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Enhanced Blood Warmer Regulation with Temperature Based on Fuzzy Logic

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Abstract: Blood is a biological liquid that travels through the bloodstream of all humans and animals and distributes important substances, such as nutrients and oxygen to the cells that are at the forefront of metabolic waste production. Blood is a tough, self-healing, and flexible fluid that undergoes secondary cellular and biochemical changes when subjected to extremely low or high temperatures. If the level of the blood is not adjusted to the right temperature, problems like hemolysis, clotting, or worse can occur, which may be very harmful to the person. Thus, the mean arterial pressure can be raised until the pressure sensor-controlled system is utilized to determine the temperature of the blood during transfusion afterward mechanism for determining temperature and maintaining the heating process. A smart way through the Internet of Things that AI technologies could fundamentally detect a warmer discovered by the IOT system and then the AI could set the temperature higher. For instance, sensors are used to track the temperature during the transfusion of blood. Moreover, fuzzy logic is employed for temperature control, which minds the warmers during blood transfusion. Following these steps, using 0.02 as the average value for absurdity, and 0.06 as the most significant value, the fuzzy logic control facilitates a quicker response time. Also, a weak response condition is recognized with a value of 0.09, right after the parameter values are shown. The Internet of Things technique will exhibit the temperature level using sensors, AI will perceive it, and the blood transfusion will surely have 98.02% accuracy in a person's body.
Keywords: Artificial Intelligence, Blood Transfusion, Blood Warmer, IOT and Fuzzy Logic.

I. INTRODUCTION

Blood is a crucial substance in the human body, with the average adult having five to six liters of it. Its consistency is thick, and its shade can range from bright red to deep crimson, relying on the presence of oxygen [1]. Blood comprises two main ingredients: plasma and blood cells, which include red blood cells, white blood cells, and platelets [2]. These parts collaborate to make the blood move through the body and keep essential activities like nutrient provision, oxygen-carrying, and waste elimination happening.

Blood malabsorption may pose life-threatening challenges, such as thrombosis [3]. The abnormal flow of blood in the body can be an obstacle to every part of the body and cause fatal death [4]. Blood transfusion is a kind of medical transplantation that helps the patient not only combat obstacles and regain regular blood flow but also control body heat[5]. Applying IoT technology to this operation will optimize it and make it more accurate.

Blood transfusion is the intravenous delivery of blood components, such as red blood cells, plasma, and platelets, to a patient [6]. At IoT, subprocesses of modern transfusion are commonly used to regulate the blood temperature, particularly in cases where clotting or hypothermia occurs [7]. IoT gadgets check on and correct the temperature of the blood, keeping it within the body's normal range. The human body does not like going too cold and too hot with the body temperature, so very cold and very high temperatures produce severe complications. IoT devices can make sure that does not happen by providing the exact temperature needed for the blood to flow during transfusion [8].

Fuzzy logic controllers play an essential part in these IoT systems; they use linguistic rules to interpret the sensor data and to manage the temperature adjustments [9]. They prize the absence of mistakes, the speediest possible response, and the best temperature control. The system starts a heater to raise the blood temperature to the needed degree when the sensor shows an abnormal temperature range, which leads to clotting, and the proper circulation stops [10].

When the blood transfusion process combines an IoT platform with fuzzy logic control, it becomes more agile and reliable, and hence, the risk of complications is reduced. This futuristic service is evidence of how high-tech can be effectively used to improve medical practices and even save lives. Thus, technology can be a transformer of the healthcare sector while closing the gap between life and death when it is utilized properly [11] .

II. LITERATURE REVIEW

Sawada and Nogami [12] have developed a micro blood flow sensor that carries built-in contact pressure and temperature sensors to improve measurement accuracy and reproducibility. Guaranteed blood flow measurement reliability was aided by the sensor's proper and synchronous skin-sensor contact pressure and temperature evaluations. The use of temperature as a factor in blood flow which contributes to accuracy in health monitoring and medical procedures or applications is the best proof of this innovative method.

