International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I4P113
Volume 72 Issue 4, 131-136, April 2024

Original Article

Design and Implementation of IoT-based Low-Cost Smart Saline Micro Pump

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Received: 20 October 2023 Revised: 9 February 2024 Accepted: 1 April 2024 Published: 24 April 2024

Abstract - *The present healthcare scenario teaches quite a lot to humanity. The increasing ratio between patients and nursing staff deteriorates health care services. Simple saline can cause deadly patient situations and chaotic conditions for healthcare workers. A proper intravenous medication system can avoid reverse blood flow, blood clots, vein inflammation, extravasation, air embolism, and hypervolemia. This proposed research article is based on an Internet of Things-based low-cost smart saline micro pump for the healthcare system. The prime objective of this research article is to design an IoT-based micropump, and the micropump is placed between the saline bottle and the patient to control the flow precisely. The entire process is controlled by a mobile application to minimize the staff workload, time, and chaotic conditions. The controlled device has information like the working of the micropump, status parameters such as saline flow rate, saline injection time duration, the inflow of IV infusion to the patient, saline completion status, patient bed number, etc. Implementing the proposed system can be a stepping stone for new healthcare devices.*

Keywords - *IoT, Piezoelectric Micro Pump, IV infusion, Healthcare Device.*

1. Introduction

A saline micropump, a little mixture gadget, is intended for controlled oversight of saline or injectable drugs to the patient. This is intended to control the clear progression of the injectable liquid. Immature, inconspicuous, or elderly patients are countable when prescribed prolonged injectable drugs. In this scenario, a controlled micropump-based saline system comes into the picture [1]. Stream rate control is crucial for using microfluidic bead frameworks [2]. In the manual fluid medication conveyance system, the variance happens while working by an attendant or clinic staff [3]. The absence of medical staff during medication may cause hazards like the reversal of blood from the human body to an empty saline bottle through a connecting pipeline [4].

In this present work, the article is intended to implement a controlled micro pump device for the healthcare sector. Arduino Uno R3-based microcontroller with ESP82 GG Wi-Fi module is used in a physical model to give the user remote control. IoT is the systems administration of actual gadgets inserted with hardware gear, programming, sensors, actuators, and network, which guarantees the gathering and trading of information among the frameworks [5], [6]. Subsequently, saline micropump can be made brilliant by consolidating security frameworks and cloud servers to store data for all time in the distributed storage and patient's ward for additional examination. This might decrease hazards and save time separately. Besides, the security framework is intended to safeguard delicate patient data and secure caution framework to alarm the clinic staff during gadget failure. Nonetheless, the primary objective of this work is to zero in on IoT-based medical services application to innovative medication conveyance framework [7] utilizing a particular proposed clinical saline micropump gadget [8]–[11].

A piezoelectric material-based coreless micropump in the equipment section is proposed to control the prescription's stream paces. Our proposed gadget is planned with a shrewd saline micropump with diminished cost and improved effectiveness. IoT-based saline micropump having availability with cell network is likewise suggested. This gadget will again have security highlights to guarantee smooth activity at the patient's bedside. The strategy is simple, riskless, and efficient for specialists, patients, and nursing staff individually. This work is ordered in five areas, barring the reference portion. In the segment, we depict the starting focuses for which this came into the picture. II is the proposed model and 3D printing of this examination work, including the micropump plan, framework engineering, and their sensible investigation. Results, conversation, and end statements are made separately in areas III and IV.

2. Proposed Model

The prime goal of this exploration article is to plan an IoT-based, low-cost smart saline micro pump for medical utilization. The micro pump is set in the middle of the saline container, and the patient controls the stream precisely. Figure 1 portrays the proposed framework with appropriate documentation of each part. The whole interaction is constrained by versatile applications to limit the staff's responsibility and time, and the converse stream of blood, including intravenous blockage needle, can be tried not to utilize this framework.

2.1. Modelling using Comsol Multiphysics

COMSOL Multiphysics 6.1 version is an adaptable Software for a multi-area investigation to construct complex models definitively. For many years, the Piezo-Micro pumps have acquired broad consideration due to the expected applications in biomedical gadgets, organic and synthetic exploration, miniature gadgets cooling, and space investigation[12]–[15].

