Fabrication of Smart Syringe Infusion Device: A Solution for Healthcare Industry

Zunair Tariq*[1], Zuha Anjum[1], Laiba Memon[2], Ghulam Rasool[1], Rajnesh Kumar[1]
[1]Department of Electronic Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan.
[2]Department of Electrical Engineering, Quaid-e-Awam University Engineering, Sciences and Technology, Pakistan.
***Correspondence:** zunairtariq94@gmail.com

Citation | Tariq. Z, Anjum. Z, Memon. L, Rasool. G, Kumar. R, "Fabrication of Smart Syringe Infusion Device: A Solution for Healthcare Industry", IJIST, Vol. 6 Issue. 4 pp 1736-1750, Oct 2024
Received | Sep 26, 2024 **Revised |** Oct 22, 2024 **Accepted |** Oct 23, 2024 **Published |** Oct 24, 2024.

Accurate medication delivery is essential in intensive care units, where precision in drug delivery is crucial. In order to address the need for increased accuracy and efficiency in workflow, this study proposes a semi-automated smart syringe infusion device with a unique refill mode integrated with Electronic Health Records (EHR). The device was tested in both manual and virtual control modes, with a stepper motor-driven syringe used for precise fluid infusion. The refill mode was evaluated based on its ability to automate the refilling procedure. The results showed precise dosage control in a variety of scenarios, with minimal discrepancies between the desired and actual amounts. The refill mode effectively automated the withdrawal and refilling processes, lowering human error and increasing efficiency. Additionally, the device's effortless interface with EHR systems streamlined the documentation process, enabling real-time data logging and enhancing workflow. This device offers a dependable, cost-effective solution for improving medication delivery, making it a valuable tool in healthcare, particularly in resource-limited environments.

Keywords: Precision Medication Delivery, Smart Syringe Infusion Device, Wireless Remote-Control System, Electronic Health Records (EHR) Integration, Patient Safety.

Introduction:

The evolution of smart syringe infusion devices in healthcare has attracted significant attention due to the demand for precise drug delivery systems and improved accessibility. A comprehensive literature review reveals several research studies on the development, challenges, and innovations in automated syringe infusion devices. A syringe infusion pump designed for telemedicine and healthcare was developed, featuring a DC motor, GSM module, and Arduino programming for precise control. However, due to some mechanical challenges, a smarter solution for hospitals was proposed by integrating it with IoT [1]. Another study aimed to monitor patients using a syringe pump equipped with an MG995 servo motor. However, faced signal delays, leading to recommendations for upgrading the microcontroller and replacing the servo motor with a stepper motor for better accuracy [2]. Further research employed a syringe pump control controlled by Arduino. For enhanced functionality and to ensure precise flow, a worm thread mechanism and spring were utilized respectively. While, suggesting the incorporation of a numerical keypad, push button, and database connectivity [3][4].

Furthermore, another design focused on designing low-cost, reusable, non-electric syringe pumps suitable for low-income settings, utilizing pneumatically pressurized hydraulic drive pistons for constant volumetric flow [5][6][7][8]. The importance of ensuring patient safety through precise drug flow control and real-time alarm notifications on smartphones was emphasized, although challenges in areas with poor network connectivity could potentially impact timely intervention for patient safety [9]. In another study, a portable infusion pump was proposed featuring bubble detection, improved fluid delivery precision, and increased flexibility for medical settings was proposed [10]. An IoT-based semi-automated syringe pump was introduced, featuring real-time monitoring and control of direction flow, flow rate, syringe size, and dosage. This system is designed for syringes of 15ml capacity, achieving fluid delivery in various time frames [11]. Research on IoT-based syringe pump applications also focused on incorporating sound sensors for detecting line occlusion and end alarm [12]. Another study targeted the design of a syringe pump for bedside patients comprising of Node MCU V3 Wi-Fi module with a force circuitry to assemble a DC motor-driven syringe pump. The armature of the DC motor utilizes the pulse width modulation to adjust the voltage for diverse flow rates, with a deviation of less than 5% from the favored float rate [13].

Furthermore, investigation into the limitations of infusion pumps focused on developing Smart IPs utilizing intelligent infusion management systems to enhance the safety of intravenous administration [14]. A cutting-edge syringe infusion pump was introduced to address the limitations of current models, ensuring accurate and reliable delivery of medications and fluids in healthcare settings. Thus, the syringe is designed for a 20 ml capacity and was able to deliver fluid at specific rates [15]. Another syringe pump was developed to monitor the body temperature of the patient during injection and detect the contrast material bubbles. The system consisted of steel rods to push the syringe piston at a set speed, with the device calibrated based on the fixed inner diameter of the syringe and the required amount of liquid to be injected [16][17].

Novelty Statement:

This study highlights major progress in smart syringe infusion devices and aims at resolving the issues of existing systems. Developing semi-automation along with remote control for adaptable drug dispensing combined with a groundbreaking refill syringe mode positions this solution as a better alternative to traditional systems. By integrating EHR systems the device effectively delivers medication while optimizing medical workflows.

Objectives:

The primary objectives of this research are as follows:

- To design and create a semi-automated syringe infusion pump with a manual and remote control, enhancing flexibility in medical applications.

- To develop a patented refill syringe mode for autonomously withdrawing and refilling to increase the precision and tempo of fluid delivery.
- To integrate the syringe pump system with the electronic health records (EHR) for enhanced documentation, safety of patients, and management of healthcare.
- To fabricate a low-cost, dependable device for both rural areas and urban areas healthcare configuration thereby providing for accessibility and resource constraints.

Sustainable Development Goals (SDGs):

- **SDG 3:** Good Health and Well-being,
- **SDG 9:** Industry, Innovation, and Infrastructure
- **SDG 10:** Reduced Inequalities

The emphasis on neglected regions allows this project to contrast healthcare access inequities. Built for use in constrained resources, this infusion system serves to unite the healthcare services of cities and villages. With its affordable and expandable features, the device encourages fair healthcare access for marginalized groups.

Material and Methods:

System Methodology:

The proposed smart syringe infusion device comprised four key units:

- **Mechanical/Electrical Unit:** This element formed the central structure of the device and contained the necessary elements for delivering fluids. The syringe plunger was advanced by a stepper motor and its associated controller. This device featured a lead screw that converted rotation into precise linear displacement for advancing the plunger.
- **Stepper Motor, its Controller, and Indication:** A stepper motor and controller were integrated along with a red and green LED for visual confirmation. During dispensing the green LED lit up to indicate active status, while the red LED illuminated at rest or not in use.
- **Microcontroller for Monitoring and Controlling All the Units:** A microcontroller manages the whole system's operations at the heart of the device. The microcontroller-controlled processes interpreted data and implemented a motor control algorithm to meet the intended fluid flow. A quick toggle was achieved physically through a keypad or via a convenient mobile app.
- **LCD Display for Getting the Information in Visual Form:** The LCD panel displayed vital data clearly so that healthcare workers could observe device functions and details.