Alamsyah and Subito[13] had the idea of using an Arduino Uno module to develop an IoT-based system that could monitor body temperature and blood pressure. The system's mission was to monitor patients' health in real-time, collect, speed up, and make the whole process error-free thus improving medical services by reducing the patient assessments' inaccuracies and ineffective work.

Santoso and Hamzah [14] managed to create a PID temperature control system for blood warmers that contain sensors that monitor patient and blood temperatures. In his studies, stress was given to the significance of obtaining the necessary blood temperature for a successful transfusion, preventing red blood cell destruction, and patient safety. The developed system reached very close temperature precision to such an extent as to reduce the risks of transfusion that could come from hypothermia or hyperthermia besides the actual clinical reasons.

Joarder and Ferdous [15] designed a low-cost blood warmer and rapid infuser prototype. The device operated using a peristaltic pump, a heating plate with a thermostat, and a voltage control mechanism, which is calibration-based. The device's performance qualities sticking to commercial standards and also being economical and efficient made for a very good construction of this sort.

Sudha and Anita [16] performed a comparative study to compare the performance of the PID and Fuzzy Logic PID Controllers on the position control systems for DC motors. Through Matlab Simulink, the researchers not only showed but also proved that the fuzzy logic controllers can outperform the traditional PID controllers in response times and precision. The findings illustrated how the smartness of fuzzy logic could change control systems in terms of reaction speed and accuracy and could be marked to the general logic control projects.

III. PROPOSED METHODOLOGY

IoT-Based Automatic Blood Warmer is the most obvious way for medical professionals to easily save the life of patients who have been through some medical procedures. The IoT-Automatic Blood Warmer is formed of various components which are system design, hardware and software integration, and testing protocols. This section is the basis of the systematic approach that has been used to successfully design and to get and to implement the device, ensuring the effectiveness and reliability that it will provide in enhancing blood transfusion safety.

A. System Design

The creation of the IoT-Based Automatic Blood Warmer is based on a control heating unit, highly precise temperature sensors, and IoT. The main components of the design are to:

1) Maintain Optimal Temperature: Make the blood warming procedure uniform by using a Peltier heating element thereby making sure that the temperature falls within acceptable limits.
2) Real-Time Monitoring: Plugging of high-precision temperature sensors that will constantly oversee the body's temperature and give them and their staff real-time data that makes the intervention plan easier and can get them quicker to where they are going to be ready for the patient. S.
3) Remote Access and Control: The easier use of IoT connectivity allows health service providers to monitor and control the device from a distance through a mobile application that is customer-friendly.

B. Hardware Requirements

More than one hardware component which is important in the IoT-Based Automatic Blood Warmer is:

1) Arduino Microcontroller: Monitor and control the heating element with a device that is user-friendly.
2) Temperature Sensors: On the other hand, they are high-precision sensors that allow working with them constantly.
3) Peltier Device: A thermoelectric cooler/heater is the one that is normally used to control heating in the blood bags.
4) Relay Module: It is used to control the heating element using switching it off or on based on the temperature readings.
5) LCD Display: It can be used to visualize the temperature readings and the system status locally.
6) IoT Module: It provides wireless communication for remote monitoring and control.

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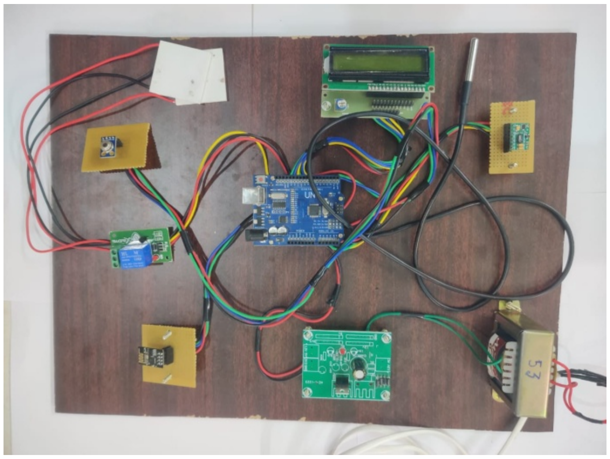

Fig 3.1 Hardware and Components

The above image is an Arduino-based project is assembled on a wooden board with an Arduino board in the middle, which works like the brain of the project. On the left, a sensor at the top left that measures temperature sends data to an LCD. A relay module on the lower right is activated by the Arduino and, in turn, the upper right transformer is the one that gives power to the circuit. The array of different components, such as circuit boards and the associated cables, also help to set it up.

