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A Cost-Effective Remote Saline Level Monitoring Device for Local Hospitals

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Abstract— **Continuous patient monitoring plays an important role in healthcare industry. The purpose of this research was to develop a new device to remotely monitor the saline level of a patient in cost-effective manner. For that, a prototype has been developed using an IR sensor, load cell, LCD display, servo motor embedded gripper mechanism and a GSM/GPRS module. The load cell is used to measure the weight of the saline bag and the IR sensor is used to detect and count the saline drops that fall through the drip chamber. The saline drop count is displayed on LCD at each time and when level of saline in the bottle reaches the critical level, then the servo motor embedded gripper mechanism is automatically turned on to control the blood backflow and at that time, the clinician will receive an SMS alert to his/her mobile phone through the GSM/GPRS module. To validate the developed system, a test was done using the load cell with standard weights and then, counted the saline droplets with the load cell, servo motor, LCD display, GSM/GPRS module and two LEDs as indicators. Furthermore, an experiment was done with the actual saline fluid with desired drop rate and weights at each time were observed. Arduino Uno has been used as the main controller in this saline level monitoring system. The validated results of this prototype showed that, this system can be installed in the local hospitals and care homes.**

I. Introduction

Today, technology has been applied rapidly in different industries. As a result of modern IoT-based wireless technology and mobile services, Engineers have been combined with medical specialists to use this technology for their activities to enhance the efficiency and safety in the medical field. Patient monitoring can be defined as the continuous observing of several parameters of the patient. In this case, oxygen saturation, temperature, blood pressure, heart rate, saline level monitoring and more other parameters can be monitored. In most cases, the patients need to be taken the saline as an intravenous therapy and in those cases, the clinician needs to monitor the saline level of the patient each time.

Continuous patient monitoring plays an important role in healthcare and these monitoring methods can be classified as traditional methods and modern methods. Those traditional methods are very time consuming and labour-intensive, as in traditional methods, clinicians need to be attended to the patient all the time to monitor their saline level and if not there will be a backflow of blood to the saline bottle at the end of the saline supply, which may cause harm to the patient life. Moreover, the saline drop counting is also an important process in saline supplying. Also in pandemic situations, there is highly important to have a system to remotely monitor the saline level of patients. The clinicians cannot be reached the patients in

those pandemic situations due to the high risk. And also in sometimes, clinicians fail to attend the patients due to the high volume of patients in their hospitals. As a result, a huge number of patients are potential of being risked in the healthcare and hospitals. Hence, having such patient monitoring systems while enhancing the capability of a real-time alerting method in cost-effective manner is important. In the present market, there are different types of infusion pumps that can be used to solve the identified problem. They include a drip rate control mechanism. Nevertheless, those systems are very expensive in the market and bulky in design as they include different components and they are not stand-alone systems.

Saline has become one of the very important and most popular intravenous therapy that plays a major role in the management of critically ill patients [4]. In most hospitals, doctors and nurses need to attend to the patient to check the level of the saline from time to time during his or her admission period. That means continuous reach to the patient has been needed. This is a very time consuming conventional method and sometimes it will fail by the doctors and nurses to check the status due to the high volume of patients and it will result in the patient life.

Nevertheless, modern engineering and technology have been coupled with the medical field to solve that problems to save the patient's life and enhance the safety and efficiency of hospitals worldwide. The modern patient and health monitoring systems are based on IoT [5], [7], [15] and other wireless technologies. The Internet of things(IoT) [13] is allowing the integration of the devices capable of connecting to the Internet and providing information on the state of health of the patients and it provide information in real-time to doctors, nurses or other clinicians who assist. They were getting developed with the help of electronics components including sensors [15], actuators, controllers (Arduino, PLC, raspberry pi), etc. Those technologies have used in heart rate monitoring [15], oxygen level monitoring, saline level monitoring [1], [2], [3], temperature monitoring [15] and many more parameters monitoring of the patients.

In past decades, Microcontroller ATMEGA 328 [2], Wireless module CC2500 [2], Bluetooth module [8], IR sensors [1], weight sensors [6], [8] Arduino Uno, AD8232, LCD [3], [9], Raspberry Pi board [14], IoT, GSM technology [10], HX711 chip, LM358 dual comparator and other software (Arduino and android based) and remote devices have been used for the development of patient monitoring systems, especially in the saline level monitoring systems.