The system employed a microcontroller to manage the stepper motor's speed via motor driver circuitry, ensuring accurate fluid delivery into the patient's body. The motor, coupled with a lead screw, converted rotational motion into linear motion to precisely push the syringe plunger. User inputs, including flow direction, rate, syringe specifications, and dosage, were processed to calculate the plunger's push rate. Real-time feedback on pressure and flow rate was transmitted to the hospital's electronic health record or a mobile application via Wi-Fi (Figure 1).

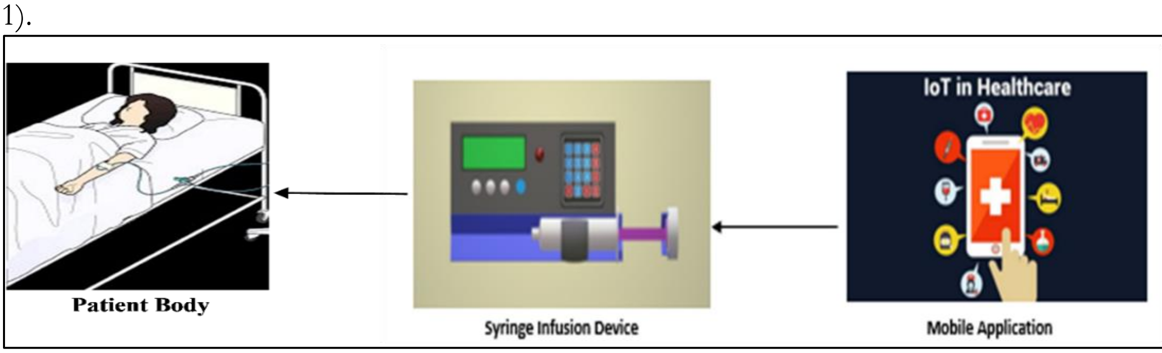


Figure 1. Illustrated the working of the Smart Infusion System

System Block Diagram:

The system block diagram (Figure 2) illustrated the integration of essential components for seamless operation,

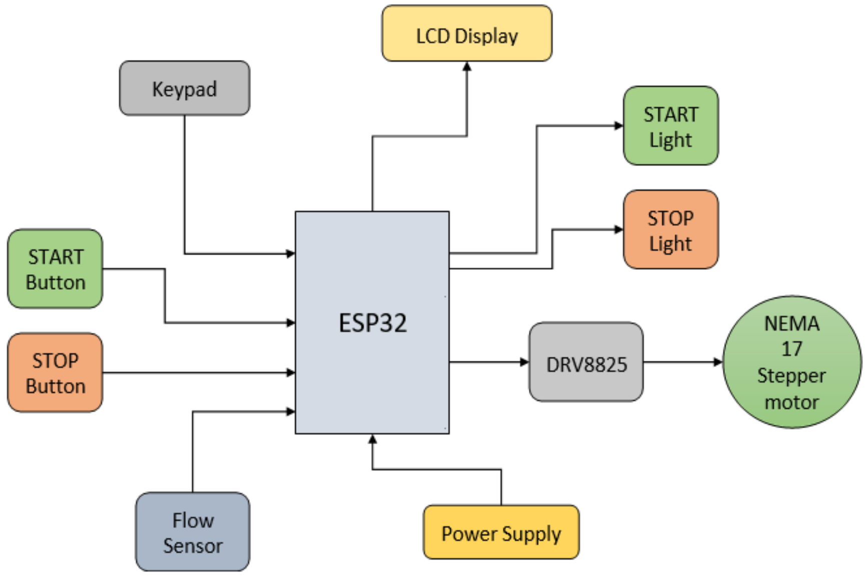


Figure 2. Infusion System Process

3D Parts Selection:

Critical 3D parts (Figures 3-6), including the motor part, end part, and middle part, were meticulously chosen and fabricated using 3D printing technology. These components ensured precise alignment and reliable performance during medical procedures.

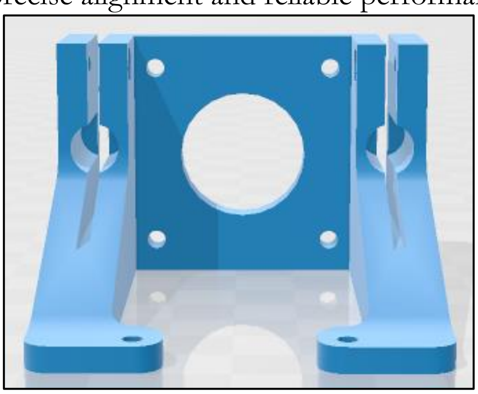


Figure 3. 3D Model of Motor Part

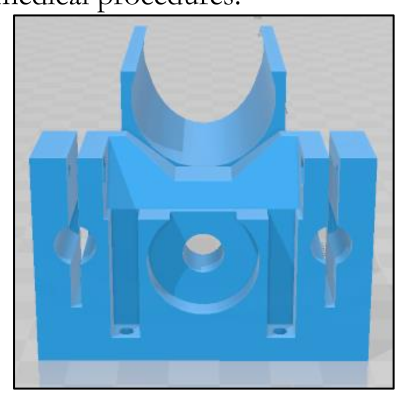


Figure 4. 3D Model of End Part

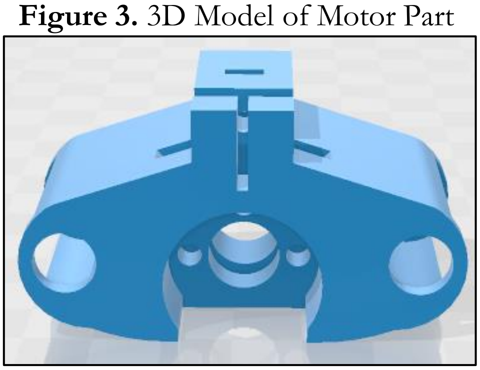


Figure 5. 3D Model of Middle Part

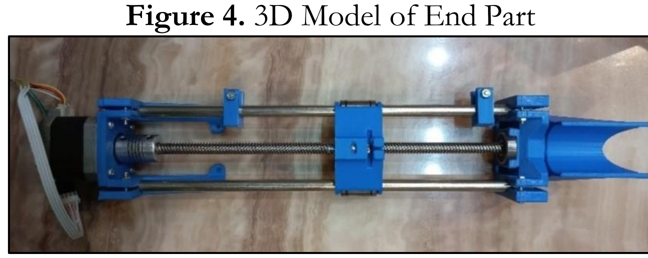


Figure 6. Assembled Structure

Integration with Blynk App:

The mobile application (Figure 7) leveraged the Blynk app for connectivity, enabling remote control and monitoring of the smart syringe infusion device. Blynk facilitated secure communication between the mobile app and the device, ensuring patient data confidentiality.