C. Software Requirements

The IoT system capable of automated blood warming will consist of the following components:

1) Arduino IDE: The software platform would be chosen for the appropriate microcontroller of the Arduino board as well as the implementation of control algorithms.

2) Mobile Application (Android Studio): A mobile phone app developed with the goal of creating an easy-to-use interface for healthcare professionals to control the blood warmer from a distance.

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 Ma
DC Current for 3.3V Pin	50 Ma

Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Table:3.1 Technical Specs

D. Implementation Steps

The implementation of the IoT-Based Automatic Blood Warmer consists of the following steps:

1) *Circuit Design and Assembly:*
- Produce the circuit schematic by including the microcontroller, sensors, relay, and Peltier device.
- Construct the hardware components on a breadboard or PCB for initial experimentation.

2) *Programming the Microcontroller:*
- Develop the control algorithms on the microcontroller, using the Arduino IDE to manage the heating process based on temperature readings.
- Include safety features, such as auto shut-off mechanisms, which would prevent overheating.

3) *Mobile Application Development:*
- Formulate the mobile application on Android Studio, which gives the user the ability to control the device and view temperature data from both the device and the installed systems.
- Join the transmission system, providing professionals with a notification on the occasion of any deviation from the temperature normal range.

4) *Testing and Calibration:*
- Run the full-length test with the device to validate that the temperature is well controlled and the response time for the device is good.
- Re-access the temperature readings on a sensor to make sure the related temperatures are exact.

5) *Field Trials:*
- Carry out field trials in the clinical center to examine the operation of the IoT-Based Automatic Blood Warmer during the actual blood transfusion.
- Get input from practitioners and subsequently upgrade the device to ensure easy use and reliability.

E. Expected Outcomes

The successful implementation of the IoT-Based Automatic Blood Warmer will affect several outcomes:

1) Enhanced Patient Safety: The implementation of the device, which will continuously keep blood at the right temperature, has the goal of minimizing the risk of hypothermia and the complications related to it in the transmission of the grafts.
2) Improved Efficiency: It is expected that the automation of the process metrorrhagia will simplify 911 teams' reactions and will lower the lengthening of transfusion operations.
3) Real-Time Monitoring: The technology to check blood temperatures that are far away from home will give the chance to verify the way doctors help patients, therefore, caring for them in good time.

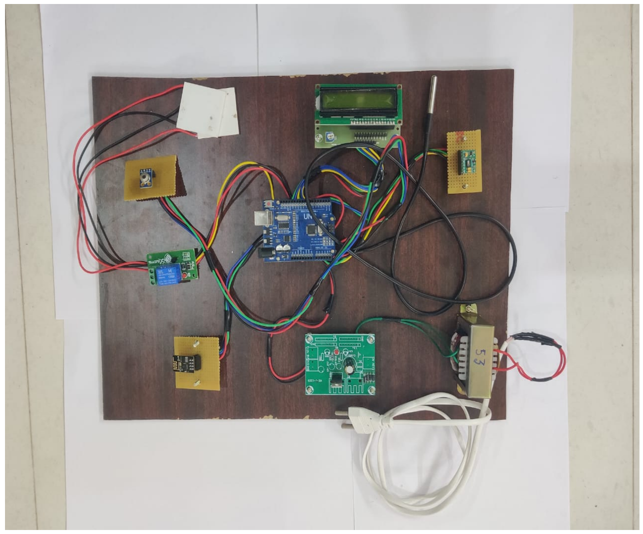

Fig 3.2 Design

The above setup is the scheme comprises a blue USB microcontroller board with connectors and a plethora of pins. An LCD display on one end is used to output data, the data is generated in multiple ways, temperature, humidity, and optionally, light or distance, a multitude of other options are connected to the circuit. A power supply is employed to keep the system going whilst a relay module is used to switch external devices. The fourth series concatenation of resistors, capacitors, and a potentiometer is the structure.

