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Research article

Design and Development of Saline Infusion Administration System Using IoT

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Abstract: According to the current deficiency of medical personnel due to many COVID-19 patients today, the workload of nurses and caregivers increases. One of the costliest tasks for healthcare professionals is monitoring and controlling the administration of saline solutions to bedridden patients. This research aims to develop a monitoring and regulating system to conduct the saline solution to patients using IoT technology. The Arduino UNO R3 and Node MCU ESP8266 microcontroller board are used as a processor to receive the saline weight input from the load cell and control the saline flow rate by the servo motor arm. The developed system can also be remotely monitored and controlled online via Wi-Fi, Internet, and cloud computing with mobile and web applications developed by Flutter. From the results of trying that determine the saline flow rate with different periods, it was found that the system was able to control the flow rate for the specified time with a total meantime accuracy of 88.47%. It was also found that the accuracy rate would increase if the flow rate were set for a short period, while the accuracy rate would decrease if the flow rate were set for a long time. The experiment revealed that the developed prototype system could monitor, alert, and automatically control the flow rate of saline administration to patients as the specified objectives.

Keywords: Saline Infusion; Saline Controlling; IoT

1. Introduction

According to the ageing society of many countries and the Covid-19 epidemic, the number of patients increases continuously. As a result, it exceeds the ability of nurses and caregivers. Reducing the workload of healthcare workers is therefore essential. Monitoring and controlling the administration of saline to patients is one of the nurses' tasks that pose a considerable burden. Thus, the researchers aim to develop a system that can automatically monitor and control saline administration to reduce the workload of healthcare professionals. In addition, with the development of Internet of Things (IoT) technology, it is possible to develop sensor-based monitoring and reverse-control with actuators through the Internet, mobile applications, and cloud computing.

Furthermore, the ability to automatically adjust the saline flow rate according to the doctor's prescription and monitor and alert the active status via a mobile application reduces the burden on caregivers. Another factor is the price which must be more cost-effective and less expensive than the digital infusion pumps available in the market. Examples of digital infusion pumps available on the market cost about $240 to $300. The proposed system can also collect the patient's history and behaviour data to reduce the workload and care benefits.

2. Related Works

A literature review on the development of IoT-based saline monitoring and control systems revealed that, in addition to using IR sensors to detect saline water content. We also found that load cell [1-3], ultrasonic sensor [4-5], tilt sensor [6], level sensor [7], and flow sensor [8] were used to perform the functions of detecting the volume and flow rate of saline from a bottle. However, the developed system can only detect the amount of saline and notify the nurse or caregiver [1-5], [8-9], primarily through mobile applications, and output only through the LCD [5, 7]. In contrast, some systems, in addition to detecting the amount of saline, can also control the saline flow rate according to the doctor's prescription [7-8]. However, in the system that can control the flow rate, it was found that the nurse had to set the saline drip-rate manually. The system can automatically adjust the saline drip rate, but caregivers must also monitor whether the physician directs the saline infusion time. Furthermore, systems using solenoid valves to control flow rate require that the saline flows directly through the device, potentially contaminating germs or foreign matter [7]. While the research performed a servomotor control method [8], the caregiver had to calculate the saline drip rate to control the saline depletion at the doctor's schedule. The system cannot control the rate of saline administration to the patient within the amount of time the doctor can determine. Another essential prerequisite for developing IoT-based saline monitoring and control systems is when the patient goes to the bathroom or other cases where the saline flow or drip rate is abnormal. Most systems cannot detect vibrations both from the patient's body and from the surrounding equipment, which affects the abnormal flow of the saline solution. Only research studies [6] can address this problem with tile sensors. Moreover, to prevent blood flow backwards during the saline container is empty, the operation needs to hold the saline flow when the container is almost blank. Only the [8] system can squeeze the saline tube to prevent the backflow of blood. Also, most systems fail to demonstrate the validity of the trials to monitor and control saline administration by a physician-prescribed system. This research focuses on designing and developing an automatic monitor and control saline feeding and adjusting the saline flow rate system. Additionally, nurses or caregivers can monitor the flow rate and residual saline volume through a mobile application. As well as to prevent abnormal saline flow rates from patient movement, the system can detect abnormal flow rates from distorted weight signals from the load cell. In addition, if the saline content in the container is less than 5% weight from the original volume, or there is severe vibration of the container detected by the load cell, the system will squeeze the saline line to prevent the backflow of blood the saline tube.

