A Smart Infusion Pump System for Remote Management and Monitoring of Intravenous (IV) Drips

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***Abstract*— The current state of the art of intravenous (IV) fluid administration systems lacks remote monitoring and control capabilities. This study presents an intelligent infusion pump system for automatic and remote management and monitoring of IV drips. This work used Arduino based microcontroller for controlling drop counter, detecting tube blockage and monitoring the emptying of drip bag. This system used low power laser diodes and optical sensors for the aforementioned monitoring tasks. The flow rate (in drop per minute) and infusion-interruption problems were monitored remotely via transmission of data wirelessly to users' smartphones using Blynk mobile application and computer based applications. This study found no difference between the manual and automatic counting reading. In addition, the system is able to notify its users of empty bottle and line blockage. This work concluded that the developed prototype may be further enhanced (in its design and features) and tested for its effectiveness and consistencies in real clinical settings.**

Keywords*— *infusion pump, intelligent, monitoring, IV drips

I. Introduction

Following the exponential growth in human population, there is an urgent need for affordable and quality healthcare services to help support and accommodate the demand of general public of different socio-economic classes. Intravenous (IV) treatment is a common and superior strategy used in hospitals and medical facilities to deliver fluids or medications through an IV route into a patient. This system can be used to either provide hydration and nutrition or to transfuse blood and/or administer medicines [1, 2]. A basic IV set consists of either a bag or a bottle containing a solution, a drip chamber that allows an estimate of the rate at which the fluid is administered, a roller clamp that controls the flow rate, and a cannula held in place with adhesive. Nursing staff usually determine the IV rate by using a mathematical formula relating the fluid volume and infusion time as given in [3, 4], and the flow rate should be checked regularly [5]. For the patients' safety and well-being, it is important for the caregivers to give accurate dosage and agreeable administration of medicines for the diseases [6].

Reverse blood flow is a major challenge when inserting IV solution into human body, which could sometimes happen in the IV line. Even though this situation may be harmless to the patients [7], this condition would lead to unnecessary blood loss [8]. Study in [8] further highlighted the problem of lack of continuous monitoring of IV administration, which includes occurrence of air embolism in the IV line, especially when the (fluid administration) bottle is empty. In addition, an infusion system either of gravity or pump driven may introduce small air bubbles in the drip tube. The sizes of these bubbles may increase with changes in surrounding temperature and pressure [9]. This causes air embolism when the gas entered a person's blood stream. This may bring adverse consequences and may result in serious morbidity and death [10-13]. Thereafter, to ensure the safety of the patients during IV infusion, there is a need to develop an efficient IV monitoring system.

To address the above mentioned problems, the IV drop rate mentioned [3, 4] was automatically determined in [14] using optical and capacitive based systems for drop and fluid level detection, respectively. Both of these devices were placed lining the walls of the chamber. Another system was proposed in [12] to improve the control, and accuracy and precision of the intravenous delivery process through the use of drop counter and level sensor. This system also contained automatic air bubbles detection and removal system to minimize incidence of air embolism [10-13]. Other work in [15] used obstruction of the light beam from transmitter (e.g. light emitting diode, LED) to a phototransistor (detector) placed on the opposite side in calculating the drop rate. This is viable with the change in voltage level measured by the detector so long as the obstruction exists. The signal is electronically processed for controlling peristalsis on the tube and for actuating alarms in case of malfunctioning [15]. Similar study in [16] used an infrared (IR) sensor attached to the drip chamber to determine drop per minute and used a wireless peristaltic pump installed to IV tube to control the flow of the fluid. The latter is controlled by a personal computer (PC).