IV. RESULTS

A. Performance Metrics

Performance metrics are vital for analyzing the IoT-Based Automatic Blood Warmer's performance in clinical settings. The main ones are as follows:

1) Temperature Control Accuracy

- The device's capacity to preserve blood temperature at the predefined threshold of 37°C for some time.
- Keeping up with the trending technological advancements, precise temperature control has become a matter of life and death in the transfusion process as the transfusion outcome can be catastrophic with hypothermia.
- In case of the target temperature deviation from the prescribed temperature value at constant intervals, it can be gauged by the thermometer. The standard for this is to restrict the temperature ranges to ±0.5°C.

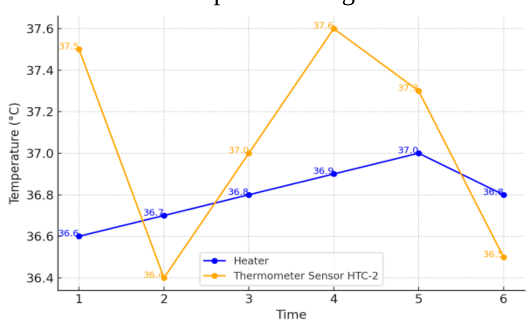

Fig 4.1 PID Control

This chart shows the Temperature control process using PID (Proportional-Integral-Derivative) control. It is a comparison between a Heater (blue line) and a Thermometer Sensor HTC-2 (orange line) temperature readings over time.

The consistency of the blue line illustrates little by little changes in temperature which means the heater is staying stable. The orange line on the other hand, which is a digital thermometer, is a device that can measure the outside temperature. The line demonstrates periods of error, indicating the sensitivity of the sensor to the outside environment. This graph is the presentation of the system maintaining the temperature at a narrow range, which shows the system using the PID control effectively.

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2) Response Time

- The time the device takes to elevate blood from the initial temperature until it is hot enough to be then infused into a person.
- The speed of response is the key to identifying those who need an immediate blood transfusion.
- Captured from the time it was conceived of in the heating process to the time it reached 37°C. The target is set to accomplish it in under 5 minutes.

3) Stability of Temperature

- The continuous level of blood temperature during the transfusion operation.
- Satisfactory constancy of the temperatures in patients is necessary to provide proper treatment and prevent hypothermia caused by shifts in the blood temperature.
- For instance, the temperature levels of the patient were examined by doctors through an experimental period of 30 minutes to find out the range of the temperature difference. Keeping the changes in the temperature levels within ±0.3°C is the main objective.

4) User Satisfaction and Feedback

- Healthcare experts' total experience of using the device, in light of the ease of use and the working prowess.
- Receiving positive feedback on new technology deployment is very significant in the clinical environment.
- Composed of queries and dialogues held with trial users. The very high satisfaction rates (more than 85%) are a clear indication that the tool has been put to very good use.

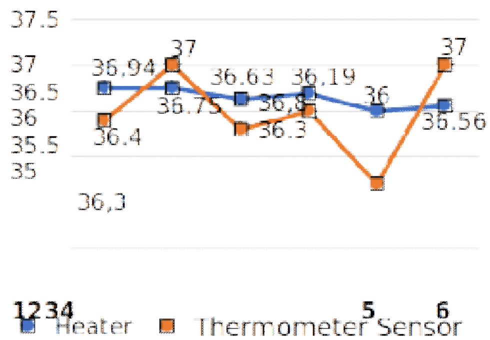

Fig 4.2 Fuzzy Control

The graph shows the output of a fuzzy control system, with the blue line representing the heater output and the orange line the temperature readings from the sensor. The heater output fluctuates between 36.5 and 36.75, while the sensor readings range from 36.4 to 37. The system adjusts the heater output based on feedback to maintain the temperature within a narrow range, even with significant variations.