3. Materials and Methods

Responsible for the objectives of this research, the research team has designed a system that focuses on enabling the system to respond to IoT-based operations. The ESP8266 Node MCU and Arduino UNO R3 are used as the central processing unit, enabling integration with cloud computing via a Wi-Fi network. For the principle of operation of the system, initialize the beginning load of the patient saline container or bag to define the initial saline substances by the Load Cell, Shear type as 10Kg measured load and 1.0 ±0.15 mV/V measured output. The HX711 amplifier module amplifies the signal received from the load cell and forwards it to the Arduino UNO R3. The traceability status information is sent to the ESP8266-12E Node MCU to deliver cloud computing. Firebase and Mongo DB are used in this development. Firebase, a Google service, is used for online notifications. MongoDB, private cloud storage, is chosen for data management and patient data security. This research developed both mobile applications and web applications for the user interface. Flutter is used to create mobile applications that can run on either Android or iOS platforms. The servo motor is commanded by the Arduino UNO R3 board and is used to steer the saline tube's compression or repose to increase or decrease the saline flow rate, respectively.

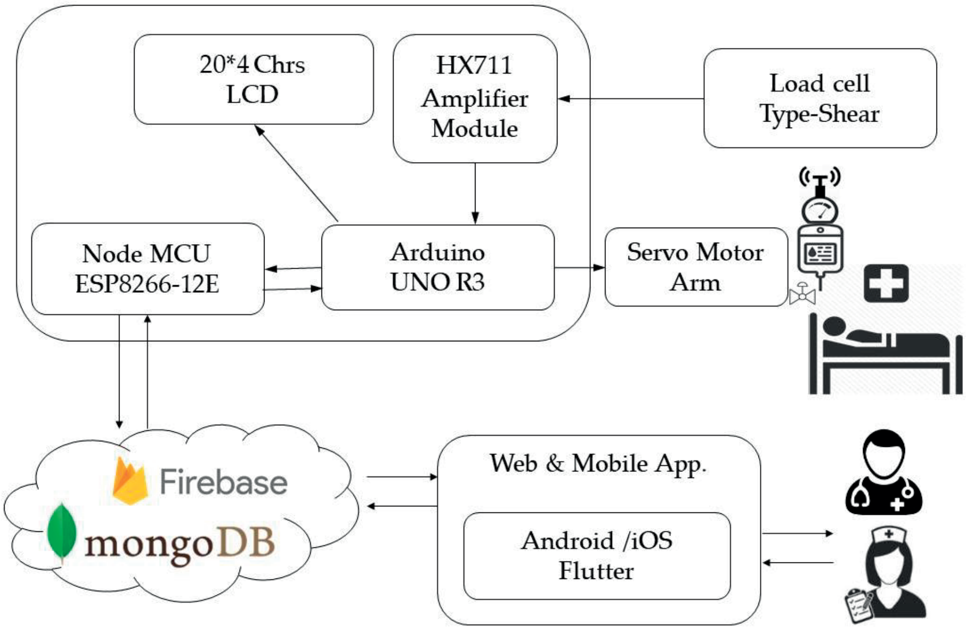

Figure 1. System Framework

Figure 2 shows an algorithm to observe and regulate the flow rate of saline solution as prescribed by the physician. It starts with determining the weight of the saline bag due to the various initial packaging and volume of the saline solution as *Init_Wt*. The nurse or caregiver will then select an order to determine the duration of the saline solution, such as 1, 3, 5, or 8 hours directed by the doctor, then transfer to minutes as *Infusion_Time*. Then determine the final weight for the saline drainage stop as *Stop_Wt*. The flow rate is calculated based on the lost weight by the initial weight divided by the infusion time determined in the previous step.