Meanwhile in terms of off-site attributes, the acquired data in [14] were transmitted to cloud for further processing. This enables healthcare givers to overcome the problem of lack of continuous monitoring of IV administration [8] by checking the drip status wirelessly. Another work by [17] used a microcontroller-based intravenous piggyback infusion system to monitor and control the infusion rate by using PC and mobile phone using wireless sensor network. A significant advancement from this prior work is the inclusion of a feedback mechanism in the system, wherein in the case when there is a difference between the actual (i.e. reading from IR sensors) and set values (based on the mathematical formula), a pop-up window would appear on both monitoring devices to enable termination of the infusion. Park *et al.* [18] recommended the use of an IR laser in flow detection due to its consistent intensity and small divergence over a long distance, while non-modulator laser sensor module and light dependent resistor (LDR) were suggested in [19, 20] as the suitable sensors. Another study in [21] aimed to overcome the budgetary problems through the development of a syringe pump system for IV infusion purpose, whose cost may vary from $ 250 - $ 5000 [22]. The corresponding work used Raspberry Pi to control the syringe pump while a webpage was developed for the ease of record and retrieval of information on the operating conditions. Since there is an increase interest in research done in this field, [23] systematically reviewed the existing reports on both clinical measurement and modeling studies, and reported on the key findings and weaknesses in these prior arts. It must also be mentioned that Internet of Things (IoT), which is a technology paradigm that allows connection of physical device, software, sensors and other communication technologies for easier and more rapid data collection and exchange, has been popularly adopted for remote monitoring of patients in crowded emergency department [24, 25].

Most of these above mentioned systems can be improved, specifically those without IoT devices. For this reason, a low budget smart infusion pump is built in this work. The aim of this study is to develop a smart infusion pump system for remote management and monitoring of IV drips with IoT technology. This system is able to detect and notify its users of the presence of bubbles, blockage along the IV line, and in the case of empty fluid bottle or bag.

II. Methodology

There are two phases of project development: hardware and software development. While the hardware scheme consists of the development of an integration of drop counter, empty bottle/air bubble, and tube obstruction detection system, the software module includes data acquisition and an user interface for interactive remote monitoring and control of the entire system. The general block diagram of the whole system is shown in Fig. 1.

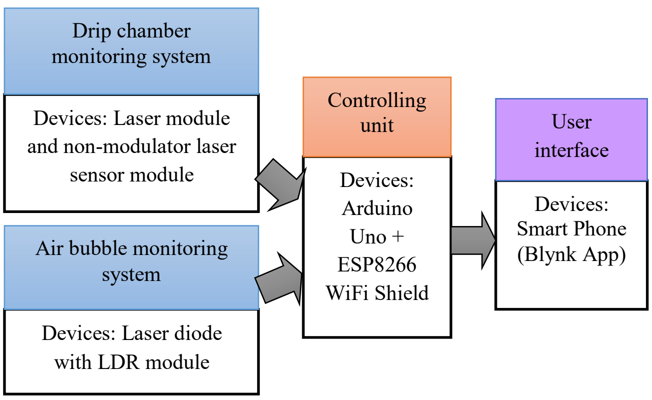

Fig. 1. General workflow of system development.

A. Drop Chamber Monitoring System

The developed drop counting system used a continuous wave 5 mW laser (BB-LASER-650) to emit light of wavelength 650 nm. Light passing through the drip chamber was detected by a non-modulating laser sensor (SN-NM-LASER-MOD) placed opposite to the emitter as shown in Fig. 2. This system was powered up and controlled by Arduino Uno R3 and ESP8266 WiFi Shield. The latter allows the Arduino microcontroller to connect to the internet for efficient transfer of data for display on a smartphone (via user interface).

This work assumed the output of the sensor is in the high state when it receives light from the laser module. Since the drip chamber was sandwiched by the laser module and the sensor, counting of fluid drops is feasible through the detection of high-low state of the sensor. Faults would be notified via information sent by the wifi module to the medical professional in cases of no drop detected for more than 30 seconds, which indicates empty fluid bottle. This warning is also given in the form of blue LED lights onboard.