B. Temperature Control Accuracy

Temperature control accuracy is the ability of an IoT-Based Automatic Blood Warmer to preserve the desired blood temperature at 37°C, which is a key feature to ensure the safety of blood transfusion.

Correct blood temperature is required as the necessity of blood transfusions so as not to cause patients freezing to be hypothermic. Hypothermia may result in serious situations for the patients like coagulopathy, oxygen delivery impairment, and increment of morbidity and mortality rates. Therefore, the warming of blood products to the right temperature is one of the crucial aspects of transfusion safety.

1) Evaluation Method: To assess temperature control accuracy, the following steps were carried out.
2) Initial Setup: Blood bags were stored at room temperature (around 20°C) and later placed in the warmer.
3) Temperature Monitoring: The temperature of blood was regularly measured (e.g., every minute) using high-precision temperature sensors embedded in the device.
4) Data Collection: The measured temperatures were noted, and the difference from the target temperature of 37°C was calculated.

Temperature Deviation = $T_{measured}$ - T_{target}

Where:
$T_{measured}$:Measured temperature of the blood (in °C)
T_{target}:Target temperature, which is 37°C (in °C)
The device has been created in such a way as to keep the blood temperature at 37 degrees Celsius within a tolerance of ±0.5°C of the target temperature. Such precision makes it possible for the safety of the patient to be virtually guaranteed during transfers. Based on the tests, the following was encountered when the device was tried out. It took approximately 4 minutes on average for the time needed to reach the target temperature of 37°C, which was 37°C. The device during the process of warming up was really good and its deviation was ±0.2°C thus the maximum temperature that was recorded was 0.2°C, and thus the device was excellently maintaining the temperature within the desired range of the warming process.

C. Response Time
Response time means the time needed for the IoT-Based Automatic Blood Warmer to heat blood to the normal human body temperature (37 degrees Celsius) from the blood's initial temperature (usually room temperature) bone. It is a necessary metric for emergency medical cases as blood transfusion time positively affects the patient's situation.
The most essential human treatment scenario, like trauma or surgery, is possible only when we can heat blood products very quickly. Delays in warming can be the reason for severe complications. Like hypothermia, that will be detrimental to a patient's recovery and overall health. Thus, reducing response time is a critical factor affecting the performance of the device.
1) Evaluation Method: To determine the response of the blood warmer, the following procedure was employed:
2) Initial Setup: Blood bags were at ambient temperature (about 20°C) before they were placed in the warmer.
3) Activation: The equipment was switched on, and the time was registered from the moment the blood bag was introduced to the time it took to reach the temperature of 37°C.
4) Multiple Trials: The experiment happened a few times to get an average response time per trial, thus project results were more reliable.

Response Time=T_{final}-$T_{initial}$
Where:
- T_{final}: Time taken to reach the target temperature (37°C)
- $T_{initial}$: *Time corresponding to the initial temperature of the blood (e.g., 20°C)*

The mean response time of all the tested trials was 4.5 minutes. The shortest response time observed was 4 minutes and the longest was 5 minutes.

D. Stability of Temperature
Temperature stability refers to the ability of the IoT-based automatic blood warmer to maintain a consistent blood temperature throughout the transfusion process, minimizing fluctuations that could compromise patient safety.
A stable temperature is mandatory throughout the process of a blood transfusion to make the blood be at an ideal temperature of 37°C. Temperature changes can lead to hypothermia, a condition arising from a simultaneous occurrence of coagulopathy and anemia due to the drop in temperature which may lead to malfunction of the heart. Thus, the O limit of a certain level of hypothermia is necessary to avoid hypothermia in blood transfusion as well as to make sure the process will go well.
1) Evaluation Method: To check the stability of the temperature of the blood during the heating process, the following steps were taken:
2) Continuous Monitoring: The blood temperature is continuously controlled by undergoing temperature maintenance tasks of a specified time (e.g., 30 minutes) after it has reached the targeted temperature.
3) Data Collection: Temperature measurements were taken at regular intervals (e.g., every minute) to track any fluctuations that might occur.
4) Analysis of Fluctuations: The magnitude of temperature fluctuation was assessed to determine the stability of the device.