Arduino Uno has been used in many previously developed cost-effective saline level monitoring systems as the controller [1]. All the sensors, modules, displays have connected to this microcontroller. Android applications have been created to use in some systems [2] and the level of the saline was monitored and critical levels have sent to the mobile phones applications through IoT and GSM technology. The clinicians can remotely identify the patients' saline levels [15] and it will result in reducing labor-intensive and time-consuming. The raspberry pi was the other controller that has been used and it was used Linux based operating system. The CC2500 wireless module transmitter was the commonly used wireless module in those systems [2].

In previously developed saline level monitoring systems, servo motor mechanisms [7], [9], solenoid valves [11], IV non-return valves [17] and blood pressure cuff have been used to control the blood backflow at the end of the saline supply. The solenoid valve is an electrically controlled valve. The most commonly used fluids control element was the solenoid valve and work according to an electrically generated magnetic field. when the saline level is reached the critical level, then the saline tube or the valve closes automatically and as a result, the backflow of blood is stopped. The IV non-return valve was a simple mechanism that has been used in existing systems. It is allowed to flow saline in one direction only. when using this valve, only the saline liquid can flow to the patient's body and if blood backflows then it will not be gone through the valve to the saline bottle. The servomotor mechanism was the other common method used for blood backflow control in some saline level monitoring systems. It stops the blood backflow by controlling the saline supply. when deeply studies those mechanisms, most of those technologies have stopped the blood backflow by closing the IV tube before end the saline in the bottle.

For the measurement of saline level, different kinds of sensors and technologies have been used. In previous saline level monitoring systems, the most common sensor that has been used for the measurement of saline level was the IR sensor [1], [2], [7], [9]. The droplet coming from the saline bottle has detected using an IR sensor. There was a transmitter and a receiver part. When the transmitter of the IR sensor detects the saline droplet, the signal is transmitted to the receiver and so that the receiver can receive the droplet and sends it to the LM358. The LM358 [2] was a dual comparator that has used to modify the weak signals coming from the IR transceiver. The other commonly used sensor was the load cell and it has used with an HX711 module [8]. The weight of the saline bottle has considered when using this sensor. The load cell is a transducer that is converted force into a measurable electrical output. The HX711 module amplifies and converts the analog voltage of the sensor into the pulse width modulated (PWM) digital voltage and send it to the Arduino. Some systems have used load cells with the help of encoder and decoder ICs [6]. The ultrasonic sensors have also used in a system to detect the saline level [5].

Some present saline level monitoring systems have been included automatic saline bottle change method [12]. when a bottle is emptied, it is then changed to the other new saline bottle automatically. In the market, there are some complex saline level monitoring systems including pump mechanisms, automatic drop control mechanisms [11], and many more features with large number of tools. Those systems not only include the saline level monitoring part but also temperature monitoring, heart rate monitoring etc. (All in one systems). [15]. And the ability to set time intervals to supply the saline to the patient was a new feature of that system.

The IR sensors, load cells were the most common sensors that have been used for saline level monitoring and to control the blood backflow they have mainly used solenoid valve and servo motor mechanism. The other common thing was the wireless technology which was used to send data to mobile phones [10]. Arduino has been used in more previously developed saline level monitoring systems. Those previously developed saline level monitoring systems have mainly focused to monitor the saline level of patient time to time, control the drop rate and send specific data to the clinicians' mobile phones through IoT and GSM technology with a warning alarm (buzzer) [2], [7].

[16] In the present marketplace, there are some systems called infusion pumps and it infuses fluids, nutrients or other medication into the circulatory system of the patient. When clinicians use this pump to treat patients, it usually requests some details about the infusion. The infusion pumps are two types as large volume pumps and small-volume pumps. Large volume infusion pumps have used for the saline solution. The peristaltic pump was a kind of a roller pump and works as a rotary pump. In the small-volume infusion pump, there was a motor that was controlled by a computer. There are some safety improvements. Those infusion pumps have included a battery and as result, though the power fails system can be operated. These systems are very complex designs and there are sensors called "up pressure" and "down pressure" sensors. While the up pressure sensors detect the empty syringes or bags, the down pressure sensors can detect if the vein of the patient is blocked. Most of those infusion pumps have included an embedded system to control the processes.

The Table 1 shows the difference between proposed system and other available saline level monitoring systems in the market.

