Automated drip rate monitoring and control system for intravenous fluids of varying viscosities

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Abstract: Nurses play an essential role in society by advocating for health promotion, educating the public and patients on injury and sickness prevention, engaging in rehabilitation, and giving care and support. However, increasing patient loads significantly affect nurses' available time for critical tasks, such as monitoring intravenous (IV) fluid flow. The accuracy of IV administration can also be affected by the viscosity of the infused fluid, making precise drip rate control challenging. This study aims to develop a cost-effective IV fluid monitoring and flow rate control device using a Raspberry Pi Pico microcontroller board. The device would enable nurses to monitor and control the IV drip rate accurately and easily. The accuracy of a prototype sensor for measuring drip rates in different fluids with varying viscosities is evaluated through comparison with a manual method. The results indicate that the experimental method shows good agreement and accuracy compared to the manual method, with minor biases and acceptable ranges of differences. Control charts demonstrate higher precision in the experimental method, indicating stable and consistent measurements. Overall, the findings suggest that the prototype is effective in measuring drip rates and has potential for drip rate monitoring applications. The prototype demonstrated excellent performance in handling fluids of varying viscosities, surpassing 85%. The average percentage errors were 7.5% for Sodium Chloride, 7.67% for Hetastarch, and 8.09% for fresh milk. The prototype demonstrates the ability to enhance safety and precision in IV infusions.

Keywords: intravenous (IV) therapy; IV fluid monitoring; drip rate control; viscosity

1. Introduction

Nurses play a crucial role in promoting health, educating disease prevention, facilitating rehabilitation, and providing essential patient care. However, increasing workloads can interfere with their ability to perform patient safety tasks effectively (Carayon & Gurses, 2008; Hong, 2025). In the Philippines, nurse-to-patient ratios often exceed the ideal 1:12 ratio recommended by the Department of Health, creating challenges that affect nurses' ability to take breaks, maintain concentration, and ensure high-quality care (Tamayo et al., 2022). Such conditions underscore the importance of examining ways to support nurses in managing their workloads without compromising patient safety.

A substantial body of research highlights the critical nature of proficiency in tasks such as intravenous (IV) therapy calculation for ensuring patient safety, especially as nursing care increasingly integrates advanced technologies (Malbrain et al., 2023). IV therapy is essential for treating a wide range of medical conditions and requires careful monitoring to prevent complications. Medication errors, particularly during IV administration, remain common despite technological advancements, and these errors can have significant impacts on patient safety (McDowell et al., 2009). Studies reveal frequent inaccuracies in IV medication rates, with reports suggesting up to 35% of IV infusions are administered at incorrect rates, potentially resulting in serious health risks (Schnock et al., 2017). Research further shows that factors like fluid management accuracy and infusion methods can directly influence error rates (Alharthi & Alshagrawi, 2024; Ding et al., 2025). While smart IV pumps have been introduced to reduce

such errors, they are not without limitations, including high costs and potential technical challenges (Shah & Jani, 2020; Skog et al., 2022).

Additionally, certain medications, such as chemotherapy drugs, often require manual gravity infusion, introducing unique challenges for accuracy and monitoring (Barroso et al., 2024; Eedes et al., 2018). Studies suggest that nurses spend considerable time on lower-value tasks, such as setting up infusion pumps, which underscores the need for efficiency improvements within these procedures (Evans et al., 2007; Song et al., 2020). The modern healthcare landscape relies on various monitoring devices to ensure patient safety and quality care, yet there's room for improvement in certain areas of medical device development. Accurate control of drip rates is crucial to prevent complications arising from under or over-infusion of fluids. Traditional gravity infusion sets, though commonly used, suffer from decreasing flow rates over time due to their elastic nature. Flow regulators offer a solution by maintaining consistent flow rates throughout the infusion process. Studies, such as Ko et al. (2022) highlight the impact of fluid viscosity on the accuracy of infusion flow regulators, emphasizing the need for healthcare professionals to consider viscosity when selecting regulators. IV therapy is essential for various medical conditions, requiring vigilant monitoring to prevent complications. Iftikhar et al. (2023) developed an automated monitoring system using sensors to detect IV fluid levels and vital signs, with alert systems for complications.