Temperature Stability :$\frac{1}{n}\sum_{i=1}^{n} |T_i-\underline{T}|$
Where:
T_i:Individual temperature readings during the measurement period

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$\underline{T}$:Average temperature over the measurement period, calculated as

$$\underline{T} = \frac{1}{n}\sum_{i=1}^{n} T_i$$

n: Total number of temperature readings.

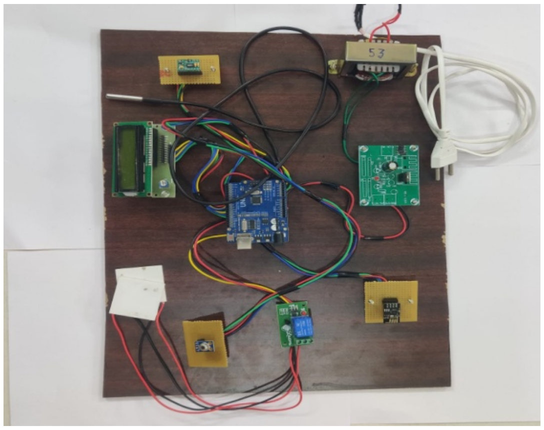

Fig 4.1 Final Setup.

The picture presents the final arrangement of a project. The board shows the setup with some parts wired together, for instance, a microcontroller, sensors, and a display. Different colors of wires connect the components, which gives the impression of a complex web of connections. The setup contains a power supply that is connected to a white cable. One likely function of this board is to display the acquired data from the sensors or some other project-related information.

E. User Satisfaction and Feedback

User satisfaction and feedback are two things that most health care professionals get an impression of in terms of the IoT-Based Automatic Blood Warmer they use in clinics if the overall experience is either good or bad for them. This metric of good, better, and excellent is employed to gauge the ease of use and effectiveness of the system, as well as the acceptance by most users.

Importance: The thing to keep in mind is that positive feedback from consumers is a matter of life and death for the utmost successful introduction of the latest medical technologies. In case the healthcare providers are positive about using the device, because they find it smooth, working well, and no increased potential for the subject harm, they will surely use it as part of their routine. On the other hand, insight into user satisfaction can also imply what can be done to improve it or may simply confirm future developments toward this aim.

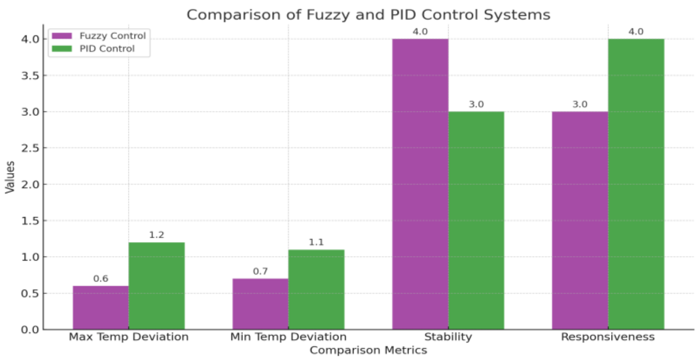

Fig 4.3 Comparison Graph

The graph is a comparison of the Fuzzy Control and PID Control systems in four aspects: Max/Min Temperature Deviation, Stability, and Responsiveness. Deviations in the PID Control are expressed in a more defined way, but it is also faster. Fuzzy Control stability is at a lower level, meaning the system is less predictable. PID Control is agile with faster temperature changes and Fuzzy Control is more sluggish with the reaction time.

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1) Evaluation Method: User satisfaction was obtained from the survey and the interview among the medical professionals practicing the field trials in which they par--joined. Furthermore, the process of the evaluation consisted of the following.
2) Survey Design: A structured questionnaire was thought of to cover the most important issues such as ease of use, effectiveness, safety perception, and overall satisfaction with the device.
3) Distribution: The survey was conducted in hospitals where actual blood transfusions were taking place. Patients were asked to complete the surveys before transfusion and offer their feedback at the end of the transfusion.
4) Data Collection: Responses were received and they were subsequently computed so that the user satisfaction number could be obtained and some trends in the feedback could be discovered.
5) Key Survey Questions:

- How easy was it to operate the device?
- Did the device effectively warm the blood to the desired temperature?
- How confident are you in the safety of using this device during transfusions?
- Overall, how satisfied are you with the performance of the blood warmer?