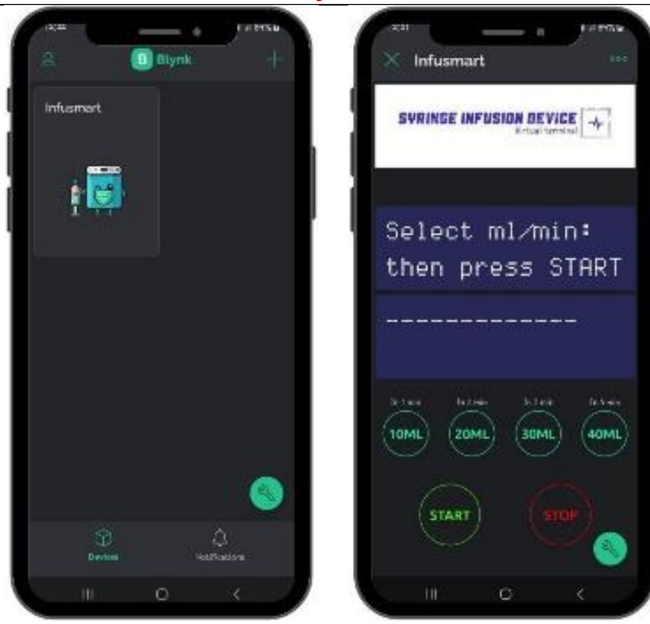


Figure 7. Blynk App User Interface

Web Form for Data Entry and Google Sheet Storage:

The system combined effortlessly with electronic health records (EHR) systems by using an HTML web form for collecting information. The records were automatically sent to a Google Sheet guaranteeing effective tracking of infusion processes (Figure 8).

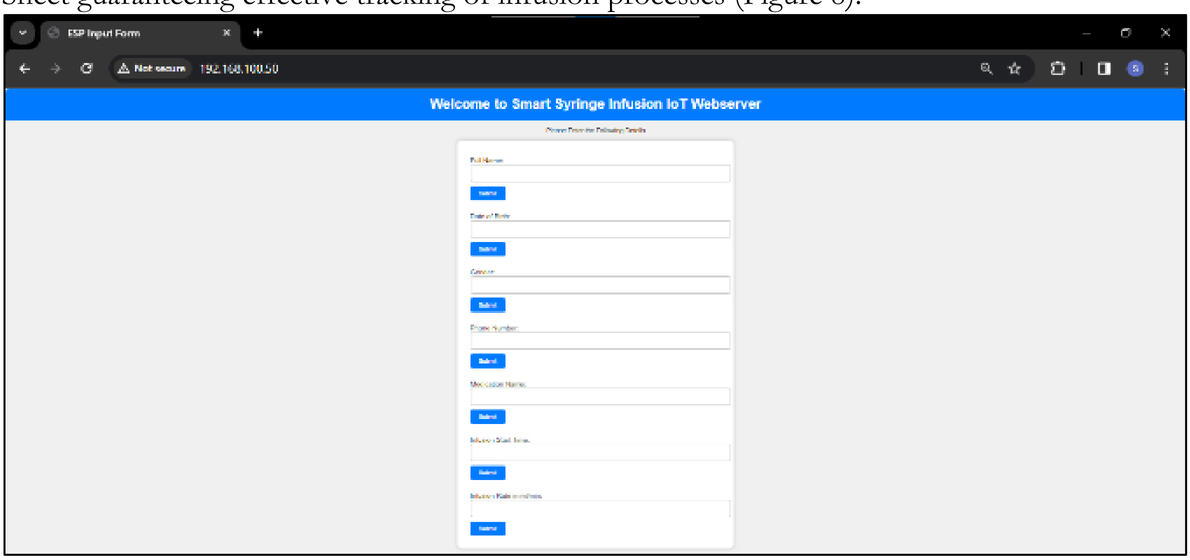


Figure 8. Web Form to Fill Patient Details

Flow Chart:

The diagram (Figure 9) depicted the targeted system for handling fluid administration and tracking with accuracy,

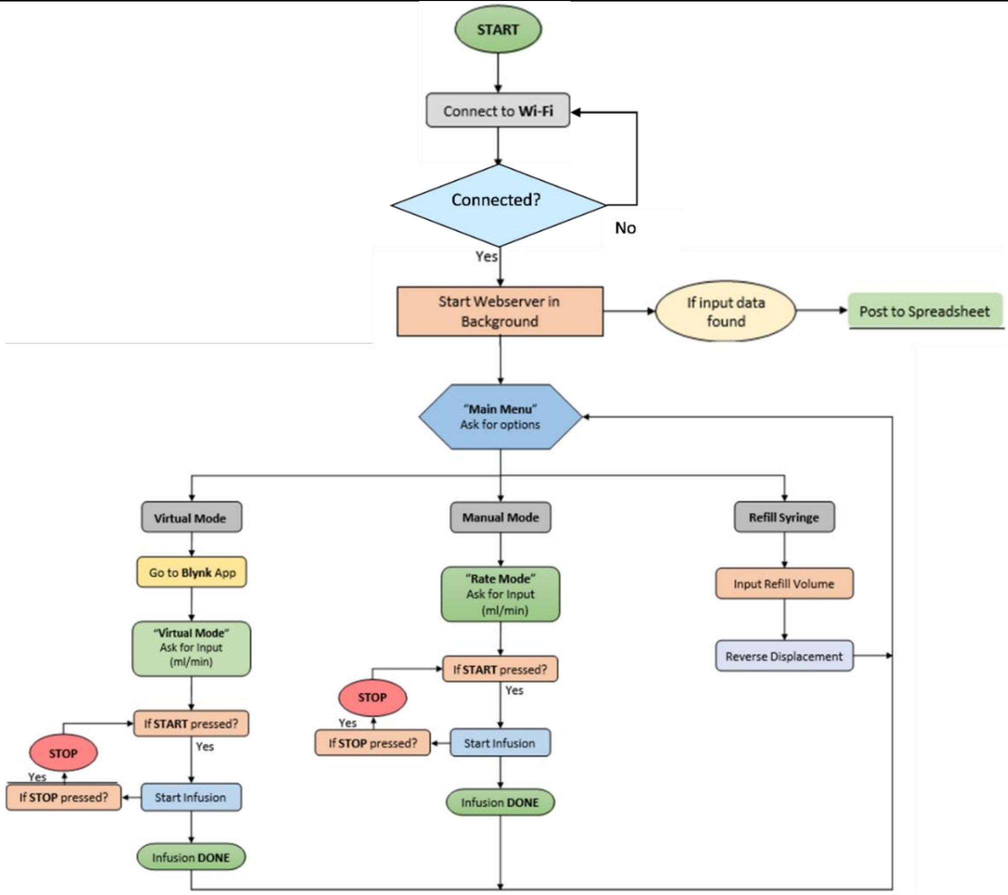


Figure 9. Flow chart of the proposed algorithm.