Proper calculation of drip rates is vital, as seen in studies by Atanda et al. (2023) and Oh et al. (2025) where nurses need to ensure accurate rates for various treatments like blood transfusions and chemotherapy. The drop factor and flow rate equations are essential for calculating drip rates accurately. A study by Nimi et al. (2022) and Oros et al. (2021) used a GSM module to alert nurses and will automatically turn off the flow of the IV fluid when the level is very low. GSM modules have a bandwidth lag because multiple users share the same bandwidth so that the transmission can encounter an interface. It can also interfere with certain electronics due to pulse transmission technology. Also, nurses will just be alerted through buzzers and SMS but cannot determine the cause of the alert. A study by S. et al. (2020) implemented IoT to constantly monitor the temperature, pulse rate, BP, and temperature, drip rate, and fluid level. Although, it will not be energy efficient since it will require a lot of power to collect data and monitor IV fluid because IV fluid therapy will usually take hours. Given these insights, there is a need for further investigation into cost-effective solutions that can support IV therapy administration while reducing nurse workload.

This study aims to address gaps in the current literature by exploring the development of affordable and efficient IV monitoring devices that can improve medication practices, reduce the likelihood of errors, and ultimately enhance patient safety. By addressing these challenges, the study seeks to contribute to nurse satisfaction and healthcare efficiency.

2. Methods

2.1 Research design

This study followed an experimental-prototyping method to evaluate the performance of the IV drip monitoring and control device. The prototype's automated drip rate readings were compared with manually measured values obtained from a standard IV infusion setup to test its accuracy and reliability under controlled but realistic conditions. The independent variables included the drop rate sensor, IV fluid volume, infusion time, and drop factor. The dependent variables were the servo motor rotation and the displayed rate. Three IV fluids with distinct viscosities were used to simulate different clinical conditions namely 0.9% Sodium Chloride, 6% Hetastarch, and Fresh Milk. Each fluid was tested several times to confirm consistency and account for variations in physical properties. To simulate an actual hospital environment, the tests were carried out in a room similar to a patient's setting. A licensed nurse administered the manual setup and drip rate calculations, which served as the baseline for comparison. Data from the manual and automated measurements were statistically analyzed to assess the prototype's level of accuracy, consistency, and overall performance stability.

2.2 System overview

The IV drop monitoring and controlling device, connected to a Raspberry Pi Pico, utilizes a beam break sensor attached to the drip chamber to detect each drop passing through. The system flowchart outlines the process of inputting parameters such as IV fluid volume and infusion time to achieve the desired drip rate, typically set to 20 drops per minute. The system flowchart, depicted in Figure 1, calibrates the device and adjusts and servo motor's rotation based on the difference between the acquired and desired drip rates. This ensures the drip rate remains consistent, with the device continuously monitoring and adjusting as needed to maintain the desired rate.