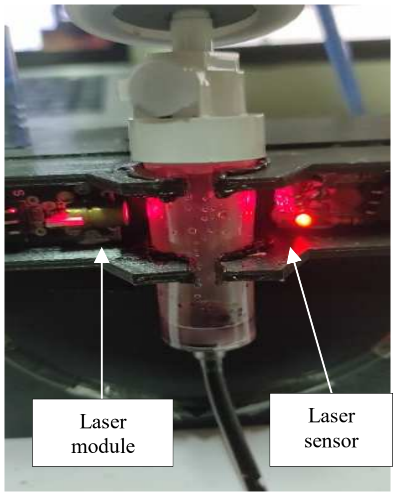

Fig. 2. Laser and laser sensor lining on the walls of the IV drip chamber.

B. Air Bubbles/Empty Bottle Detection System

Fig. 3 shows the connection of 5 mW laser diode (DS-LASER-650) with 650 nm wavelength and LDR module (SN-LIGHT-MOD) from the microcontroller of Arduino Uno R3 for air bubbles and empty fluid bag detection (i.e. indicated by prolonged occupation of line by air). Similar to the design of drop chamber monitoring system, the laser diode and LDR module were controlled by the Arduino connected to the WiFi Shield. The output logic of LDR module is High when it receives laser light from the laser diode, and otherwise is true for Low output. These components were attached at the tube line of intravenous administration set and would notify its users (via red LED and Blynk application) in cases of presence of air bubbles.

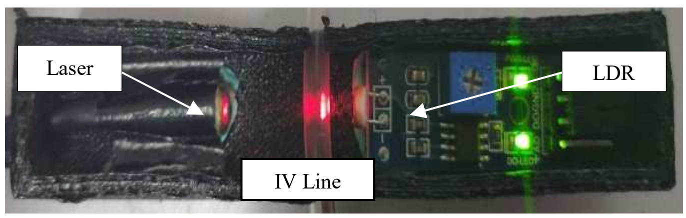

Fig. 3. Air bubble detection system.

C. Integration of Intelligent IV System

Fig. 4 shows the design of the IV infusion prototype using SketchUno. The design of this system included housing for (a) water drop sensor, (b) air-bubbles detector, (c) Arduino and other circuitry, and (d) system cover. This model was printed out using a 3D printer (Creality Ender

3). All the wires used herein were protected using heat shrink tube heated up to melt as shown in Fig. 5.

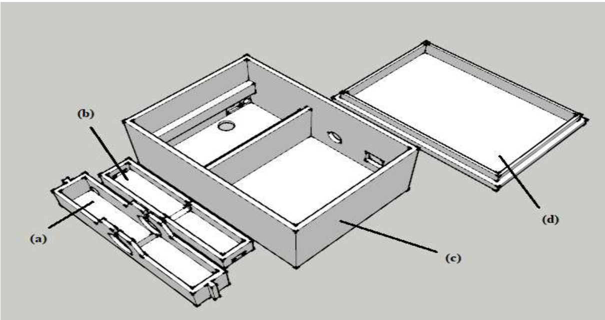

Fig. 4. SketchUp drawing of the hardware layout. The illustrated parts included compartment for (a) drop counter, (b) air detector, (c) circuitry system and (d) cover.

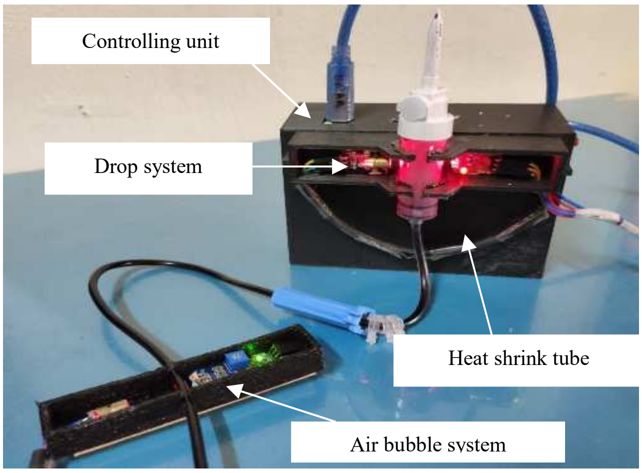

Fig. 5. A diagram of completed hardware system.