$$Flow\_Rate = Init\_Wt\ (g.)/Infusion\_Time\ (min.), \quad (1)$$

The system then determines the degree of the servomotor arm that compresses the saline tube so that the saline solution flow rate is relative to the required time. The system then calculates the weight of the lost brine from the previously lost weight minus the weight of the brine imported from the load cell at that time. In addition, the system determines the average flow rate as a basis for detecting possible abnormal flows. The normalized flow rate average as *Norm_Flow* is calculated by the previous mean plus standard deviation. The system then compares the weight lost from the flow with the flow rate. If the weight loss as *Curr_Flow_Wt* from the flow is greater than the flow rate as *Flow_Rate*, then the brine flow is too high, the servomotor arm is forced to squeeze the tube more to reduce the flow rate. Conversely, if the weight lost from the flow is less than the flow rate, then the brine flow is too small, the servomotor arm is forced to squeeze the tubeless to increase the flow rate.

In addition, if the load cell vibrates signal occurs by comparing the current flow weight with average normal flow, which means an abnormality. The system will command the servo motor arm to squeeze the tube to stop the saline flow for safety reasons. The system will repeat the above process until the saline is 5% or less, depending on the requirement. Finally, the system will instruct the servo motor arm to squeeze the saline tube to stop flowing for safety and prevent backflow of blood. Then, the system will send a notification to the caregiver or nurse for further action.