The micropump comprises an annular piezoelectric actuator on top of the liquid area, which is associated with an elastic layer. Figure 2 (a) portrays the micropump gathering, including the inlet, barrel-shaped ring organized FA@ZnO composite-based actuator, adaptable liquid space, and the outlet source start to finish separately. The Mesh utilized for a model calculation assumes an instrumental part in how the model is settled, as it decides factors. In the sequence type of the Mesh section, User controlled mesh type has been chosen. In Element size, calibrate for General physics is picked out. The type for general physics is extra fine. The selected parameters are element size (max 1.05, min 0.045), maximum element growth rate (1.35), curvature factor (0.3), and resolution of narrow regions (0.85). Meshing plays a vital role in the calculation of size, thickness, and the number of components of every structural assembly. The actual controlled network structure is utilized to plan this structure get-together, as shown in Figure 2 (b). The radius and tallness of the inlet and outlet are 1 mm and 5 mm, respectively.

The saline supply is three layered blocks having width, tallness and length of 30 mm, 5 mm and 30 mm, respectively. Piezoelectric material and film are planned as an empty chamber. The inward and outward radii of the disk actuator are 8 mm and 12 mm, respectively. The membrane has a height of 1 mm and radii of 12 mm. The most important part is that the supply voltage is 12 V, and the piston actuation frequency is 50 Hz.

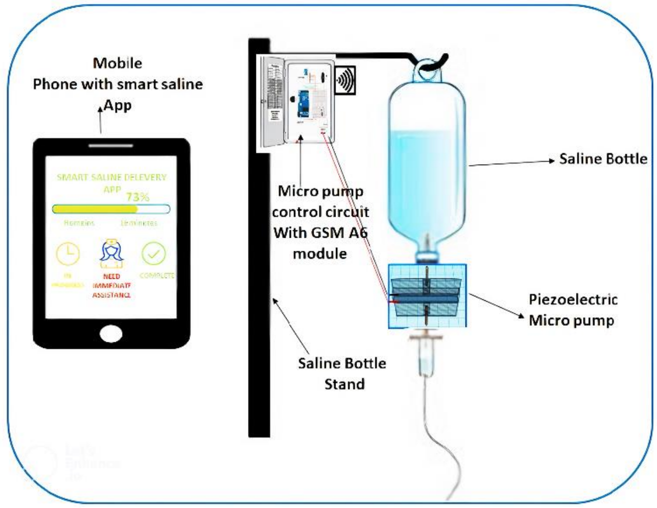
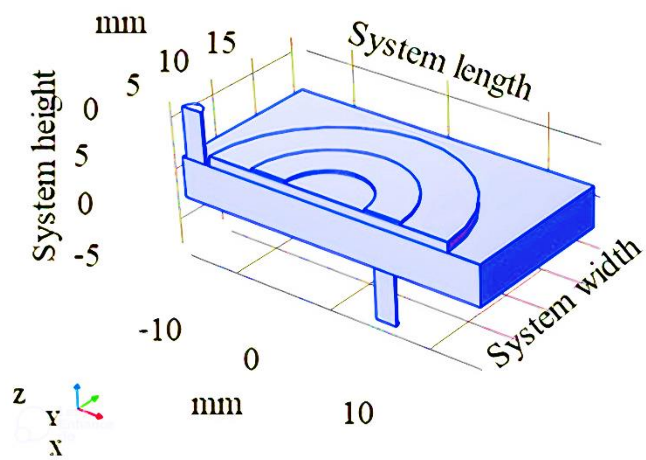
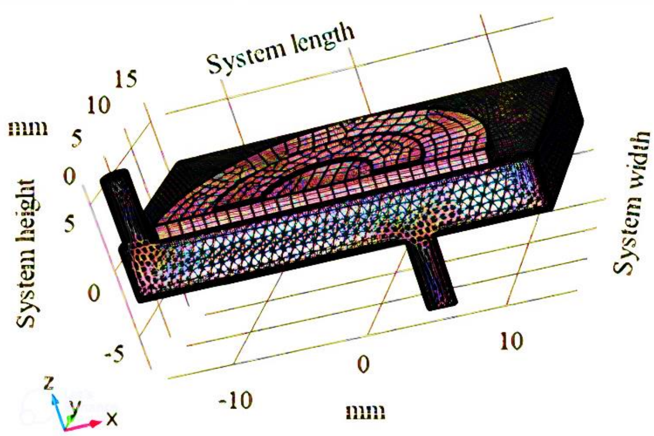