Project Schematic Diagram:

The circuit diagram (Figure 10-11) illustrated the electrical links and component parts employed in the smart syringe infusion device,

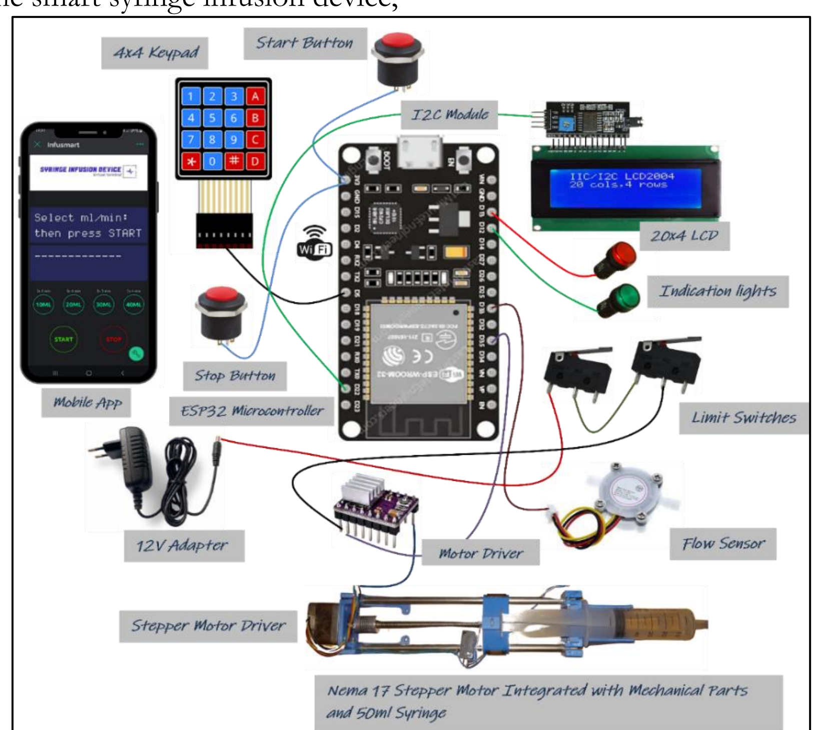


Figure 10. Schematic Diagram for smart syringe infusion device

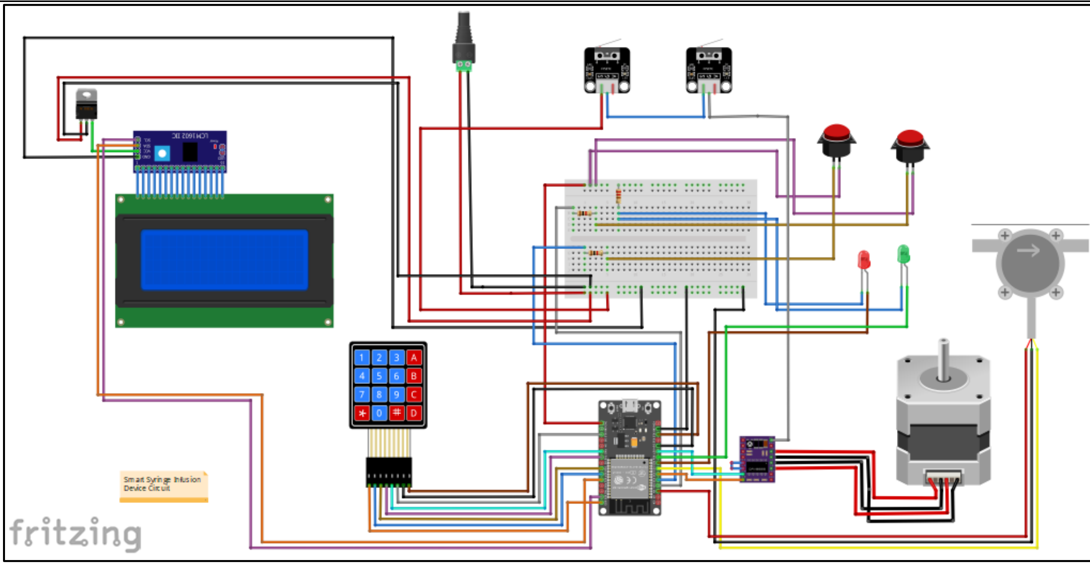


Figure 11. System Circuit Diagram on Fritzing

Integration and Design of Outer Structure:

The outer layer of the device was made from acrylic sheeting that provided protection and attractiveness while combining necessary elements for ease of use,