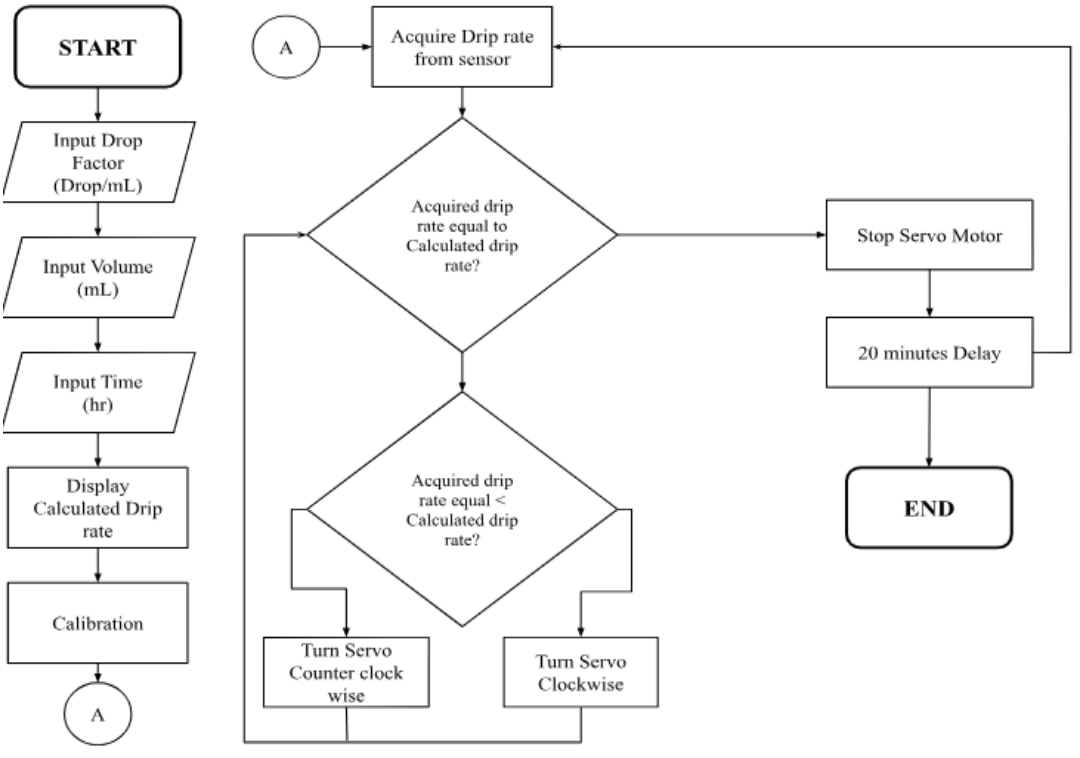

Figure 1. System flowchart

2.3 Hardware configuration

The drop sensor is attached to the drip chamber, and the drip monitoring and controlling device is connected to the IV fluid pole. The drop sensor consists of a beam transmitter and receiver. The system design is shown in Figure 2. When a drop passes through the sensor, it interrupts the beam. The device reads the signal from the sensor and calibrates it to determine the current drip rate from the drip chamber. If the device detects a drip rate that is not equal to the desired rate, it will rotate either clockwise or counterclockwise.

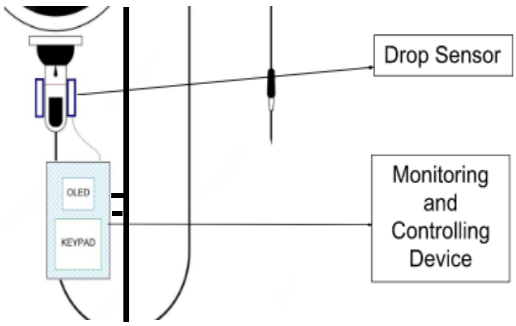

Figure 2. System design

2.4 System architecture

For the system architecture in Figure 3, the process starts with inputting the desired infusion value on the keypad. The drop rate sensor measures the actual drip rate and the device starts to adjust and calibrate to get the desired values which is then displayed on the OLED.

