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Automated IV Infusion Control System Design and Development for Medical Use

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***Abstract*- For patients suffering from pathological conditions, Intravenous infusion serves to be the go-to treatment, it requires for a medical practitioner to set up the IV infusion device up as per the doctors' instructions, followed by periodic supervision as abnormalities may occur. The objective of this paper is to demonstrate the construction of an automated intravenous infusion control system. Medical and laboratory fluid control has previously been achieved using pressure-based flow sensing, ultrasonic flow measurement, optical flow sensors, capacitive flow sensing, and thermal flow sensing. Due to its reduced susceptibility to external factors, our approach utilizing an IR sensor is particularly advantageous in IV scenarios for accurately detecting fluid drops. An IR sensor, microcontroller, servo motor/peristaltic pump, and an affordable microcontroller are used in this system to allow precise saline circulation rate control. An input control system can be implemented through either a matrix keypad or a single control network server. Controls the drops per minute and allows internet-based server-side control via IR sensor, 3x4 matrix keypad, and Bluetooth module. To accurately measure the saline flow rate and count drops, an IR sensor is integrated into the drip chamber of the saline container. In order to achieve the desired blood flow rate, the microcontroller continuously compares the sensor readings with the commands and adjusts the servo motor/peristaltic pump accordingly. Testing of the completed hardware provided satisfactory results, proving the device's ability to enhance patient care.**

***Index Terms*-- saline monitoring and control equipment; automated fluid control; Arduino UNO; flow controller; intravenous infusion**

I. INTRODUCTION

The field of healthcare is constantly evolving to meet the increasing demands of a growing population. With advancements in medical technology, particularly in the areas of automation and control systems, there have been significant improvements in patient care and treatment. Intravenous (IV) therapy plays a crucial role in delivering medications, fluids, and vital nutrients in the patient's blood [1]. Accurate control and monitoring of the IV infusion rate are essential for ensuring patient safety and optimal treatment outcomes. The process of IV infusion rate control has relied heavily on manual monitoring by healthcare professionals. However, this method poses several challenges, including the need for continuous monitoring and the strain it places on medical staff who must attend to multiple patients simultaneously. To address these challenges, researchers and engineers have focused on developing automated systems for IV infusion control [2]-[3]. A drip rate indicates the amount of fluid that is infusion during IV infusion, multiplied by a drip factor representing the amount of fluid per milliliter, which represents the drop count per minute. Traditionally, the rate of drip is manually set by adjusting the regulator on the tubing, and healthcare providers visually count the drops over a specific time interval (e.g., 15 or 30 seconds) to calculate the rate per minute [4]-[7].

However, several factors can cause variations in the set drip-rate. The dilation or contraction of the patient's veins as they warm up, the formation of tissue that may obstruct the needle, and the reduction in fluid volume in the bag over time leading to decreased gravity pressure can all affect the drip rate. Consequently, healthcare providers need to frequently check the drip rate every 15 to 20 minutes to ensure it remains within the desired range [4]. To facilitate accurate monitoring along with control for the IV infusion process, a transparent drip chamber is commonly utilized, allowing the placement of an IR-sensor assembly around it to detect falling drops. A drip rate meter that incorporates this sensing mechanism proves highly beneficial for setting and monitoring the desired drip-rate. This handheld device enables nurses to easily check and adjust the drip rate as needed [8].

To further enhance patient safety and optimize the IV infusion process, the meter can be designed to provide alarms or alerts in specific situations. Previous studies and literature in this field have explored various approaches to automate the monitoring and control of IV infusions such as Android smartphones, ZigBee, and IoT [9]-[14]. Research efforts have leveraged technologies such as sensors, microcontrollers, and communication modules to enhance the accuracy and reliability of IV therapy. These studies have provided valuable insights into the existing technologies, their limitations, and potential areas for improvement [15]-[16].

The purpose of this paper is to present a novel approach to IV infusion control that addresses the shortcomings of continuous monitoring and the deficiency of medical staff [18]. Our research aims to fill a crucial gap in the current literature by proposing an automated intravenous drop controller system. This system utilizes advanced sensor technology, microcontrollers, and intelligent control algorithms to achieve precise and reliable control of the IV infusion rate. By automating the process of IV infusion control, this research aims to eliminate the need for continuous monitoring by healthcare professionals, thereby freeing up their time for other critical tasks. Furthermore, the system aims to enhance patient safety by minimizing the risk of human error associated with manual infusion rate adjustments. The proposed system offers a cost-effective and efficient solution that can be integrated into existing healthcare settings without significant disruption. This paper will discuss the design, development, and experimental evaluation of an automated intravenous drop controller system. The results of our research demonstrate the feasibility and effectiveness of this system in addressing the challenges posed by continuous monitoring requirements and the shortage of medical staff. Ultimately, this research contributes to the advancement of automated medical applications and holds significant potential for improving patient care and treatment outcomes.