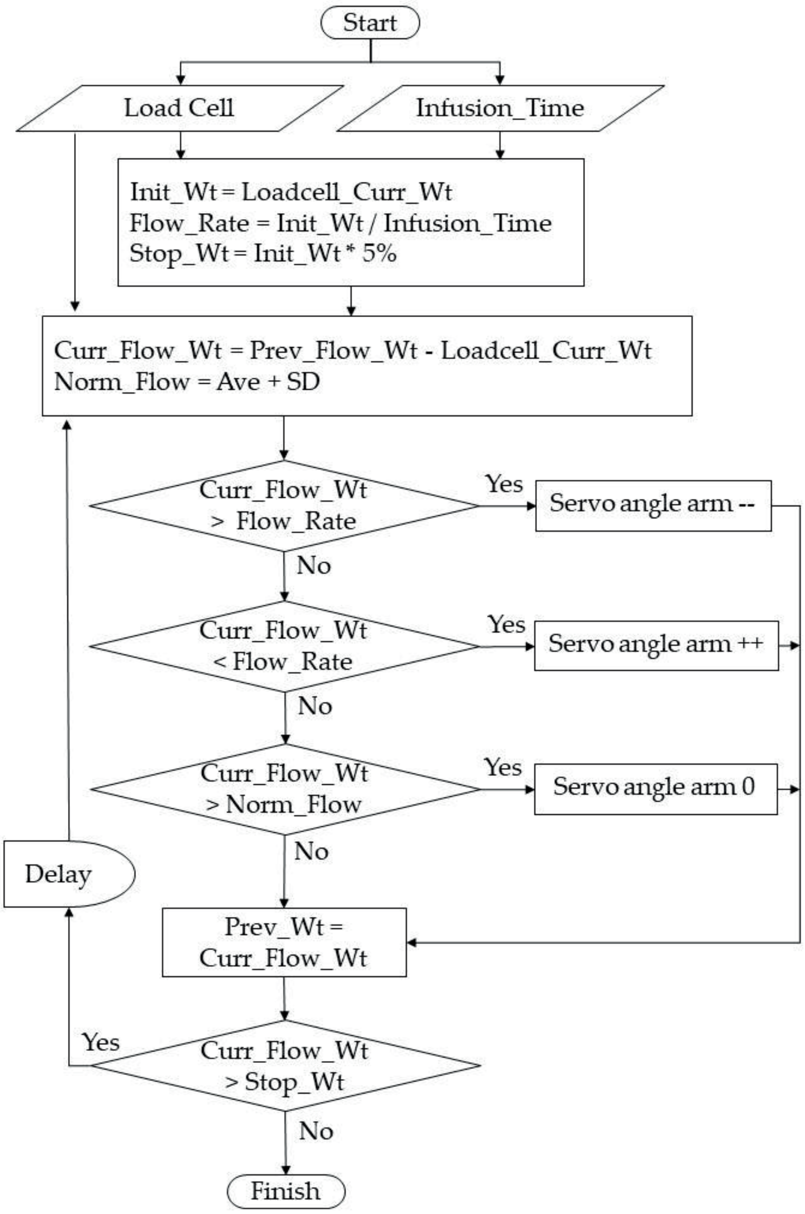

Figure 2. Algorithm to observe and regulate the flow rate of saline solution

Refer to Figure 3; the use case diagram illustrates the functions that doctors and nurses can access to the system. It consists of the following functions: *Add, Find, & Update User Profile* are functions where users can add, search, and update patient information. *Doctor's Orders* is a function that which the doctor can order the detail of saline solution, such as the type of saline solution and the duration. In addition, the nurse can take the doctor's orders from this function. *Saline Status Display* is a function that users of both doctors and nurses can track the flow status of saline solution. Furthermore, users can also receive notifications in case of abnormalities or saline depletion from the *Saline Monitor & Notification* function. To assign access rights to the system, the user must log in and deactivate from the *Login/ Logout* function.