D. User Interface

The user interface used to control and facilitate the monitoring of sensors' data was via android version of Blynk. This open source IoT app allows customized design of layout and buttons for viewing of results and control of the system.

E. Experiment Protocol and System Performance Evaluation

The performance of the developed system is evaluated by comparison with that obtained from manual readings. As mentioned in earlier paragraphs, the conventional means of determining administration rate, Q, is via calculation. This is with the information on the amount of fluid or medication to be delivered, L (i.e. typically 500 ml/bag), and the required administration time, H, shown in (1). The drop factor, f, for adults is 20 while for pediatrics it is 60. The study began the experiment by closing roller clamp (i.e. opening, d = 0), before it was manually adjusted to up 40 % opening at a step size of 10 %. Each experiment was repeated three times. We do not consider clamp opening of beyond 40 % as the drops are falling too quickly in the drip chamber to be able to manually count.

$$Q = (L \times f) / (H \times 60) \quad (1)$$

III. Result and Discussion

In this section, results from hardware implementation and user interface of application are presented. This work found no difference between the drop counting rate given from manual readings and automatic system. The results from automatic system at different clamp opening are plotted in Fig. 6. The plot showed the mean and standard deviation (SD) of measured flow rate. It is observed that there is a gradual increase in the drop rate with the release of opening lever. This trend can be represented by a linear line shown in Fig. 6. Also shown in the diagram is its best fitted equation. This, therefore, suggests the good response of the detection system to changes in administration rate. There is, however, a slight delay of less than one minute in its detection.

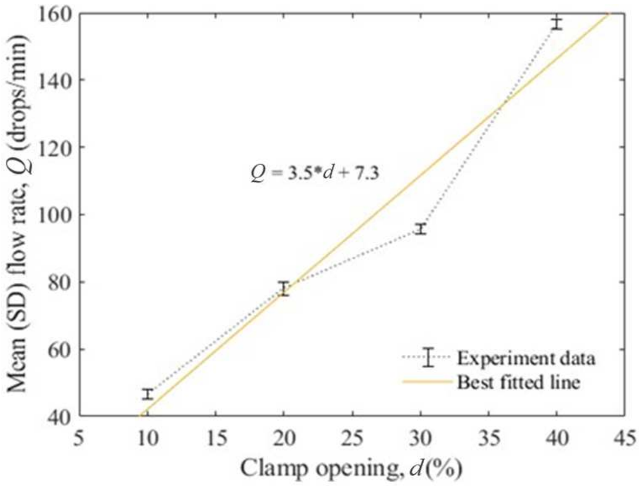

Fig. 6. Changes in flow rate, Q with roller clamp opening, d.

Meanwhile the output of Arduino serial monitor showed the system can successfully be connected to the internet during the experiment. The Blynk app required approximately 22 seconds to establish the connection prior to acquisition and transferring of data. Following this start-up period, the system took about 6 seconds to connect to the apps via Wifi for transferring of information of water drops counted in the drip chamber. This work also found the ability of the system to detect obstruction and air bubbles in the tube. These faults were rapidly notified by the LED indicators at near site, however a slight delay of less than 20 ms were observed in receiving of notification via the users' smartphones. The feasibility of the developed prototype for the intended applications may suggest its potential use in clinical settings. Nonetheless further work is necessary to enhance the design of the system and to rigorously test the system for use on human subjects.

IV. Conclusion

In conclusion, the strategies for remote management and monitoring of intravenous (IV) drips have been demonstrated in this study. This study found no difference between the readings given from manual and automatic counting. The increase in the drops rate with the clamp aperture was found to be governed by a linear equation, suggesting the sensitivity of the system in remotely detecting the flow changes in the drip chamber. Even though there is a time lag of about 1 minute for monitoring of drops count, near real time performance was observed in the event when in line bubbles were detected.

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