II. MATERIALS & METHOD

The suggested system is depicted in Figure 1,that illustrates the block diagram of the developed solution. It incorporates automatic flow rate control functionality, allowing the system to adjust the infusion rate based on user commands. To track the pace at which the IV fluid circulates, an IR sensor was integrated in the drip chamber of the saline bottle. By continuously monitoring flow rate, the system ensures that it aligns with the specified command received from the user. Any error readings are addressed through a signal conditioning circuit, while an isolator circuit removes any unwanted interferences or disturbances.

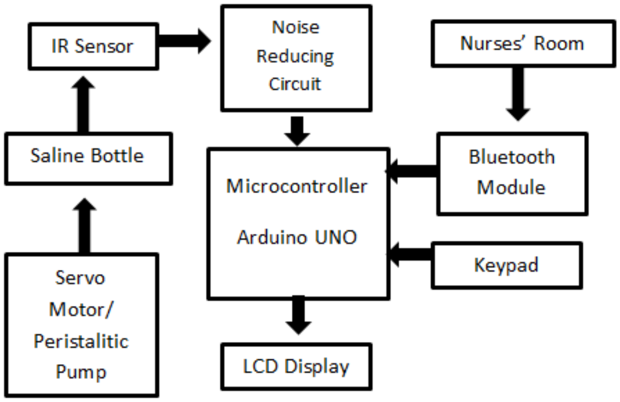

Fig. 1 ***Flow Diagram of Proposed Design***

A. Choice of Component

The suggested system uses an infrared (IR) module as a fluid drop sensor and counter. This sensor detects infrared light. Compared to an ultrasonic module, which was the first choice as a flow control sensor, the IR module offers better performance for IV scenarios due to its ability to accurately detect and count fluid drops in the drip chamber. Its precise measurement capabilities make it suitable for monitoring and controlling the rate of IV fluid flow. A board for microcontrollers is the Arduino UNO that serves as the controlling unit in the project. It is chosen for its versatility, ease of use, and extensive community support. With its robust processing power and a wide range of compatible libraries and shields, the Arduino UNO provides an ideal platform for implementing the necessary control logic and integrating various components of the system. The LCD module is a display unit consisting of a 16x2 character matrix. It is used in the project to provide a visual interface for displaying relevant information such as the current drip rate, settings, and system status. The LCD module offers clear and concise information presentation, enhancing the usability and user-friendliness of the system. The buzzer is an audio output device used in the project to provide audible feedback and alerts. It is employed to generate sound signals for various events, such as exceeding the set drip rate limits or indicating system errors. The buzzer's audible alerts ensure that healthcare providers can be promptly notified of any critical situations, enabling quick intervention and preventing potential complications. The 3x4 matrix keypad is an input device used for user interaction with the system. It consists of a grid of buttons arranged in rows and columns, allowing users to input commands and adjust settings conveniently. The keypad provides a compact and intuitive interface for users to specify the desired drip rate and interact with other system functionalities.

Both the servo motor (HS 645 Hitec) and peristaltic pump (G528 DC12V) are options considered for efficient flow control. The servo motor, controlled by the microcontroller, can adjust the position of the peristaltic pump tubing to modify the fluid circulation rate. By squeezing and releasing the tubing, the peristaltic pump enables precise control over the infusion rate. The Bluetooth module HC05 is a wireless communication module used in the project. It enables seamless communication between the IV fluid control system and external devices, such as smartphones or computers. The HC05 module allows for remote control and monitoring of the IV infusion process, enhancing convenience and facilitating efficient patient care management.