Fig. 1 Proposed IoT-Based Saline Micropump System for Healthcare Sector



(a)



(b)
Fig. 2 COMSOL Micropump
(a) 3D model (b) Meshing, respectively

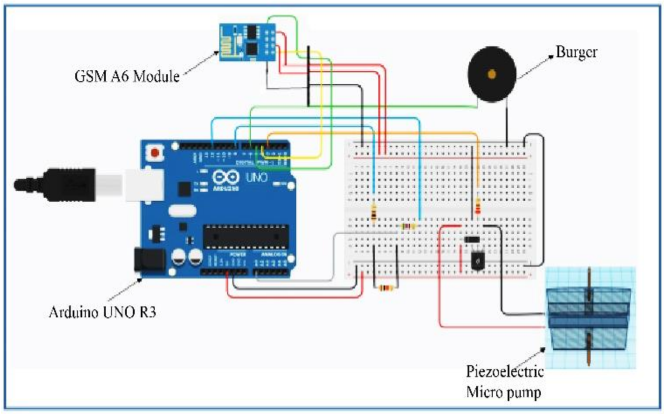


Fig. 3 Circuit diagram of the proposed IoT-Based Saline Micropump System

2.2. Proposed Microcontroller Model Assembly and System Architecture

Figure 3 shows the microcontroller and equipment model gathering. The equipment configuration comprises of following: FA@ZnO composite-based micropump, microcontroller (Arduino UNO R3), Wi-Fi module (GSM A6), buzzer, input switch and association wires. The heaviness of the gadget is roughly 150 g, and the aspect is 25 cm ×15cm. The creators propose the GSM A6 module of the ESP8266 module family to help better proficiency and execution. Other correspondence standards like Wi-Fi, ZigBee, Bluetooth, etc don't impact this. This is a small GSM/GPRS center improvement board in view of the GPRS A6 module. Along these lines, it upholds double band GSM/GPRS organization, accessible for GPRS and SMS message information distant transmission. GSM modem is the correspondence standard for remote detecting and estimating of a few remote checking stations including the focal stations. The SIM (Subscribers Identity Module) is joined to the GSM module for correspondence through the server. Cell phone tracks their present situation by their closest pinnacle of radio wire with the assistance of the GSM framework, and it offers genuine power and practical help. GSM A6 module highlights are conservative size and low current utilization. With the power-saving method, this utilization is essentially as low as 3mA in rest mode. The functioning recurrence of this module is in a quad-band network with 850 or 900 or 1800 or 1900 MHz. The versatile application empowers the controlling part by conveying and getting a message for the activity of the saline micropump unequivocally.

Buzzer module is additionally executed for additional insurance for the functioning staff, thus with regards to the patient orderly. If blockage or saline over should arise, the ringer framework initiates by conveying a stop message to the microcontroller. After the enactment of the stop signal, the microcontroller suspends the information potential to the micropump. The Internet of Things (IoT) contains many implanted gadgets and trades enormous measures of information from one side of the planet to the other. Combination with IoT makes a gadget more astute to decrease chance, time, and attention.

Figure 4 portrays the proposed framework engineering, which emphasizes working on the micropump, status of boundaries like saline stream rate, saline infuses time term, an inflow of IV mixture to the patient, saline consummation status, and so on. The main attention of the model is to select a solid material for the soft copy designing of a micropump, which is done with the help of 3D printing. It has a base that has a periodic array structure for liquid storage (shown in Figure 8a and discussed therein) and having an outflow facility. The upper layer is a completely flat solid layer having an inflow facility.

To control the flow rate, a piezoelectric disc (FA@ZnO composite) is used which will vibrate the liquid in the storage chamber by an applied potential. Now, a cut will be made in the upper layer equal to the size of the piezoelectric disc to fix it.