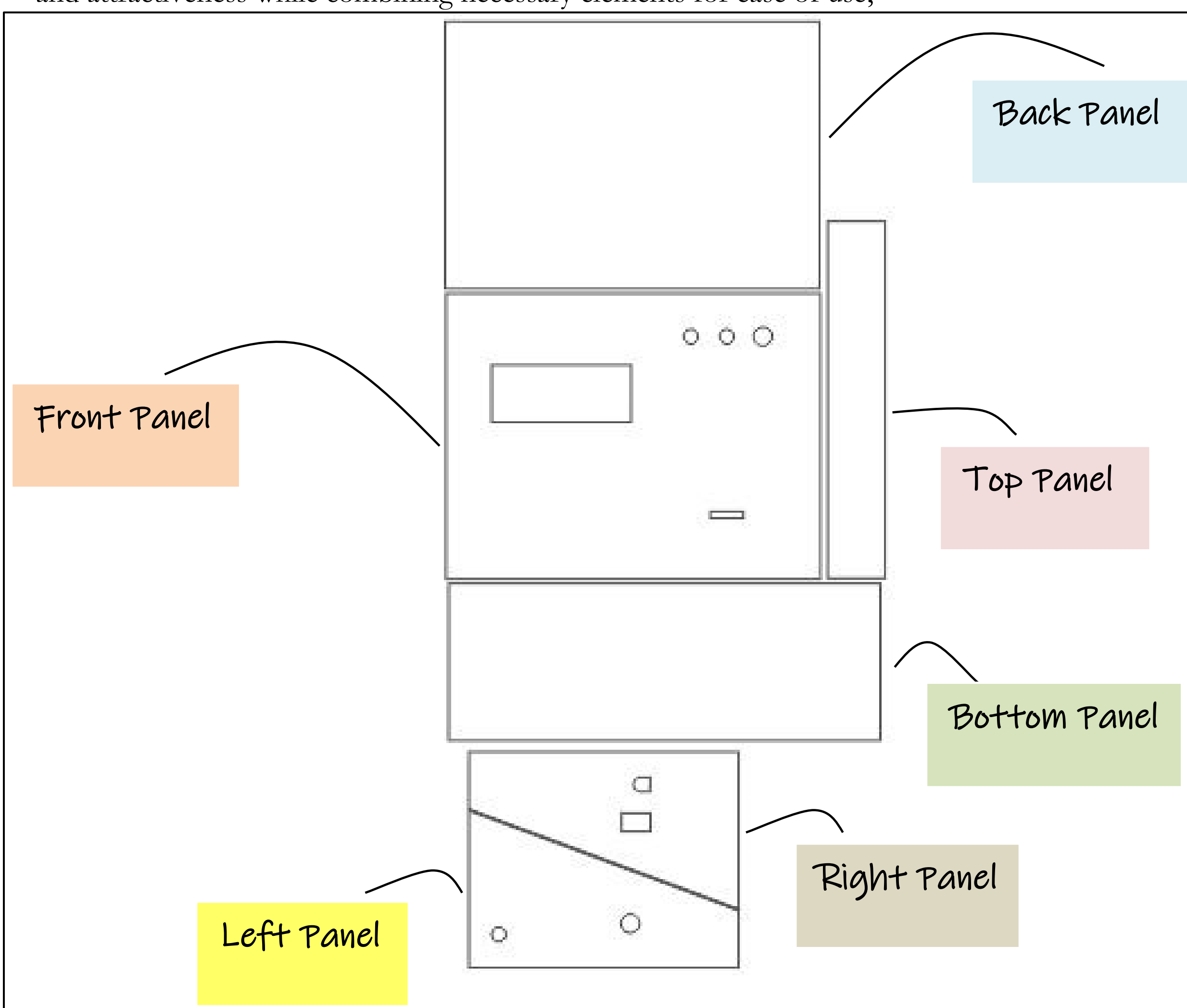


Figure 12. Design of Chassis

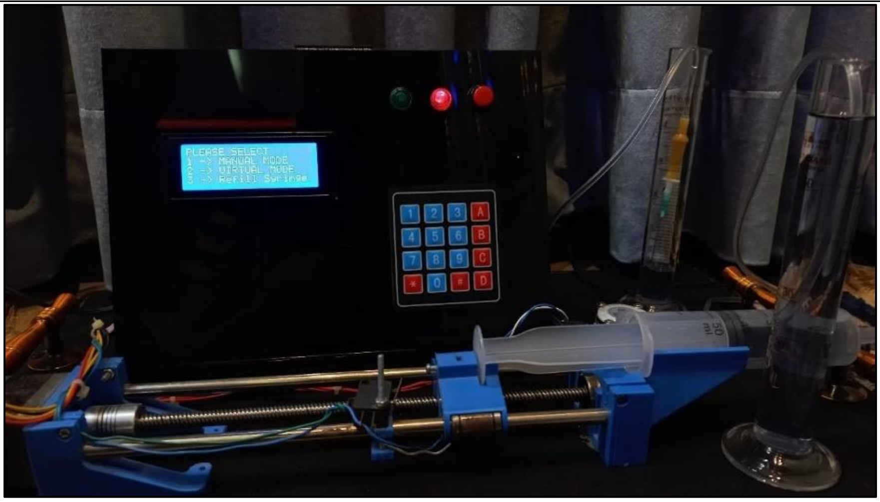


Figure 13. Integration of Chassis with components

Results and Discussion:

The experiments evaluated the device's performance in various operating modes: manual, virtual control, and refill syringe options. The integration of electronic health records (EHR) functionality was examined. The device was tested to assess its performance in real healthcare scenarios to each mode for accuracy, efficiency, and usability.

Dosage Control in Manual Mode:

The smart syringe infusion device was tested in manual mode for its ability to accurately dispense fluids across a wide range of dosage rates. Dosage rates from 2 to 40 mL per minute were tested over durations ranging from 1 to 10 minutes. The results, as reported in Table 1, reveal that the instrument was extremely accurate across all settings.

The dispensing rates shown in Table 1 have minimum departure from the predicted values, which is significant in clinical situations where precise dose management is required. For example, at a dose rate of 10 mL/min, the device provided fluid at 0.17 mL/sec over 1 minute and 0.03 mL/sec over 5 minutes, demonstrating the system's capacity to appropriately scale performance throughout time intervals. The number of delays in response was minor, indicating real-time accuracy.

Figure 14. Infusion of 2mL in 3 minutes

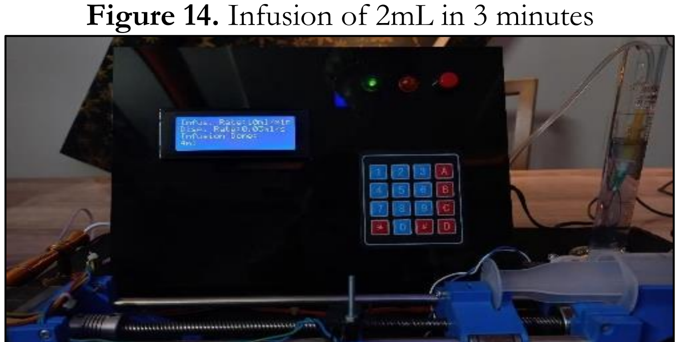


Figure 15. Infusion of 10mL in 5 minutes

Table 1. Testing of the device with varying dosage rates and time durations in manual mode

Dosage (mL/min)	Dispensing Rate (mL/sec)					Time Delay (sec)
	1 min	2 min	3 min	5 min	10 min	
2	0.03	0.02	0.01	0.005	0.003	No delay
5	0.08	0.04	0.03	0.02	0.008	1
10	0.17	0.08	0.05	0.03	0.02	2
20	0.33	0.17	0.11	0.07	0.03	5
30	0.50	0.25	0.17	0.10	0.05	8
35	0.58	0.29	0.19	0.11	0.05	9
40	0.67	0.33	0.22	0.13	0.06	10

As seen in Table 1, the device yielded high accuracy while operating in manual mode, with minimal variances between the target dosage rates and the actual delivered quantities. Over extended periods, it remained consistent, ensuring that patients received accurate medication without interruptions or errors.

Dosage Control in Virtual Mode:

In virtual mode, the device was tested with a mobile application that allowed remote control of the dose parameters. Table 2 shows that dosage rates ranging from 10 mL to 40 mL per minute were provided without delay in reaction time. The testing proved the device's reliability in distant healthcare settings.