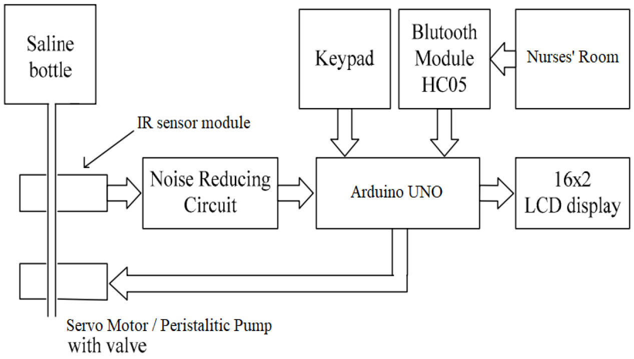

Fig. 2 ***Functional Diagram of Proposed Design***

III. COMPARISON OF FLOW CONTROL MECHANISMS: SERVO MOTOR VS. PERISTALTIC PUMP

The microcontroller compares the input command with the actual rate of flow to see if any modifications are required. When a servo motor is used to control flow rate, the microcontroller gives instructions for it to rotate either clockwise or anticlockwise. By adjusting the distance between the valve and the pipe, it is possible to smoothly modify the depth between 0° and the diameter of the saline pipe at 180° through the servo motor's connection to the valve shaft. The saline pipe undergoes regulated compression and release as the servo turns, efficiently controlling the liquid flow.

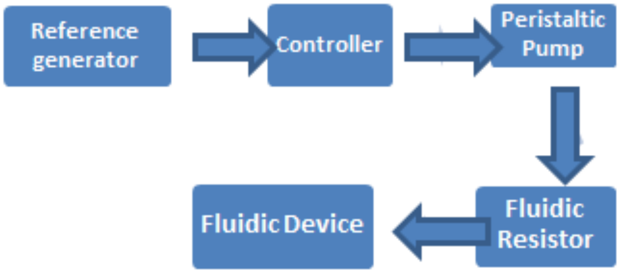

Fig. 3 ***Peristaltic Pump Flow Diagram***

In the case of controlling the flow rate via a peristaltic pump, a peristaltic pump, a backflow prevention valve, a fluidic resistor and a fluidic device. The fluid is then passed through a peristaltic pump, which gives it more energy and raises the fluid's pressure inside the fluidic system. After that, the fluid goes through a backflow prevention valve, which boosts the peristaltic pump's performance by preventing the fluid from flowing back out of the input. The fluid then travels via a fluidic resistor to lessen its sensitivity to changes in the power supplied to the peristaltic pump in the fluidic system. The fluid then flows into the fluidic device (IV set). The principle behind pump peristalsis is to squeeze and release sections of a compressible tube, with the squeeze drawing fluid in and the release pushing fluid out of the pump. However, it is essential to evaluate their performance and characteristics to determine the optimal choice for the specific requirements of the automated IV infusion control system.

Table 1

Servo vs. Peristaltic pump: Comparison

Control Mechanism	***Servo Motor***	***Peristaltic Pump***
Advantage	Precise control over valve position and liquid flow	Consistent and reliable flow rate
	Smooth and adjustable depth adjustment	Minimal risk of contamination
	Ease of integration with the system	Reduced chances of tube blockage
Limitation	Limited to controlling valve-based flow systems	Complex setup and calibration
	Mechanical wear and tear over time	Noise generated during operation
	Slower response time compared to peristaltic pump	Limited flexibility in adjusting flow rate without tube changes

B. Circuit Diagram

The fluid control device circuit diagram, depicted in Figure 4, showcases the integration of various components for seamless operation. Sensors, signal conditioning circuits, keypads, servos with valves, LCD displays, Arduino UNO processors, and Bluetooth modules comprise the key elements. Pins 7 through 13 of the Arduino are connected to the LCD display for the purpose of establishing keypad functionality, and pin 3 of the LCD has been connected to the Arduino's 5 volt supply via a potentiometer in order to adjust the contrast. For servo motor control, the servo is connected to the Arduino UNO's PWM output pin 9.

Incorporating Bluetooth capabilities, the Bluetooth module interfaces with the microcontroller using the RX and TX data pins. The input data channel (R_x) of the Bluetooth module connects to the output data channel (T_x) pin (digital pin 1) of the Arduino, while the output data channel of the Bluetooth module connects to the input pin 0, digital of the Arduino UNO.

The circuit diagram reflects comprehensive integration of these components to ensure efficient fluid control and monitoring within the system.