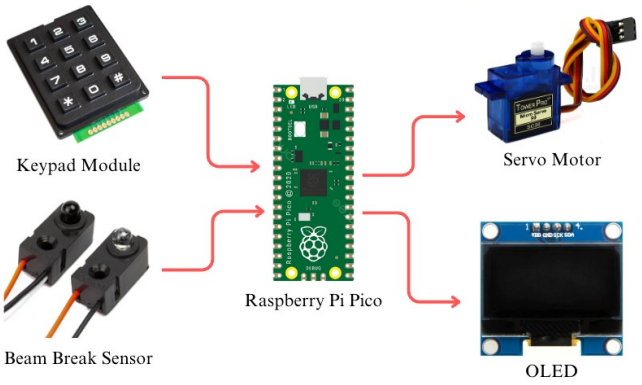

Figure 3. System architecture

2.5 Population and sampling

For the population and sampling, a professional nurse was responsible for setting up an IV infusion set and calculating the drip rate. The prototype was then sampled using three different fluids that possess varying viscosities: 0.9% Sodium Chloride, 6% Hetastarch, and Fresh Milk (a blood alternative). Fresh milk is used since it has a viscosity of 5 mPas and many cardiovascular handbooks consider blood viscosity values between 3.5 to 5.5 mPas (Nader et al., 2019). The purpose of this sampling was to assess the effectiveness of the prototype across different types of IV fluids. Data was collected using an alarm clock to measure the drip rate at 20-minute intervals.

2.6 Experimental setup and data collection

The study was conducted in a room that was like a patient's room to create a setting that would closely resemble the real-world conditions in which IV fluids are administered. Figure 4 shows the actual implementation of the device. The prototype maintains the integrity of the traditional setup but introduces a modification by integrating a solution wherein the roller clamp of the traditional infusion set is attached to the device. This device then automatically rotates or adjusts the roller clamp according to the needed drip rate.

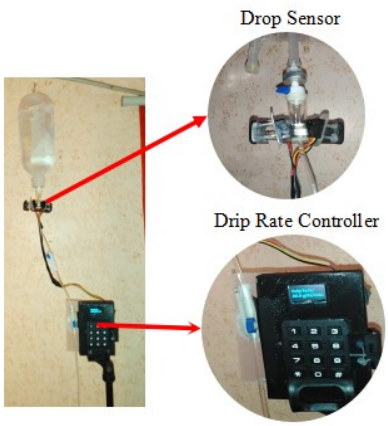

Figure 4. Actual Implementation of the device

3. Results and discussion

3.1 Device implementation and output

Figure 5 illustrates the conclusive output of the device. The researchers successfully achieved the proposed and planned design of the device, incorporating a few minor additions and modifications.

Figure 5. Actual prototype

3.2 Comparative measurement and statistical analysis

Accurate comparison of measurement techniques is crucial for validating the performance of newly developed devices and protocols in clinical settings. In this study, the experimental automated intravenous infusion monitoring device was compared with the manual gravity-assisted method, in which nurses determine drip rates by visually counting the number of drops per minute (gtt/min) through the IV drip chamber. To statistically evaluate the level of agreement between the two approaches, the Bland–Altman analysis was employed which is a recognized method for assessing concordance between quantitative measurement techniques. From this analysis, critical parameters such as mean difference (bias), standard deviation, and limits of agreement (LOA) were computed for each test fluid of varying viscosity. These statistical results provide a clear understanding of the accuracy and reliability of the automated system compared to the conventional manual observation method, supporting its potential for effective integration into clinical IV therapy practice.

3.3 Results for 0.9% sodium chloride

The calculated mean difference of the two methods is 0.67 units and it is represented by the center blue cyan line in Figure 6. This indicates that, on average, the experimental measurements are 0.67 units higher than the manual measurements. The standard deviation of the differences is 0.98 units, it indicates how far the differences between the two methods are to the bias or mean difference. The lower limit of agreement (LOA) is -1.26 units, suggesting that the manual measurements can be as much as 1.26 units lower than the experimental measurements. The upper LOA is 2.59 units, indicating that the manual measurements can be as much as 2.59 units higher than the experimental measurements. Therefore, the two measurement methods in this data show some level of agreement. The bias of 0.67 units indicates a consistent tendency for the experimental measurements to be higher than the manual measurements. However, as shown, all mean differences are within LOA and this indicates acceptable agreement between the two methods.