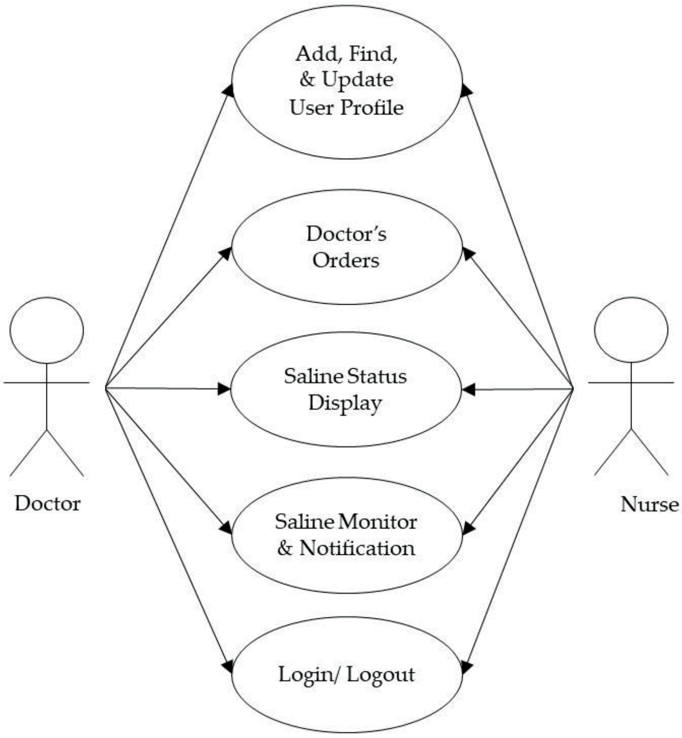

Figure 3. Use-case Diagram

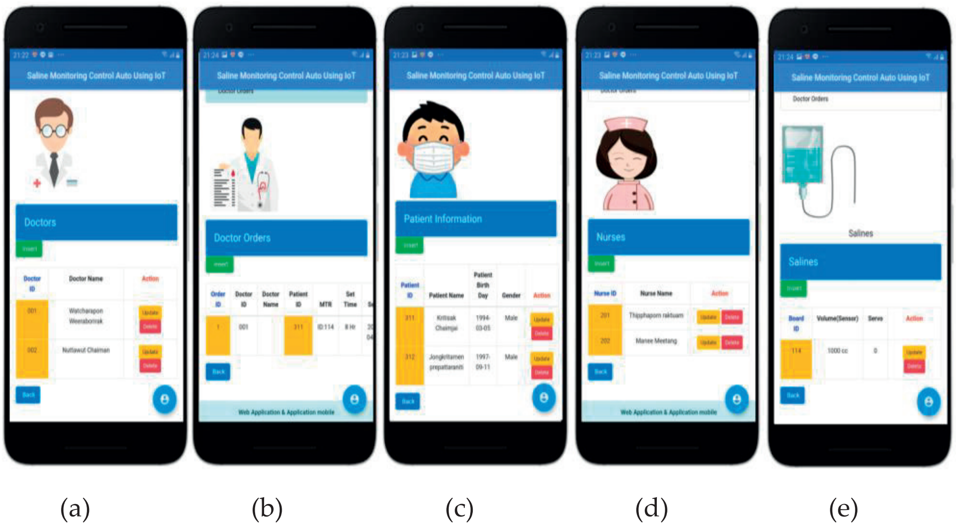

Figure 4. Example UI of Mobile Application

Figure 4 presents an example of a mobile user interface that allows nurses or caregivers to monitor, control saline administration and receive system notifications through a mobile application as follows: (a) UI for physicians to access the system, (b) UI for doctor's orders for saline solution, (c) UI showing patient information, (d) UI for nurses to access the system and work records; and (e) UI for monitoring and alerting in the event of anomalies. Not only can doctors and nurses use the system via the mobile application, but they also use the system via the web application.

An example of a web application interface is shown in figure 5. The interface shows the doctor's instructions and details and the status of saline administration to each patient.