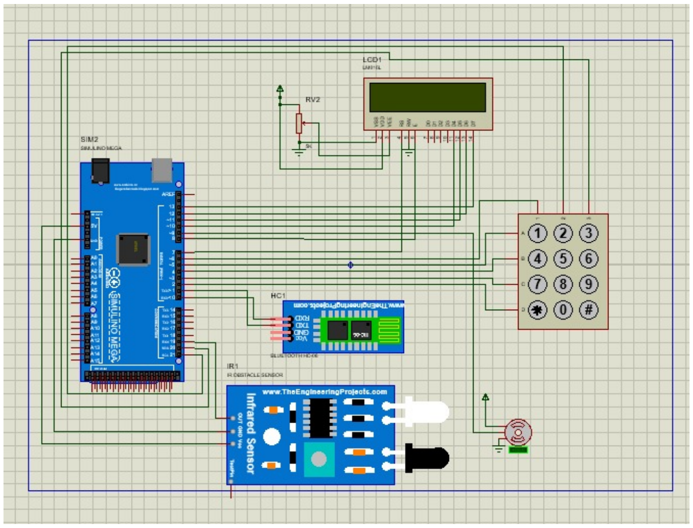

Fig. 4 ***Circuit Diagram***

C. IR Sensor Module and Noise Reducing Circuitry:

In order to accurately determine fluid flow by measuring the interval between two drops, one of the primary challenges in the system lies in determining the flow rate. To address this, an infrared sensor has been employed as a drop detection mechanism. With an IR sensor, a drop from the saline bottle interrupts IR radiations coming to the receiver, causing a charge disturbance and activating a transistor. The IR module has parallelly integrated receiver and transmitter. Initially, the system encountered issues with the accurate parallel adjustment of the receiver and transmitter which resulted in error readings by the microcontroller's detection system. To mitigate this problem, a casing was designed to hold the modules receiver and transmitter at exactly 180 degrees from one another, furthermore, a noise removal circuit was implemented using an LDR (Light Dependent Resistor) and an LED. Using this circuit, fluid flow rate measurements are accurate since high-frequency noise is effectively filtered out. Two BC547 transistors were used in the signal control circuit. First, the transistor provides low currents, while second transistors provide high currents. The signal is amplified by the second transistor, and then passed through a noise reduction circuit in order to eliminate high-frequency noise caused by sparking on the IR sensor.

The noise removal circuit operates as follows: When a drop falls on the contact, the LED blinks, and the emitted light falls on the LDR, causing a change in its resistance. The LDR, positioned in close proximity to the LED, exhibits a low resistance when illuminated, resulting in a higher voltage drop across the resistor and generating a high output. Conversely, when the LED is turned off, the LDR's resistance increases, leading to a lower voltage drop across the resistor and producing a low output. To minimize the impact of ambient light, both the LDR and LED are covered with black paper, ensuring the circuit operates independently of environmental lighting conditions.

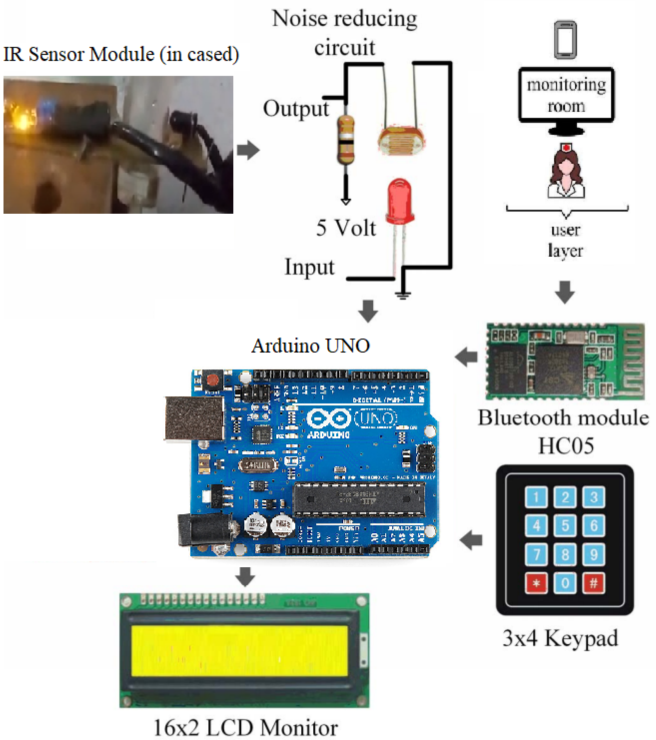

Fig.5 ***Arrangement of Hardware Components***

D. Programming the Microcontroller

The microcontroller programming for the fluid control device is designed based on the flowchart depicted in Figure 6. The flowchart outlines the sequence of operations performed by the Arduino to achieve the desired control and monitoring functionalities. This allows the medical staff to input their desired number of drops per minute. After they enters this value, the Arduino continuously reads data from the IR sensor, which detects the drops of fluid.