TABLE I: PROPOSED SYSTEM VS OTHER AVAILABLE SYSTEMS IN THE MARKET

My proposed system	**Other systems available in the market**
Limited number of tools	Different gadgets and circuits
Less power consumption	More power consumption
Easy operate	As those are advanced systems, skill is required to operate
GSM technology to communicate	Advanced systems not included GSM technology
Remote monitoring ability	Clinicians need to reach the patients or system
Cost-effectiveness	Expensive
Simple blood backflow controlling mechanism	More advance mechanisms and some systems not included this feature

II. METHODOLOGY AND RESEARCH DESIGN

To minimize those identified problems in patient monitoring, a cost-effective remote saline level monitoring system with GSM/GPRS technology was proposed and is under development. Also, an automatic blood backflow control mechanism has been applied as a prototype to the developing system. The clinicians or caretakers will be notified via LEDs and also a message on the LCD. SMS will be sent on mobile through the GSM/GPRS module. In this saline level monitoring system, Arduino Uno, IR sensor, Load cell with HX711 module, LEDs, servo motor, LCD display and GPRS SIM800l module have been used as the main components. The main controller of this system is Arduino Uno.

For this saline level monitoring system, a 5V-9V DC/2A power supply was used to power up the system. The level of saline in the bottle was measured by the load cell. That means the weight of saline in the bottle at each time is considered when measuring the saline level. The critical saline level was set at 30% of the actual weight of the saline bottle. When the saline bottle is 500g and then, the critical level is 30% of 500g. Therefore, the critical level was set at 150g.

According to the above scenario, a message is sent to the clinician's mobile phone when the saline level reaches the critical level. A warning message regarding the level of the saline in the IV bag is sent to the clinicians' registered mobile phone through the GPRS SIM 800L module at 30% of the actual weight. Two LEDs have been used to indicate the saline level as low and high. At the critical level, the servo motor needs to be turned on to block the IV tube. So that a gripper mechanism was used to loose and tighten the IV tube (Fig. 1 and 2).

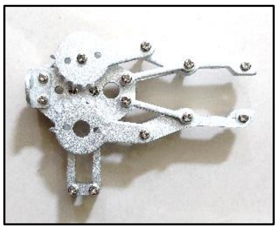

Figure 1: Gripper mechanism

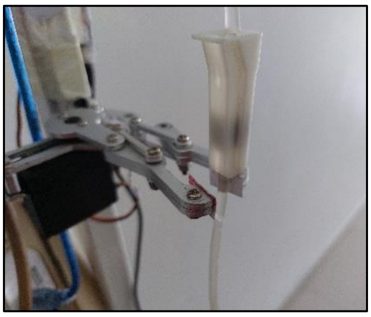

Figure 2: Gripper mechanism for loosen and tighten the IV tube

An IR sensor was used to detect the saline droplet and that information can be used to calculate the saline drop rate. This IR sensor detects the saline droplets when it falls through the drip chamber.

To validate the performance of the developed saline level monitoring system, several experimental methods were done. As the first method, a number of seven standard weights was used and their weights were measured again using the developed system with the use of load cell. This experiment was done to verify the load cell readings and the test results were displayed in the Table 2 and Figure 4.

The second experiment was done with the IR sensor to count the saline drops. At firstly, the saline drop count was done without using the drip chamber and for that, a normal syringe was used as a drip chamber and the water droplets were counted using an IR sensor without having a fault. In this case, water was used as an alternation to the saline. This experiment was conducted to verify the detection of saline droplets and it was successful.

The third experiment was done with the load cell, servo motor, LCD display and two LEDs. It was done to observe the performance of the entire system. In this case, a 500ml saline bag was used and 150 ml was used as the critical level. When saline in the IV bag was greater than the critical level, one LED (Green color) was indicated it and when the saline level reached the critical level, the servo motor is turned on while the other LED (Red color) is indicated it. The servo motor embedded gripper was used as a blood backflow control mechanism. Here, this blood backflow control mechanism was applied to this proposed system as a prototype. The Figure 3 shows the partially developed prototype of saline level monitoring system.

