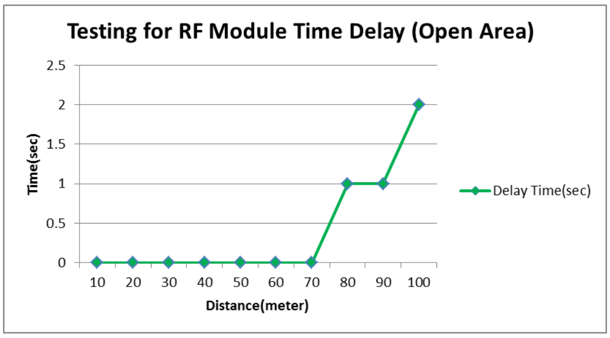

Figure 7. Time delay for open area

Data were gathered to determine the effective range of distance the receiver can receive the same data produced by the transmitter. Fig. 7 shows a 1-second time delay at the range of 80 meters up to 90 meters. When the receiver reaches 100 meters, the transmission delay was 2 seconds.

Drip rate abnormalities were also recorded for 1000 cc and 500 cc IV bags. A 100% detection rates were recorded for different drip rates and percent IV bag content. Also, the system was able to alarm when the drip rate altered from the set drip rate. Alarms were caused by unstable placement of the IV needle and as the percent content decreases, the more frequent the system was notifying the drip irregularities. Alert was also sent to the receiver if the second bag is nearly empty or it is in its 10% content.

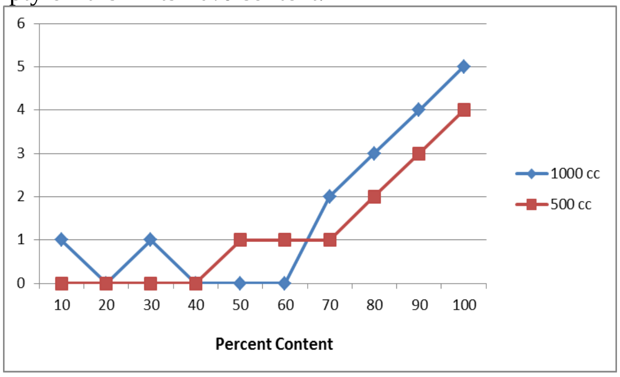

Figure 8. Drip Rate Deviation Alarm

During the cost analysis, the IV monitoring and refilling system was compared with the infusion pump available in the market. The former can also monitor the drip rate of IV, has a display board, power supply and air detect air bubble. The infusion pump, however, do not have the feature of refilling the IV bag. Market cost shows that the IV monitoring and refilling system is 72% lower in cost than the infusion pump.

V. CONCLUSION AND RECOMMNEDATION

The intravenous (IV) monitoring and refilling system is a new breakthrough in the field of medicine/drug administration. It allows more time for nurses to perform duties other than monitoring the IV therapy of patients since the system uses an alert when there is an abnormal reading of drip rate and when the second bag is nearly empty.

The system however, was not tested in vivo. It is recommended to test the system in vivo by applying some government permits to do such tests in an accredited hospital. Furthermore, additional reliability testing can be conducted for the "FAIL-SAFE" design mode. Recommended in vivo tests include applying the system to other liquid substances like nutritional formulas, blood and other drug treatment solutions. Other photo-electronic sensors can be tested for possible replacement of the optic sensors in case the latter fail.

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