As soon as the Arduino detects the first drop, it starts a timer to measure the length of time that has elapsed. A minute interval is calculated each time the timer stops when the sensor detects the subsequent drop. Following this calculation, the staff compares the calculated flow rate with the specified flow rate. A servo motor is instructed to rotate the valve in the opposite direction if the current drip rate exceeds input, indicating an excessive flow. As a result of this adjustment, the flow rate is reduced by increasing the space between the pipe and valve. A similar process is performed if the current drip rate is lower than the user's input, indicating an insufficient flow, by rotating the servo motor clockwise. This decreases the gap between the valve and the pipe, which increases flow. The servo motor remains stationary when the actual and commanded flow rates match, maintaining a constant flow rate. A continuously looping program continuously monitors the actual flow rate and adjusts the position of the servo motor for automatic valve control and flow regulation. By following this programmed logic, the system ensures accurate and automated control of the fluid flow rate.

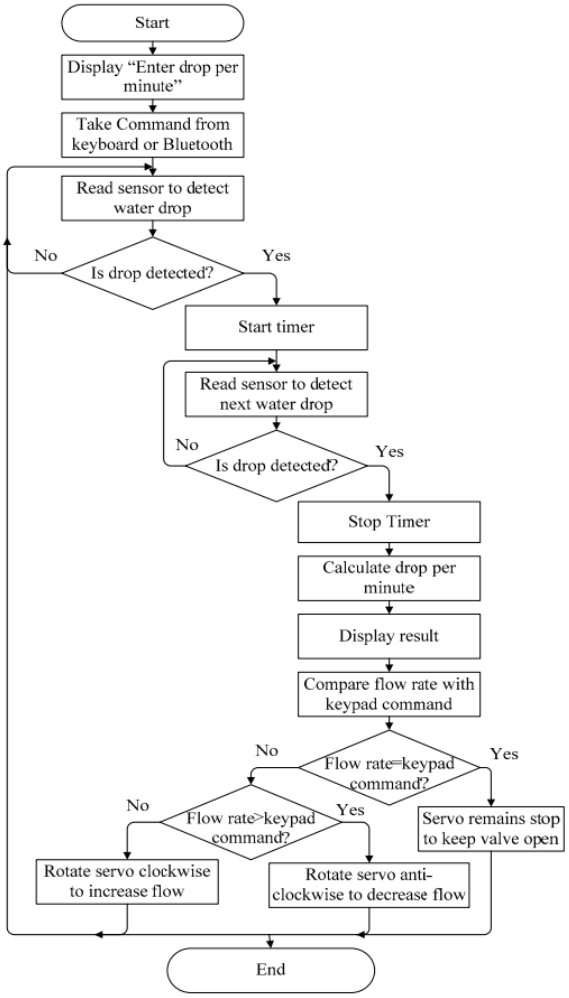

Fig. 6 ***Microcontroller Program Flowchart***

IV. PERFORMANCE EVALUATION

The developed system has successfully demonstrated its functionality through various applications. The monitoring of the current fluid flow rate is achieved using an LCD monitor, which displays the flow rate information. Additionally, the flow rate information is also displayed on the monitoring room PC, providing convenient access to the data. The system incorporates both an monitoring room PC server and a keypad, allowing the medical staff to input the desired command, specifying the number of drops per minute according to their requirements. Each number pressed by the staff is visually confirmed on the display, ensuring accurate input. The microcontroller begins reading data from the IR sensor as soon as the staff presses the start button. Upon detecting a drop, the timer is initiated to measure the elapsed time, while simultaneously the microcontroller continues monitoring the sensor for the detection of the next drop. When the subsequent drop is detected, the timer stops, and the time interval between the two drops is calculated in real-time. These functionalities work together to accurately determine the fluid flow rate.