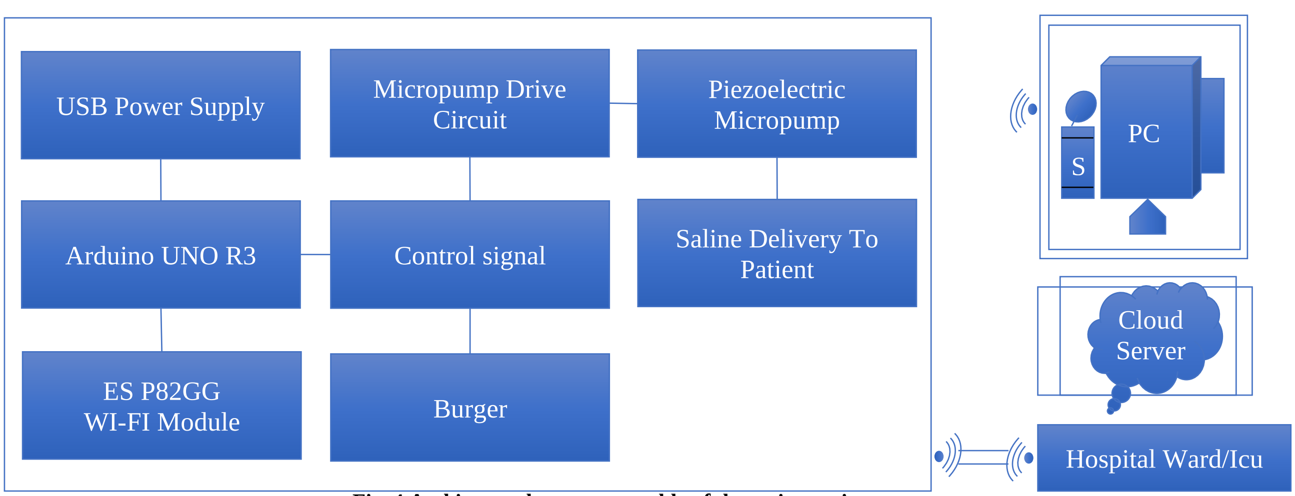


Fig. 4 Architectural system assembly of the entire project

2.3. FA@ZnO Piezoelectric Disc

To prepare a new composite material by using thermal power plant industry waste (fly ash) and zinc oxide (ZnO) as raw materials. The said with chemical additives were grinded into fine particles and classified according to size to prepare a non-conventional power source. The details manufacturing process of FA@ZnO composite through the chemical route followed by heat treatment at 1300ºC for 5 hours is described elsewhere [Materials]. The prepared disc has a thickness and a diameter of 0.7 mm and 27mm, respectively. The transducer changes the control voltage into stress or pressure due to the piezoelectric effect. [13]. The synthesized composite is semiconducting in nature, having band gaps varying from 2.51 eV to 3.09 eV depending on the fly ash content in ZnO. The piezoelectric constant (d33) of the prepared bulk sample is 3.3 pC/N. The measurement of the piezoelectric constant is carried out by SINOCERA YE2730 d33 meter. This new material exhibits excellent piezoelectric properties, i.e. generates mechanical stress when electrical energy is applied. The biasing voltage is fixed at the input side, whereas the frequency is varied from 1Hz to 12MHz to analyze the voltage output due to a change in frequency. Figure 5 depicts the frequency-dependent output voltage. To study the effect of the driving voltage on the pump flow rate, the pump was actuated with a fixed frequency of 40 kHz, with varying actuation voltage, as shown in Figure 5. As shown in Figure 6, the pump rate rises with increasing actuation voltage. The fluid was pumped in both directions due to a small difference between the pump flow rate obtained with all the driving voltages measured from the inlet to the outlet and from the outlet to the inlet. Actuation at 40 kHz provides sufficient time (0.6 s) to achieve the maximum displacement of the membrane. Even though, there is a linear relationship of stroke volume with actuation voltage. Based upon the displacement of the membrane for an applied voltage of 12V, which is calculated as $V_0 = E_0 \times t_0 \times n$, Where E0 is the Electric field strength (0.12V/µm), t0 is the piezoelectric layer thickness (0.1mm) and n is the piezoelectric layer thickness (01).