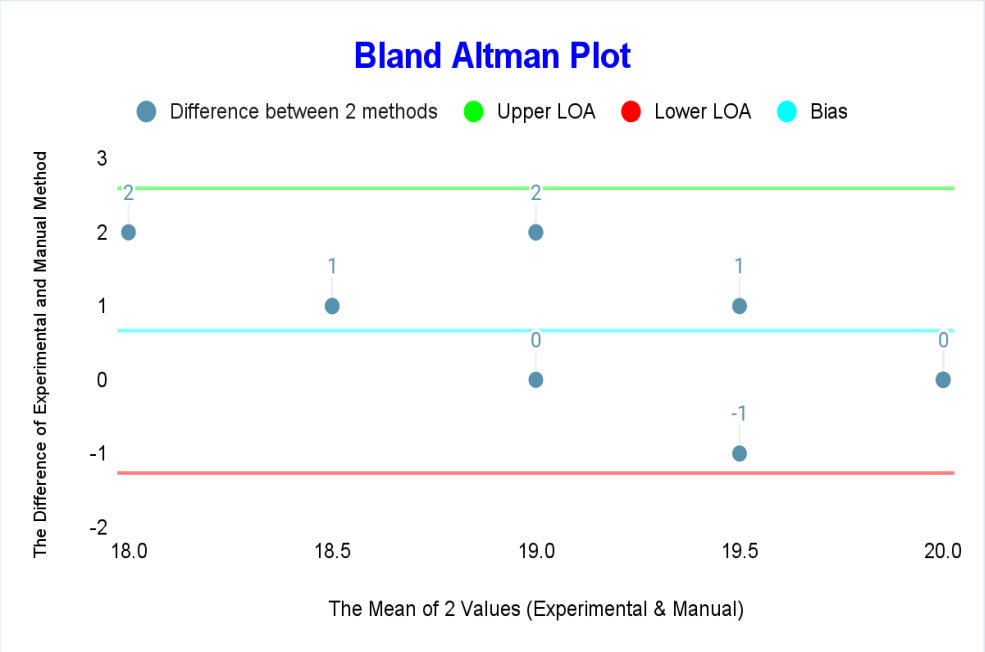

Figure 6. Bland altman plot using sodium chloride (Saline) as IV fluid

3.4 Results for 6% Hetastarch

For the testing using 6% Hetastarch as IV fluid, the range of differences observed between the two methods was from -2 to 2, while the calculated limits of agreement (LOA) ranged from -2.246 to 3.412. Since all the differences are within the LOA, it suggests a consistent level of agreement between the experimental and manual measurements, as shown in Figure 7. The mean difference of 0.583 indicates a slight positive bias towards the experimental method, but this bias alone does not necessarily indicate a lack of agreement as long as the differences remain within the specified limits. Overall, based on the provided data, it can be concluded that the experimental and manual methods demonstrate good agreement and accuracy within the given limits when obtaining drip rate using 6% Hetastarch.