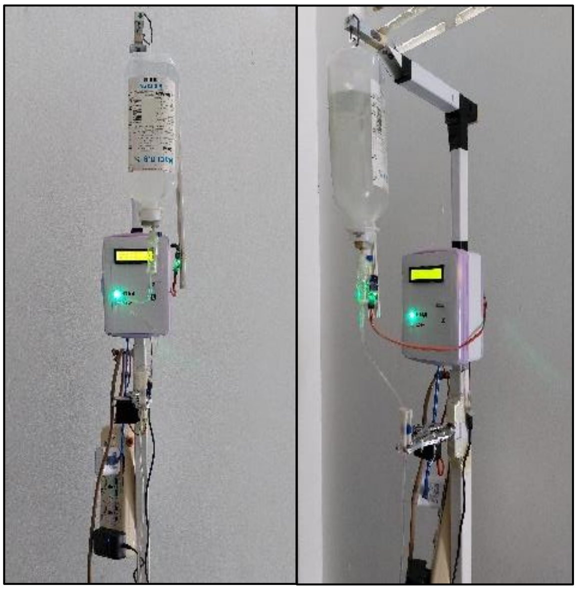

Figure 3: Developed prototype of saline level monitoring system

III. Results And Discussion

In this study, several experiments were done to validate the accuracy and the precision of the developed prototype. As this is a medical device development, it is necessary to select suitable sensors and actuators to get a more accurate output result.

The first experiment was done with the load cell to verify the reading weights. For this experiment, seven standard weights were used and those standard weights were measured again using the developed system's load cell and the results have observed as shown in Table 2.

TABLE II: Standard Weights Vs Measured Weights By The Load Cell

Standard Weight (g)	**Measured Weights by the Load Cell (g)**
45	54.19
50	59.812
90	94.234
100	105.47
250	257.17
500	514.46
700	705.24

The Figure 4 shows the difference between measured weights and standard weights. The red color bar represents the measured weights and blue color bar represents the standard weights. According to these data there is some small difference.

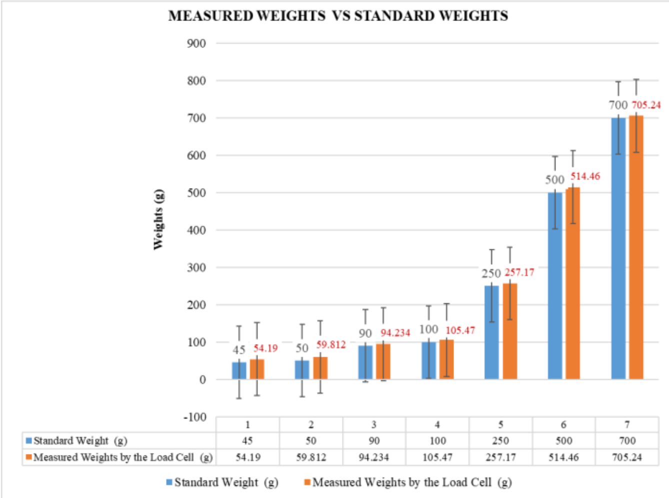

Figure 4: The graph of measured weights vs Standard weights

The second experiment was done with the IR sensor to count the saline droplets falling through the drip chamber. In this experiment, the data was observed over a one minute of period and it was included into a graph as shown in Figure 5 and Table 3 shows the IR sensor readings over a one minute of period.

TABLE III: Observed Data From The IR Sensor

Time (PM)	**Number of Drops**
19:56:12	1
19:56:17	10
19:56:20	20
19:56:32	30
19:56:59	40
19:57:05	50
19:57:10	60
19:57:16	70
19:57:22	80
19:57:28	90
19:57:35	100
19:57:41	110
19:57:48	120
19:57:54	130
19:58:01	140

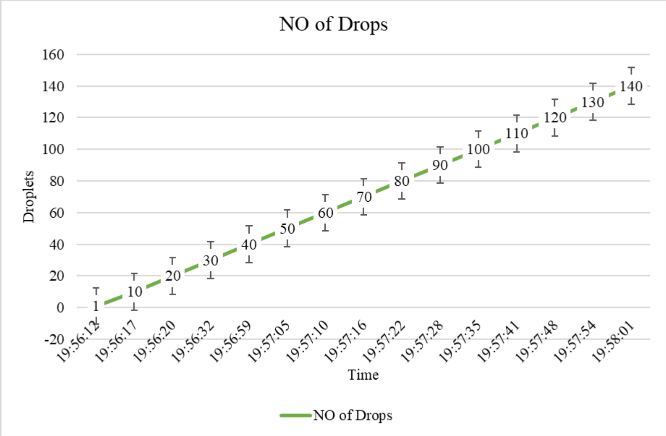

Figure 5: The graph of saline droplets falls vs time

When count the saline droplets only using the IR sensor, the data can be observed without a delay. Nevertheless, there was a delay when using the IR sensor with all other components including load cell, GPRS module, Servo motor and LEDs. The reason identified was that the Arduino program, because it runs line by line. By modifying some parts of the Arduino Program, that issue was fixed to a certain extend. There should be a line of sight between IR sensor and drip chamber without moving it freely to detect the saline droplets according to this experiment.