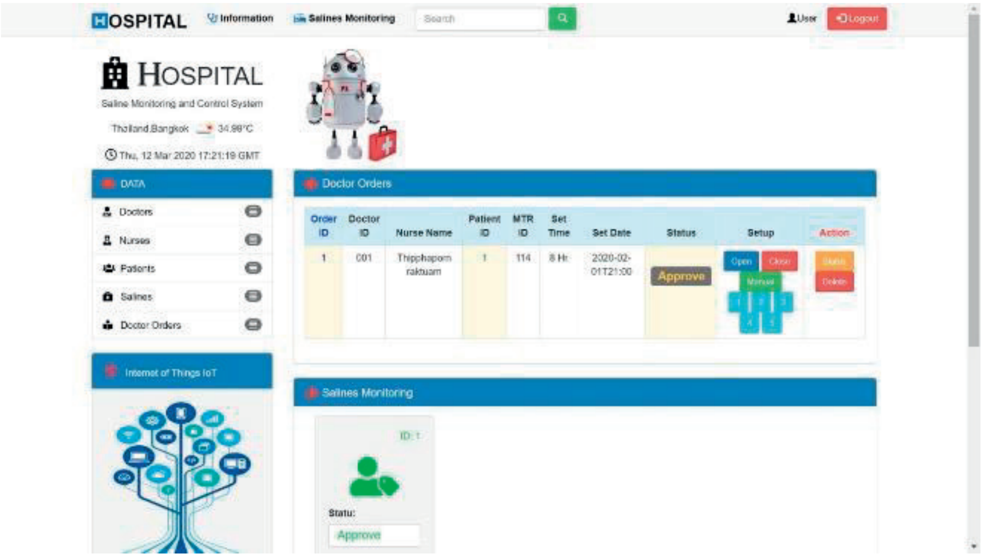

Figure 5. Example UI of Web application

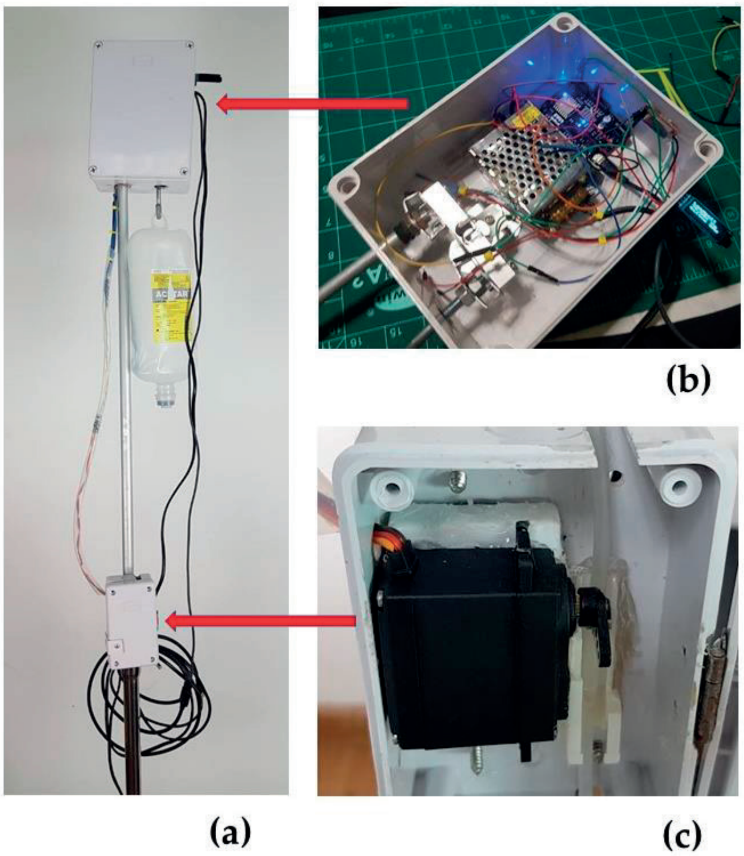

Figure 6. Hardware prototype of the developed system

Refer to Figure 6; It represents the hardware prototype of the system (a). The upper box (b) contains a Load cell Type-Sher for hanging the saline solution bag. The load cell is connected to the HX711 Amplifier Module to amplify the weight signal and forward it to the Arduino UNO R3 board to process and control the compression or release of the saline flow rate by the servo motor arm stored in the lower box (c). It can also display the weight of saline solution via 20*4 Characters LCD. The saline weight data is transmitted from the

Arduino UNO R3 to the Node MCU ESP8266-12E connected to the Internet via a Wi-Fi network, further forwarding the data to the cloud as detailed in (b).

4. Results and Discussion

An experimental simulation was created by hanging a 1000 mL saline bag on a load cell. Then, the experimental set was divided into five batches, each of which was assigned a different saline end time. Since the experiment used a 1000 mL or 1000 g saline size excluding package weight to avoid excessive saline flow and demonstrate that the system can determine the minute time, the duration of the first set of experiments was established (A) settles a time of 150 minutes or two and a half hours. The second set (B) is scheduled for 240 minutes or 4 hours, the third (C) is designed for 360 minutes or 6 hours, the fourth (D) is designed for 540 minutes or 9 hours, and the last set (E) is scheduled 900 minutes or 15 hours. Prolonged time intervals are intended only to respond to cases where the doctor wants to keep the vein open (KVO) to prevent blood clots. Then create a timer and record since the brine started flowing. The servomotor arm squeezes the brine tube to stop the flow until the brine solution is reduced to less than 5% of the starting weight. Each set of trials performed five trials for a total of 25 attempts. The results of the experiment are exhibited in Table 1.

Table 1. Comparison of the flow rate controlling of the saline solution at the specified various time

No.	Test Set (min.)					
	A (150)	**B (240)**	**C (360)**	**D (540)**	**E (900)**	**Total**
1	149.46	228.18	308.18	538.21	941.25	
2	144.14	228.33	409.58	579.62	836.67	
3	144.57	242.9	329.86	628.33	941.25	
4	146.93	240.17	329.84	580.38	836.67	
5	139.58	251.17	337.96	579.23	836.67	
$\bar{x}$	**144.94**	**238.15**	**343.08**	**581.15**	**878.50**	**437.17**
SD	**3.67**	**9.90**	**38.78**	**31.92**	**57.28**	**28.31**
Min.	139.58	228.18	308.18	538.21	836.67	
Max.	149.46	251.17	409.58	628.33	941.25	
Err. (min.)	**5.06**	**1.85**	**16.92**	**41.15**	**21.50**	**17.30**
Err. (%)	**3.38%**	**1.23%**	**11.28%**	**27.44%**	**14.33%**	**11.53%**