After computing the flow rate, the LCD display and the connected monitoring room PC showed both the commanded and actual fluid flow rates. Comparisons were made between the current drip flow and commanded fluid flow rates. In response to an increase in the current rate, the motor's angle increased, causing the servo to rotate counter-clockwise and reducing the distance between the pipe and valve, resulting in a slower flow rate. Alternatively, if the drip's current flow rate is lower than the instruction rate, the motor's angle decreases by rotating clockwise, which increases the distance between the pipe and valve, thereby speeding up the drip. A constant gap between the pipe and valve and a constant servo would occur when the current drip flow rate matched the input command. A servo adjustment maintains the equality between the commanded and actual flow rates by continually reading the sensor, calculating flow rate, and adjusting the servo in either direction as needed. Figure 7(a) depicts the input stage, waiting for the user to provide the command, while Following the command, Figure 7(b) shows the device waiting for the staff to initiate the process by a single press to the start button. Once the START button was pressed, the device began reading the sensor and calculating fluid flow. It can be seen in Figure7(c) the flow rate was equal on both the input and the current rate side. This stage followed an unbalancing stage, during which the servo remained stationary, allowing time for the commanded and actual readings to align.

Enter 3 Digit
Number :

Pess START

Drop Per Minute
Com:100 Act:97

Fig. 7 ***(a)Input (b)Initialization (c)Balance***

Table 2
Drop Counter Efficiency Analysis

Time	*Arduino Count*	*Manual Count*
1 minute	33	35
2 minutes	88	84
3 minutes	141	132
4 minutes	198	177
5 minutes	240	222
6 minutes	276	267
7 minutes	320	312
8 minutes	359	254
9 minutes	406	397
10 minutes	444	440
11 minutes	484	483
12 minutes	529	525
13 minutes	563	567
14 minutes	607	608
15 minutes	636	649

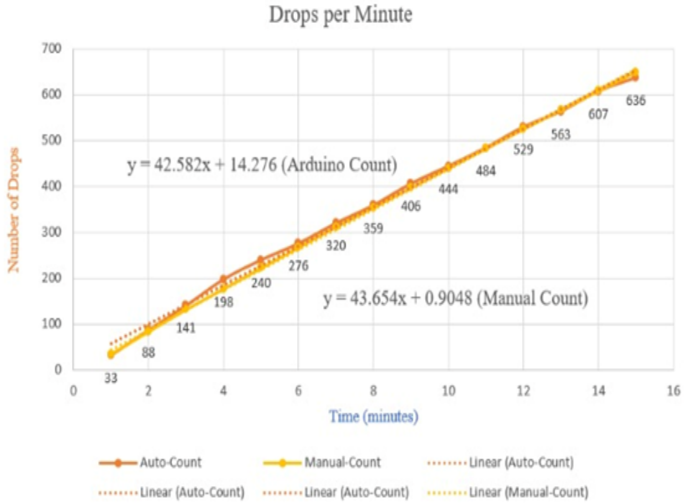

Figure 8 *Drop Counter Efficiency Graphical Analysis*

V. FUTURE WORK

In future developments of this system, we aim to introduce and modify it to detect patient discomfort stimuli and utilize this information as a standard to control the flow rate of the fluid. This expansion of functionality will enhance the system's capability to ensure patient comfort and safety during intravenous (IV) infusion. To achieve this objective, we propose incorporating additional sensors into the system that can monitor various physiological parameters indicative of patient discomfort. These sensors may include heart rate monitors, blood pressure sensors, temperature sensors, or other relevant indicators. By continuously monitoring these parameters, the system can detect any signs of discomfort or distress experienced by the patient.

VI. CONCLUSION

The combination of medicine and engineering has led to remarkable advancements in medical facilities and treatments. The field of medical care has experienced rapid progress, facilitated by innovative devices and technologies. Designing a fluid control device posed a significant challenge, particularly in terms of achieving accurate and responsive performance, as well as developing a sensor capable of detecting fluid drops. In this project, we successfully addressed these challenges by employing an IR sensor module. This sensor exhibited exceptional sensitivity, allowing it to detect various types of objects and fluids as they cut through the IR field. The versatility and responsiveness of our device make it suitable for applications in medical settings and chemical laboratories, where precise fluid flow control is essential. The affordability of our medical device holds significant potential, particularly in resource-constrained regions like Pakistan, where it can contribute to improving patient healthcare. The successful development of this low-cost medical device opens up possibilities for various applications in healthcare settings. Its accurate and reliable performance, coupled with its affordability, makes it a valuable asset for healthcare providers. By addressing the specific needs of patients, our device has the potential to enhance healthcare outcomes, particularly in developing countries

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