Figure 16. Infusion of 10mL in 1 minute

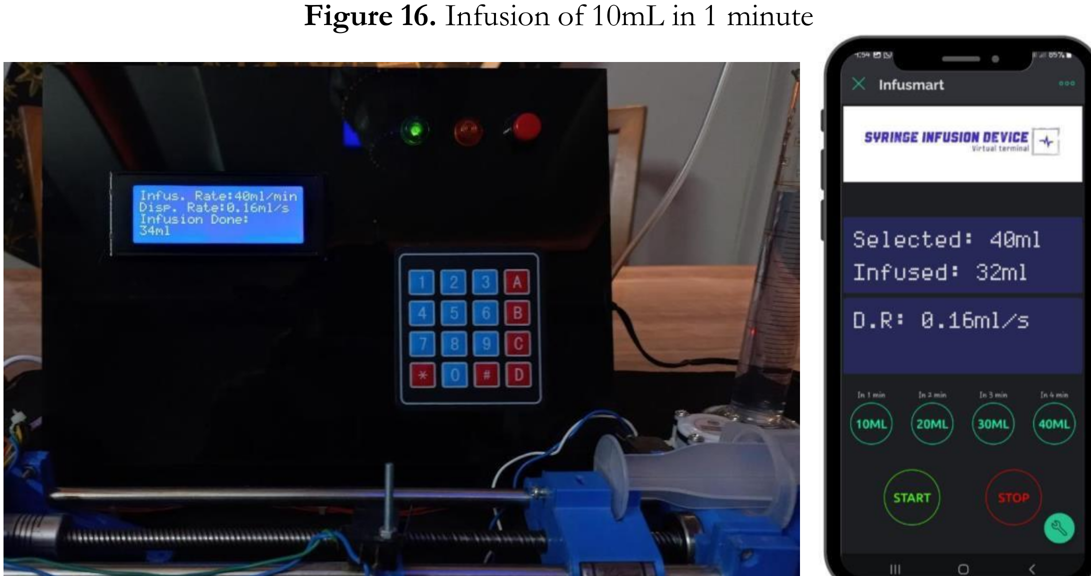


Figure 17. Infusion of 40mL in 4 minutes

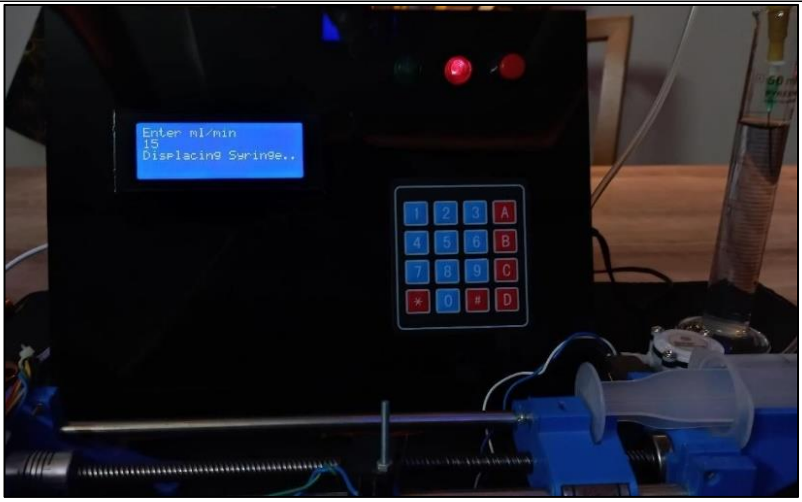


Figure 18. Refilling of 15ml

Table 2. Testing of the device with different dosing rates in virtual mode

Dosage (mL/min)	Dispensing Rate (mL/sec)	Time Delay (sec)
10	0.16	No delay
20	0.16	No delay
30	0.16	No delay
40	0.16	No delay

Table 2 shows that the device dispensed at a consistent rate of 0.16 mL/sec across various dosages, with no delay. This exact control makes the device very helpful in telemedicine, as healthcare providers may change dose rates remotely, making quick treatment modifications without having to be physically present.

Refill Syringe Mode:

The refill syringe mode was assessed for its ability to extract and replenish accurate amounts. The results indicated that the device successfully reversed the motor to pull the needed volume of liquid, refilling the syringe without mistake.

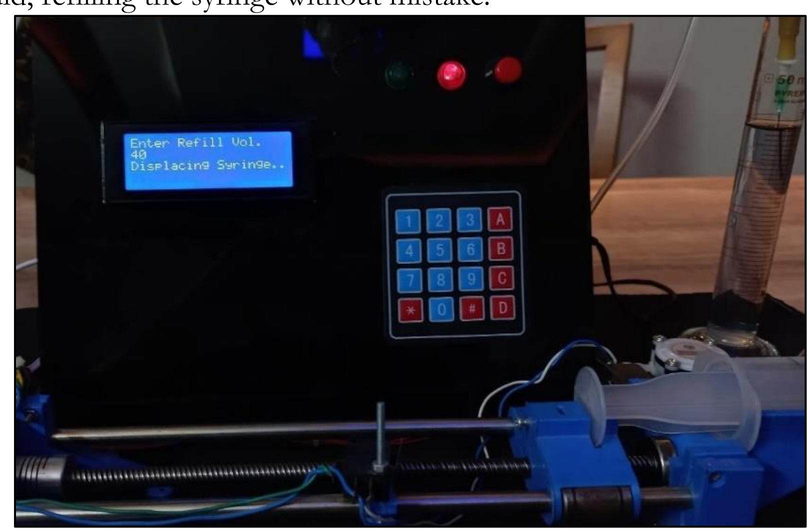


Figure 19. Refilling of 40ml

EHR Form Records:

The EHR system's interface with the device made it straightforward to record patient information, dose amounts, and infusion times. These were then immediately entered into Google Spreadsheets for convenient access. By using a static IP for the web form, infusion data could be entered quickly and securely, increasing accuracy and speed.