The main objective of the research is to remotely monitor the level of saline in a cost-effective manner. The load cell and IR sensor are the main two sensors used and those two sensors are less expensive devices in the market. Nevertheless, it should give us an accurate result. As mentioned in above, the first experiment was done with the load cell to verify the output readings. According to that experiment, load cell calibration was done with a known weight calibration method to get a closer value to the actual weight. Because the load cell is the sensor that is used to measure the level of the saline in the bottle. Therefore, the results of this experiment were very important to do a load cell calibration to get an accurate result.

The other important process is to detect and count the saline droplets falling through the drip chamber. Due to cost-effectiveness, the IR sensor has been used. Nevertheless, verifying the detectability is very important as the saline droplets are transparent. Therefore, the IR sensor experiment and its results were important to decide whether the IR sensor can be used cost-effectively or not.

From the experiment done, the IR sensor and the Load cell were verified to use with the proposed system. The IR sensor can detect the saline droplets effectively according to the results observed. The Load cell readings are also closer to the actual weights. As those two sensors not required additional components, the IR sensor and load cell can be used cost effectively.

Generally, the Arduino based systems are cost effective compared to the other available technologies. Arduino is user friendly and lower level controller that can be used in different purposes. The components that can be used with this Arduino unit are also less expensive compared to the other high ended technologies. Therefore, in this economical remote saline level monitoring system, Arduino Uno has used as the main controller and all other components are Arduino supported.

TABLE 4
IV: PRICE OF EACH ITEMS USED IN THE PROPOSED SYSTEM

Item name	**Cost of the item (USD)**
Load cell (5kg) with HX711 amplifier module	2.95
IR sensor	0.66
LCD with I2C module	5.19
MG995 Servo motor	4.64
Aluminium Gripper	4.37
Power Supply 5V 2A	4.10
Arduino Uno	10.10
GPRS SIM800L module	8.87
Control box (plastic)	1.65

The total item cost will be around 45 to 70 USD for the proposed system. In the market, it is difficult to find such a stand-alone saline level monitoring systems, they are included different parameter monitoring features (oxygen level, temperature, heart rate, etc.). However, the price for these patient monitoring systems available in the market varies between the 100 to 550 (USD) range. Apart from that, this system includes some additional features like SMS alert (Warnings alert) and simple blood backflow control ability compared to the other systems available in the market.

IV. CONCLUSION

In this paper, a cost-effective remote saline level monitoring system was proposed. It was further improved to get an SMS alert to the clinicians' mobile phone before saline in the bottle is emptied. This part is under development at the moment. Hence the proposed device is less labour-intensive and cost-effective. GPRS SIM 800L module connects the clinician's mobile phone and Arduino Uno. The other important feature is the blood backflow control mechanism. It includes a servo mechanism with an aluminium gripper, and it was developed as a prototype in this proposed saline level monitoring system. In addition, the saline droplets are detected using an IR sensor which is mounted in the system with the saline bag.

Until now, the system was developed to measure the level of saline, detect the saline droplets, and send SMS alerts when it reaches the critical point, controlling the blood backflow as a prototype and the saline level is displayed on LCD. Several experiments were done to validate and verify the sensor output reading and the remaining part will be tested the entire system and verify the outputs. The blood backflow control mechanism is under development.

According to the results observed from the validation experiments, the load cell weight measurements are working well with a minimum error. The saline drop counting is also worked, nevertheless, the positioning of the IR sensor is very important to detect the saline droplets. The SMS alert process is worked when supplying the required voltage and current range. When the level of saline in the IV bag reaches the critical level, the servo motor embedded gripper mechanism is turned on while indicating it through an LED. The system is under further testing and validation to make it a reliable device for local hospitals.

This proposed remote saline level monitoring device can be used in the local hospitals wards. The Bed Number and the ward details can be included into the programme inside this proposed system and it will facilitate to build a local control system for the entire ward to monitor the parameters on a PC (saline level, counted saline droplets) at the main desk of the ward. In addition, an external keypad can be connecting to the device to calibrate the load cell to get a more accurate value. After installing the system at the local hospitals, the clinicians can get SMS alert when the level of saline in the IV bag reaches a lower level and until the clinician attend to the patient, the IV tube will be blocked to stop the blood backflow.

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