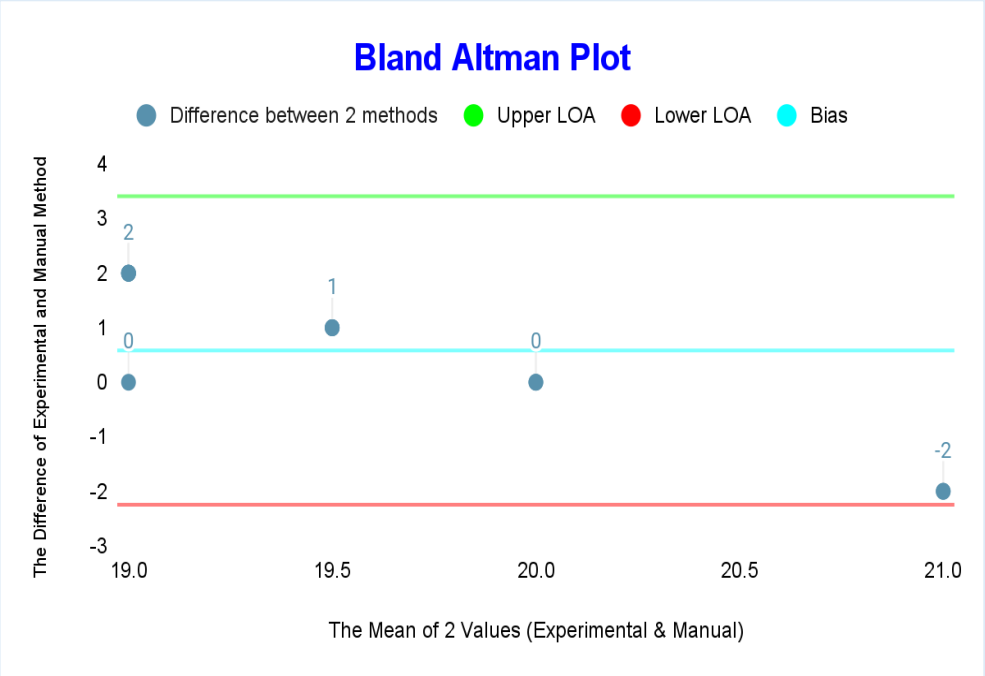

Figure 7. Bland altman plot using hetastarch as IV fluid

3.5 Results for fresh milk (blood viscosity alternative)

For the experiment on Fresh Milk as IV fluid, the mean difference between the experimental and manual methods is 0.33. This indicates that the experimental method yields higher results than the manual method. The standard deviation of 1.37 indicates the spread in the differences between the two methods. The mean differences are within the LOA, which indicates an agreement between the 2 methods. Based on these results, we can conclude that the experimental and manual methods generally show good agreement and accuracy as shown in the Bland Altman plot in Figure 8. The bias and standard deviation are relatively small, indicating that the two methods provide measurements that are close to each other on average with limited variability. Additionally, the differences between the methods fall within the calculated LOA, suggesting that the measurements obtained from the experimental method are consistent with the manual method within the specified limits.

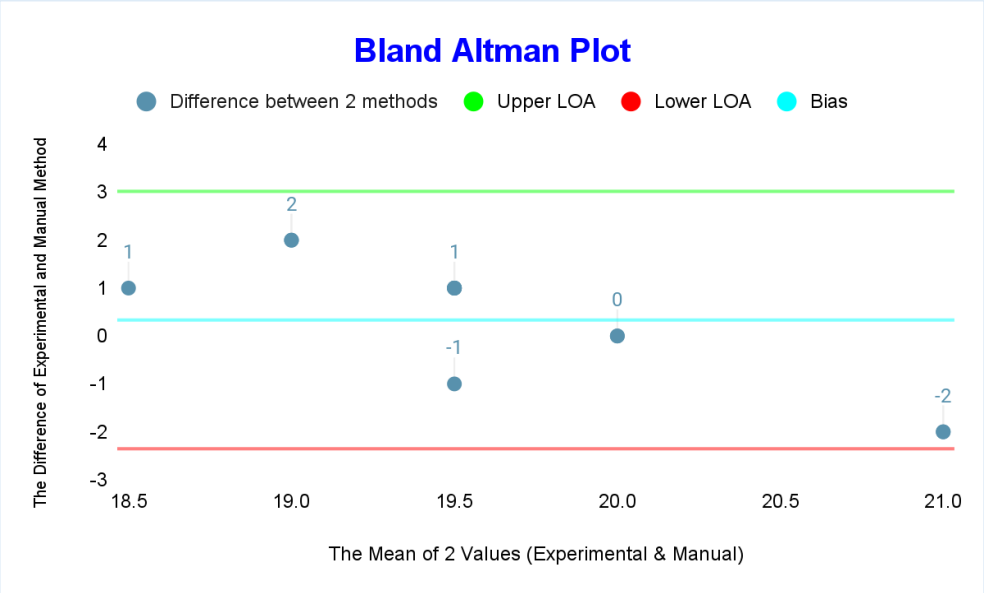

Figure 8. Bland altman plot using fresh milk as IV fluid

The standard deviation of the differences, which is calculated as 1.880, represents the spread or variability of the differences between the methods. A higher standard deviation indicates a larger variation in the differences. Based on the data provided, the mean difference falls within the LOA, indicating good agreement between the experimental and manual methods. The range of -3.603 to 3.770 suggests that most of the differences between the methods are relatively small and fall within an acceptable range.