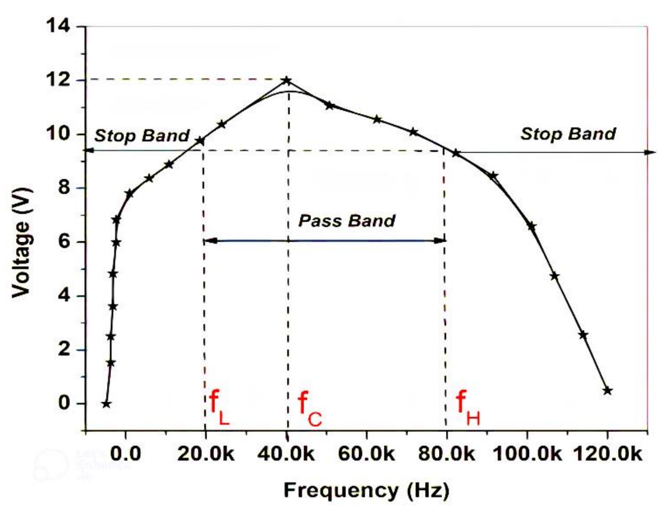


Fig. 5 Frequency variation studies on voltage output

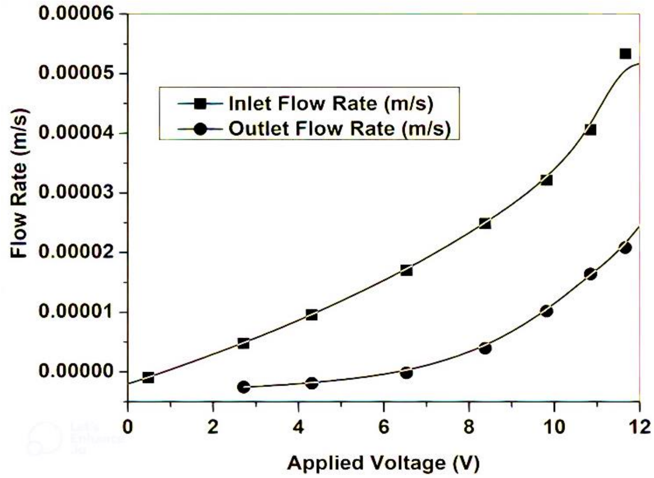


Fig. 6 Pump flow rate against applied voltage of the micro pump when actuated at 40 KHz

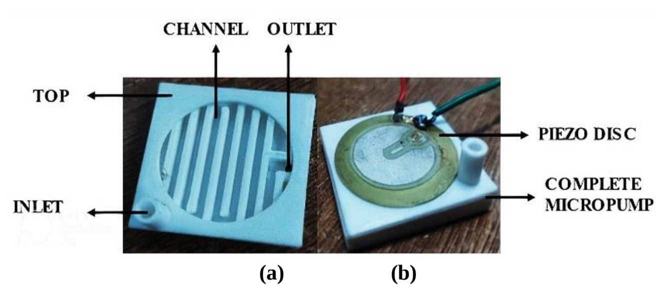


Fig. 7 Three-Dimensional Printed Model using Ender3 3D printer (a) without and (b) with Piezoelectric Actuator

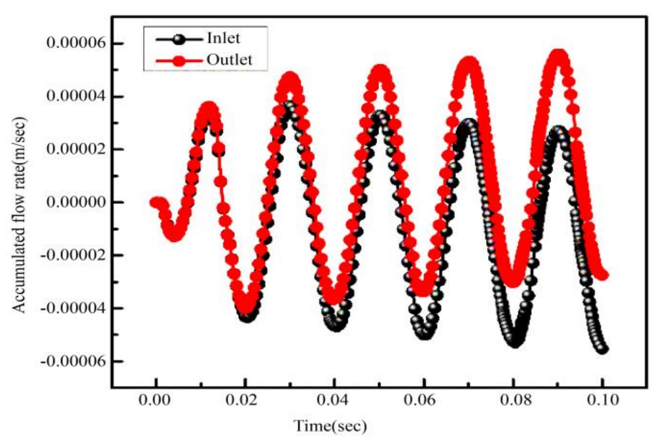


Fig. 8 Flow rates (in and outflow) of saline from bottle to patient through reservoir concerning time in sec and proof of volume conservation

2.4. Proposed Model Using 3D Printing

Figure 7 is the proposed model for soft copy designing of a micro pump. It has been created with the help of the WOL3D Ender 3D printer. The liquid comes from the saline through the inlet and is stored in the storage chamber. Applying voltage, the actuator creates pressure so that the liquid in the chamber starts to vibrate and comes out through the outlet to the pipe connected to the veins of the patient.