Table 1 and Figure 7 show the result of the (A-E) test set marks at the specified time compared to the experimentations. The results of the experiments consisted of mean, standard deviation, time-tolerance mean, and percentage of meantime error for each test set of different specified times. The results showed that the first test (A) was assigned to drain the saline solution within 150 min; the system was able to do so in a mean time of 144.94 min (± 3.67 min) with a meantime error of 5.06 min or 3.38%. The second group (B) results were determined to complete the saline solution within 240 minutes. The system achieved an average of 238.15 minutes (± 9.90 minutes), with an average time error of 1.85 minutes or 1.23%. Results of the third experiment (C) were determined to release the saline solution to be discharged entirely within 360 minutes; the system achieved a mean time of 343.08 minutes (± 38.78 minutes), a mean time error of 16.92 minutes, or an error of 11.28%. Additionally, in the third trial (D), which was timed to deplete the saline solution at 540 min, the system achieved a mean time of 581.15 min (± 31.92 min) with a mean time error of 41.15 min or 27.44%. The last set of experiments (E) was scheduled to run out of saline in 900 minutes. However, the system was able to do it in an average time of 878.50 minutes (± 57.28 minutes), with a mean time error of 21.50 minutes, or 11.53%. All trials' total meantime error was 11.53% (± 10.41%). Thus, it can be concluded that the system is accurate in controlling the flow rate of the brine solution to the required accuracy of 88.47% (± 10.41%). It was also found that in the experimental results, shorter flow intervals resulted in fewer errors. Conversely, setting a longer interval for the flow will also result in more errors.

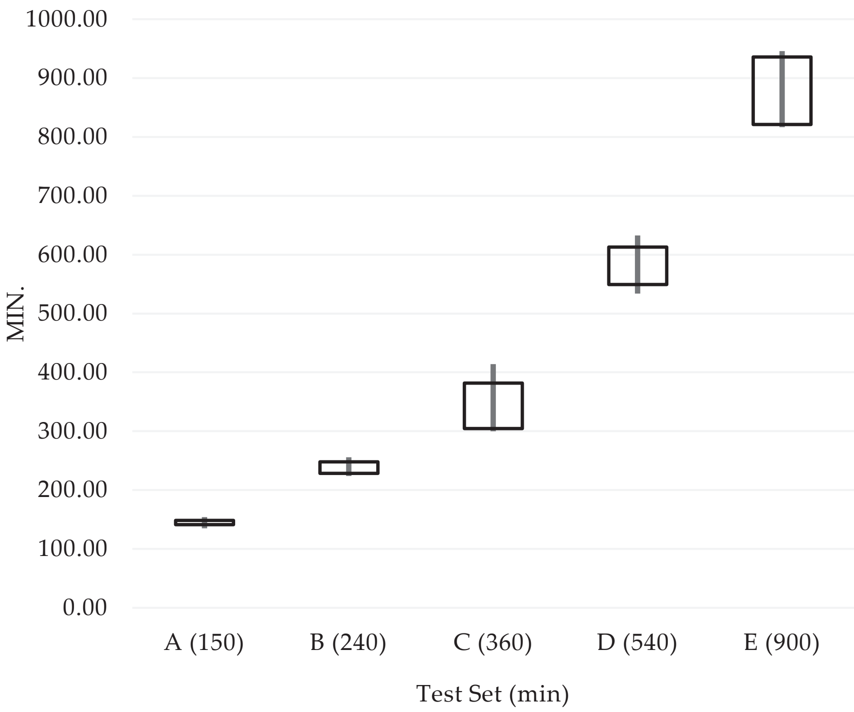

Figure 7. Schemes follow the same formatting.

5. Conclusions

The design, development, and experimentation of the monitoring and control system for saline solution in this time can be used as a prototype system. In addition, this system can work according to the specified purpose of reducing the workload of nurses or caregivers via web and mobile apps and can also automatically control and adjust the amount of saline solution to patients. Including equipment used for both load cells, servo motors and microcontroller boards are generally cheaper than commercially available devices with approximately 200 USD. It can also be monitored and commanded via the cloud, a capability that surpasses any commercially available device today. However, researchers and developers can also use the prototype system to improve the working algorithm to improve accuracy and optimize the saline solution to be more consistent and reduce errors that keep getting less.

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