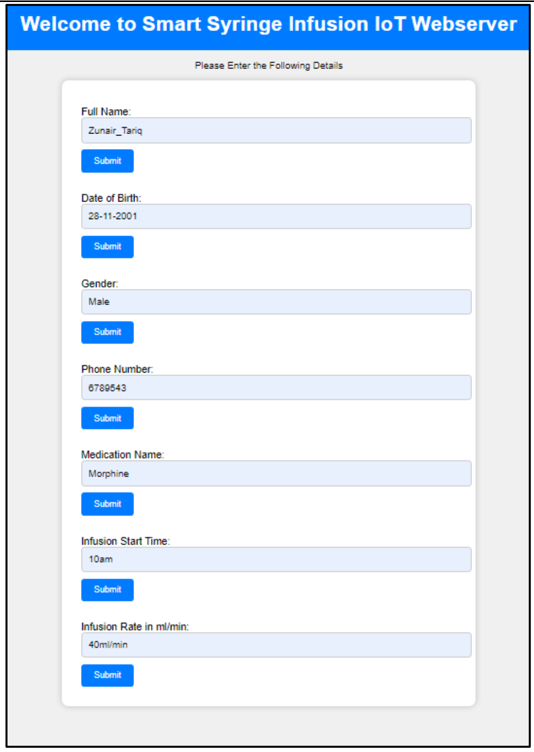
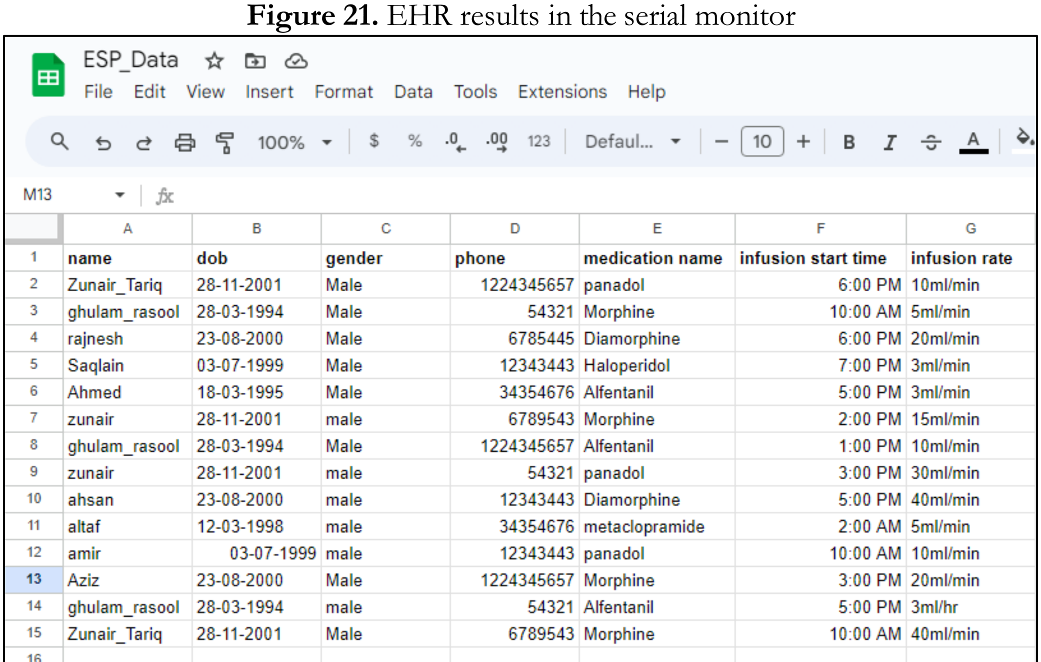


Figure 20. EHR Web Form

Figure 21. EHR results in the serial monitor



	name	dob	gender	phone	medication name	infusion start time	infusion rate
2	Zunair_Tariq	28-11-2001	Male	1224345657	panadol	6:00 PM	10ml/min
3	ghulam_rasool	28-03-1994	Male	54321	Morphine	10:00 AM	5ml/min
4	rajnesh	23-08-2000	Male	6785445	Diamorphine	6:00 PM	20ml/min
5	Saqlain	03-07-1999	Male	12343443	Haloperidol	7:00 PM	3ml/min
6	Ahmed	18-03-1995	Male	34354676	Alfentanil	5:00 PM	3ml/min
7	zunair	28-11-2001	male	6789543	Morphine	2:00 PM	15ml/min
8	ghulam_rasool	28-03-1994	Male	1224345657	Alfentanil	1:00 PM	10ml/min
9	zunair	28-11-2001	male	54321	panadol	3:00 PM	30ml/min
10	ahsan	23-08-2000	male	12343443	Diamorphine	5:00 PM	40ml/min
11	altaf	12-03-1998	male	34354676	metaclopramide	2:00 AM	5ml/min
12	amir	03-07-1999	male	12343443	panadol	10:00 AM	10ml/min
13	Aziz	23-08-2000	Male	1224345657	Morphine	3:00 PM	20ml/min
14	ghulam_rasool	28-03-1994	male	54321	Alfentanil	5:00 PM	3ml/hr
15	Zunair_Tariq	28-11-2001	Male	6789543	Morphine	10:00 AM	40ml/min

Figure 22. Data record in Google Spreadsheet

Discussion:

The smart syringe infusion device achieved great accuracy while working in manual mode, with negligible differences between target dose rates and delivered quantities, as shown in Table 1. Over time, it remained steady, ensuring that patients got proper medicine with no disruptions or mistakes. In comparison to earlier research, such as Islam, Rusho and Islam's (2019) work on automated syringe pumps in clinical settings, this smart syringe infusion device displayed greater accuracy, notably in its capacity to manage dosing rates in real-time with minimal delay. Similar studies have found flaws in syringe infusion devices owing to motor latency or software difficulties; however, this device's customized design and real-time calibration provide improved precision.

The system's performance in virtual mode was equally impressive. In contrast to the findings of Harip, Hasan, and Nordin (2022), which showed delays of up to 2 seconds in comparable systems, the mobile application guaranteed fluid dispensing without time delay (Table 2). The device's ability to be precisely controlled through remote access makes it perfect for telemedicine and remote patient care when medical professionals need to adjust dose settings quickly. The device has effectively handled the significance of real-time control by integrating Wi-Fi and mobile applications, as this comparison highlights.

Furthermore, in refill syringe mode, the ability to reverse the motor and extract accurate fluid amounts sets this device apart from traditional syringe pumps. The device reduces the risk of pharmaceutical errors during refilling, a major concern in traditional infusion systems. By maintaining the same level of accuracy for refilling as for dose administration, the smart syringe infusion device addresses a critical flaw in conventional systems. The incorporation of EHR functionalities enhances the smart syringe infusion device's utility by streamlining documentation and minimizing the risk of errors, aligning with the requirements of modern healthcare management systems. Compared to traditional devices that rely on manual data entry, this system's automated approach offers improved reliability and efficiency. The instant recording of data, as supported by studies like Assuncao et al., 2014, reduces manual errors and provides healthcare professionals with real-time access, thereby improving patient outcomes.

Practical Applicability of Research:

The smart syringe infusion device offers significant practical benefits for the healthcare industry. With the ability to dispense medications correctly, monitor fluid delivery, and seamlessly integrate with electronic health records (EHR) systems, it can help streamline medical procedures, remove human error, and improve patient results. In underserved or remote areas where healthcare professionals are not able to be present, the remote functionality of this technology becomes especially valuable allowing healthcare professionals to monitor and adjust infusion rates at remote locations, saving time and resources.

The elimination of paperwork in the hospital settings, the improvement of data accuracy, and real-time updating of patient records in the EHR integration. Furthermore, the operation of the refill syringe mode enables faster work operation efficiency by eliminating human intervention and errors in refilling. Due to unstable internet connectivity, healthcare facilities also lean toward the integration of local storage solutions to sustain their medical devices in critical care environments, in case of any disruption in internet connectivity.