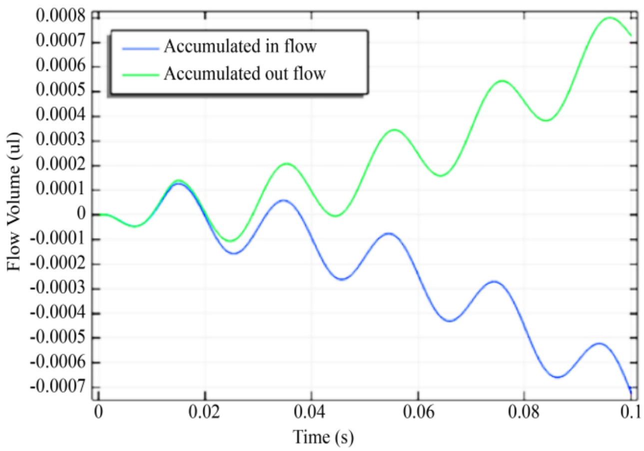


Fig. 9 Net fluid flow through the inlet and outlet over time computation using a global ODE

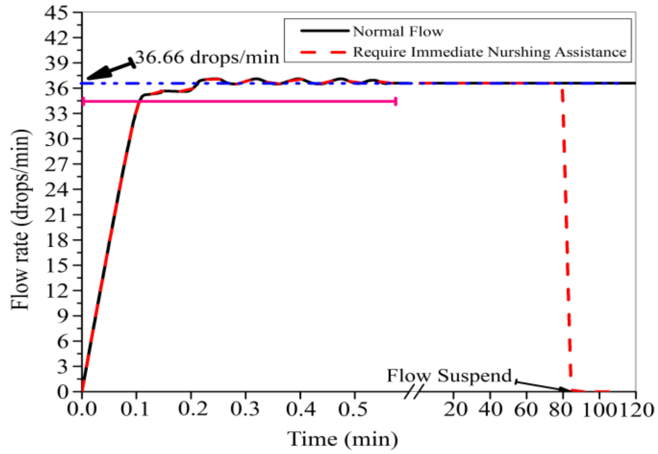


Fig. 10. 10gtt drip of 1L normal saline flow and accidental condition for medical assistance

The applied voltage is 12 V with a frequency of 40 kHz. As a result, the maximum velocity is -1.72 m/s, and the minimum velocity is -4.19 m/s. The maximum pressure and minimum pressure are 0.03×10^{-4} and 3.96×10^{-4} Pa, respectively.

3. Results and Discussion

After the initiation of the micro pump model, the liquid flow rate at the inlet and outlet has been observed with volume conservation. Thus, conforms to Figure 8. During the first 3/4th of the actuation period, the drive voltage is ramped up. Afterwards, a consistent time-periodic flow is established. The uprooted liquid volume from the membrane is based on the piezoelectric stroke, which is equivalent to the distinction between the inlet and outlet stream.

Subsequently, it affirms the volume preservation of the framework. The time-coordinated streams into the inlet and outlet of the power source are determined utilizing a global ODE and are displayed in Figure 9. The net course through the micropump in 0.05 s is 1.8 µL, relating to 36 µL/sec or 2.16 ml/min. A drop in the flow activates the buzzer system. This indicates medical assistance or attention. The micropump and microcontroller system combination enables a high-precision device for the healthcare sector. Intravenous liquid flow is expressed as ml/h. The size of the intravenous tube directs the size of the drips. Intravenous tubes are also aligned in gtt/ml, and the alignment is expected to compute the stream rate. The standard micro drips are available in 10gtt, 15 gtt, and 20 gtt.

1 ml drip is prescribed as 60 gtt. For 10 gtt drip of 1 liter normal saline is depicted in Figure 10 with an indication for accidental nursing assistance. The calculated and simulated flow rates are 36.66 drops/min and 38.88 drops/min, respectively. This shows the semblance of the proposed model with mathematical analysis by giving error values of 5.14%. The drop-in flow rate to zero activates the alarm system for medical assistance near the patient and central nursing chamber, simultaneously. By activating the alarm system, the microcontroller suspends the potential flow to the micropump without missing.

4. Conclusion

The recent crisis seeks many researchers' attention to work on different healthcare devices. The ratio of nursing staff and patients is increasing rapidly nowadays. The tricky part is attending to all the patients regularly. In the case of saline systems, blockage due to reverse blood flow is expected. To inform a healthcare staff from the patient's end is time-consuming and sometimes leads to chaotic conditions between staff and patient attendees.

In most cases, the patient is unaware of the blockage, flow, and empty bottle. To avoid these problems, this proposes an IoT-based smart saline micro pump. This healthcare device can be monitored not only from the bedside but also from the master nursing cabin. In the future, this will enable the healthcare system to save time by avoiding conventional saline systems.

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