The experimental results demonstrate that the developed IV drip rate monitoring and control device performed with an overall effectiveness exceeding 85%, showing reliable performance across fluids of varying viscosities 0.9% Sodium Chloride, 6% Hetastarch, and fresh milk. This indicates that the system can maintain consistent drip rates despite differences in fluid density and flow behavior. Compared with similar works, such as those by Bhavasaar et al. (2016), which focused on IV fluid level detection and GSM-based alert systems, the present device introduces an additional layer of automation through active servo-based control of the roller clamp. This feedback mechanism allows not only monitoring but also real-time adjustment, improving accuracy and operational safety during IV infusions.

The recorded average error of 7.5% is within acceptable limits for manual IV administration but reflects minor discrepancies that may arise from several factors. These include sensor calibration drift, variations in fluid viscosity, and environmental factors such as temperature and lighting affecting the optical sensor's readings. Mechanical play in the servo motor and the non-linear response of the drip chamber may also have contributed to minor inaccuracies. The

85% effectiveness rate achieved in this study therefore represents an advancement in practical automation for IV monitoring, particularly for low-cost and portable clinical applications. However, further refinement of sensor sensitivity, servo control precision, and algorithmic compensation for viscosity changes could reduce the remaining margin of error. Future work should explore integrating wireless monitoring for remote supervision, expanding trials to include more fluid types, and conducting long-duration stability tests. Additionally, implementing adaptive control algorithms could enhance the system's ability to self-correct and maintain higher accuracy under variable clinical conditions.

4. Conclusion

Overall, the analysis of the prototype's performance in regulating and monitoring drip rates for fluids with varying viscosities indicates a high level of accuracy, surpassing 85%. This outcome highlights the prototype's potential to significantly enhance the safety and precision of IV infusions. Both experimental and manual methods agree with each other indicating that they can be used interchangeably. By achieving such accuracy, the prototype presents a promising solution that can address critical challenges associated with drip rate regulation and monitoring in medical settings. The ability to consistently and accurately administer fluids is crucial in ensuring optimal patient care, minimizing the risk of complications, and maximizing the effectiveness of treatments. The prototype's performance in maintaining accurate drip rates, even for fluids with different viscosities, underscores its robustness and versatility. This characteristic enhances its potential for widespread adoption across various medical contexts, from routine hospital procedures to complex treatments that involve administering specialized medications or fluids. Furthermore, the demonstrated accuracy of over 85% in each fluid with different viscosities instills confidence in the prototype's reliability, bolstering its role as a valuable tool for healthcare professionals. By utilizing this technology, medical practitioners can mitigate potential errors caused by human factors or inherent variations in manual drip rate control, ultimately improving patient outcomes and reducing the incidence of adverse events.

Author's Declaration

Author contribution

Justin Suarez: Conceptualization, System design, Prototyping, Experimentation, Data collection, Writing – original draft preparation. **Allain Jessel Macas**: Conceptualization, Methodology, Data analysis, Validation, Supervision, Writing – review and editing.

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Competing interest

The authors declare that there are no financial or personal relationships that could have inappropriately influenced the work reported in this paper.

Ethical clearance

This research does not involve humans as subjects.

Data availability

The datasets generated and analyzed during this study, including raw drip rate readings, control system test data, and statistical analyses comparing manual and automated measurements, are available from the corresponding author upon reasonable request.

AI statement

ChatGPT was utilized to enhance the clarity, grammar, and overall readability of this manuscript. All technical content, data interpretation, and conclusions were solely developed and verified by the authors. The final version of the manuscript was thoroughly reviewed to ensure accuracy, coherence, and alignment with the study's findings.

Publisher's and Journal's Note

Researcher and Lecturer Society as the publisher, and the editor of Journal of Engineering Researcher and Lecturer state that there is no conflict of interest towards this article publication.

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