Conclusion:

This smart syringe infusion technology marks a vital step forward in healthcare technology by delivering accurate medication and allowing remote administration. We prove through our experiments that the device remains consistent and accurate in both manual and virtual control scenarios, along with its unique refill syringe design. The results from our prototype are encouraging yet bring additional challenges and future possibilities.

Limitation: This study does not accurately represent real-world clinical circumstances since it is restricted to laboratory tests. Furthermore, the device's remote-control capabilities depend on internet connectivity, which can present problems in places with poor or nonexistent internet access.

Recommendations for Future Work:

For reliable operation and safety in real-life medical scenarios, the device requires regular testing and valuable feedback from clinicians. Future work should focus on personalizing flow sensors to address flow range issues and implement data safety initiatives to safeguard patient information. Additionally, adding more sensors for comprehensive patient care and updating the interface layout for simplified use could significantly enhance the device's practicality and effectiveness. Regular testing in real clinical environments is crucial for ensuring the device's functionality and reliability in daily healthcare practices. The smart syringe infusion device has the potential to revolutionize medication administration, improve patient outcomes, and enhance healthcare efficiency, particularly in rural and underserved communities.

Acknowledgment: The authors would like to express their sincere gratitude to the Department of Electronics Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, for providing their assistance and resources to carry out this research. This research was funded by the National Grassroots ICT Research Initiative (NGIRI) by Ignite, Ministry of Science & Technology, Pakistan.

Conflict of Interest: There are no conflicts of interest.

Abbreviations:

- **EHR:** Electronic Health Records
- **DC:** Direct Current
- **GSM:** Global System for Mobile Communications
- **IoT:** Internet of Things
- **SDG:** Sustainable Development Goal
- **Wi-Fi:** Wireless Fidelity
- **LCD:** Liquid Crystal Display
- **IP:** Internet Protocol
- **mL/min:** Milliliters per minute
- **MG995:** Model number for a servo motor
- **Node MCU V3:** Development board for Wi-Fi connectivity
- **PWM:** Pulse Width Modulation

References:

[1] M. R. Islam, R. Zahid Rusho, and S. M. Rabiul Islam, "Design and implementation of low cost smart syringe pump for telemedicine and healthcare," 1st Int. Conf. Robot. Electr. Signal Process. Tech. ICREST 2019, pp. 440–444, Feb. 2019, doi: 10.1109/ICREST.2019.8644373.

[2] H. Elkheshen, I. Deni, A. Baalbaky, M. Dib, L. Hamawy, and M. A. Ali, "Semi-Automated Self-Monitore-Syringe Infusion Pump," 2018 Int. Conf. Comput. Appl. ICCA 2018, pp. 331–335, Sep. 2018, doi: 10.1109/COMAPP.2018.8460462.

[3] R. Assuncao et al., "Developing the control system of a syringe infusion pump," Proc. 2014 11th Int. Conf. Remote Eng. Virtual Instrumentation, REV 2014, pp. 254–255, 2014, doi: 10.1109/REV.2014.6784270.

[4] A. S. Samokhin, "Syringe Pump Created using 3D Printing Technology and Arduino Platform," J. Anal. Chem., vol. 75, no. 3, pp. 416–421, Mar. 2020, doi: 10.1134/S1061934820030156/METRICS.

[5] N. Merhi et al., "An intelligent infusion flow controlled syringe infusion pump," Proc. Int. Conf. Microelectron. ICM, vol. 2019-December, pp. 48–52, Dec. 2019, doi: 10.1109/ICM48031.2019.9021516.

[6] M. R. Rosdi and A. Huong, "A smart infusion pump system for remote management and monitoring of intravenous (IV) drips," ISCAIE 2021 - IEEE 11th Symp. Comput. Appl. Ind. Electron., pp. 285–288, Apr. 2021, doi: 10.1109/ISCAIE51753.2021.9431790.

[7] L. M. Amarante, J. Newport, M. Mitchell, J. Wilson, and M. Laubach, "An Open Source Syringe Pump Controller for Fluid Delivery of Multiple Volumes," eNeuro, vol. 6, no. 5, Sep. 2019, doi: 10.1523/ENEURO.0240-19.2019.

[8] D. Guelig et al., "Design of a novel, adjustable flow rate, reusable, electricity-free, low-cost syringe infusion pump," J. Med. Devices, Trans. ASME, vol. 11, no. 4, Dec. 2017, doi: 10.1115/1.4037935/376452.

[9] A. G. (Annisa) Anjani et al., "Application of IoT Using NodeMCU ESP8266 on the Syringe Pump Device to Increase Patient Safety," Indones. J. Electron. Electromed. Eng. Med. Informatics, vol. 4, no. 1, pp. 23–27, Feb. 2022, doi: 10.35882/IJEEEMI.V4I1.4.

[10] M. I. Ali, "Designing a Low-Cost and Portable Infusion Pump," 2019 4th Int. Conf. Emerg. Trends Eng. Sci. Technol. ICEEST 2019, Dec. 2019, doi: 10.1109/ICEEST48626.2019.8981680.

[11] R. Bhavani, S., Mishra, S. Kalpana, "Smart Syringe Infusion Pump," Int. J. Innov. Res. Technol., vol. 9, no. 2, pp. 229–234, 2022.

[12] M. Bawafie, M. Harip, C. Zawiyah, C. Hasan, and M. A. Nordin, "A Review of Internet of Things (Iot) For the Design of Smart Syringe Pump in Biomedical Application," Sci. J. Innov. Soc. Sci. Res., vol. 2, no. 1, pp. 1–12, 2022.

[13] S. Rajasekwaran, S. V Aishwarya, S. Gowthami, R. Suguna, V. Vasunthera, and S. Sathes, "Iot Based Low Cost Syringe Pump for Telemedicine and Health Care," Int. Res. J. Mod. Eng. Technol. Sci., no. 06, pp. 2582–5208, 2022, [Online]. Available: www.irjmets.com

[14] W. Xu et al., "Development of smart infusion pumps: state of the art and future perspectives," Interdiscip. Nurs. Res., vol. 2, no. 2, pp. 107–111, Jul. 2023, doi: 10.1097/NR9.0000000000000028.

[15] "Development of a Syringe Infusion Pump." Accessed: Oct. 24, 2024. [Online]. Available: https://www.researchgate.net/publication/376610555_Development_of_a_Syringe_Infusion_Pump

[16] "Computer-Assisted Framework for Automatic Detection of Structural Hand

Deformities." Accessed: May 22, 2024. [Online]. Available: http://jonuns.com/index.php/journal/article/view/826

[17] M. Batliner, M. Weiss, S. A. Dual, B. Grass, M. Meboldt, and M. Schmid Daners, "Evaluation of a novel flow-controlled syringe infusion pump for precise and continuous drug delivery at low flow rates: a laboratory study," Anaesthesia, vol. 74, no. 11, pp. 1425–1431, Nov. 2019, doi: 10.1111/ANAE.14784.