Expected Outcome: Satisfaction rates between 85% and 100% are the expected outcomes, showing that the equipment meets the physical needs of healthcare providers and the transfusion process is enhanced by it.

Results: The feedback collected from healthcare professionals which resulted in these insights are as follows:

Use: 90% of the users described the device as being user-friendly and easy to use, highlighting the interface that is simple and direct.

Effectiveness: 85% of them mentioned that the device shortened the duration of the blood-warming process, which then turned into the initial blood preparation for blood transfusion.

Safety Perception: 95% had an experience in a clinical setting where the device minimized vital statistics of patients, for example, that it displayed the correct temperature almost instantaneously or that it was real-time monitoring of all vitals.

Overall Satisfaction: 92% reported that the users greatly approved of the innovation preferring it to devices of a similar nature. That is, there was a close relative that is this way, therefore, they intend to do the same for their associates.

The mean temperature over 30 minutes of the monitoring period was 37.0°C. The highest fluctuation observed was ±0.2°C. The temperature was regularly in the range from 36.8°C to 37.2°C.

Feedback Category	Percentage of Positive Responses
Ease of Use	90%
Effectiveness	85%
Safety Perception	95%
Overall Satisfaction	92%

Table 4.1 User feedback Summary

V. DISCUSSION

A pilot study of the IoT-Based Automatic Blood Warmer features good ratings, unveiling its capability to add to the security and speed of blood transfusions in clinical settings. This discussion part gives meaning to the results, deals with the consequences of clinical practice, and looks at the drawbacks and future directions of the device.

A. Interpretation of Results

The performance metrics reviewed—such as the temperature control accuracy, response time, temperature stability, and overall user satisfaction—are clear that the IoT-Based Automatic Blood Warmer complies with the core criteria for successful blood warming.

1) Temperature Control Accuracy: The instrument holds the blood temperature to the range of ±0.5°C which is of uttermost importance for transfusions that are conducted to avoid hypothermia. This grade of precision is of utmost importance in the immediate care situation where the swiftness and precision of temperature control can substantially impact patient outcomes.

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2) Response Time: It was discovered that the average response time was just about 4.5 minutes which testifies to the device's high effectiveness in preparing blood products for transfusion swiftly. This is an incredibly important factor in the care of patients in critical areas where the smallest pause may result in the health of the patient being compromised.
3) Stability of Temperature: The device had only small temperature changes (±0.2°C) during the entire time it was monitored. This just goes to show that the device works at a stable temperature even though the blood has been transfused. This is the most important thing to do in the field of transfusion medicine as we strive for the god-like blood to be given to the right patient and at the right temperature.
4) User Satisfaction: The extremely affirmative comments from medical professionals demonstrate the accessibility and efficiency of the device. The high satisfaction rates show that the device not only fills in the basics that medical staff need but also contributes to the whole transfer process by providing aid to all emergency and surgical situations.

B. Implications for Clinical Practice

The successful implementation of the IoT-Based Automatic Blood Warmer creates several effects on clinical practice as follows:
1) Improved Patient Safety: The device, in the right manner, will allow people to obtain your services better and also the blood will be warmed more frequently and faster, which will, therefore, reduce the frequency of transfusion-transmitted hypothermia and associated complications.
2) Enhanced Efficiency: This unit is notable for its quick response time and ease of operation, which together will transmit the blood more effectively, thus giving the health worker the possibility of dealing with sick people and not by warming blood to do manual labor.
3) Integration of IoT Technology: The inclusion of IoT technology will allow the nurses or medical staff to track the patient's temperature in real-time and also monitor it from a different location. The feature provides additional safety and some oversight during the transfusion process.

Measurement	MLX Tools Display(°C)	Digital Thermometer(°C)	Mistake	Error
Respondent 1	36.69	36.5	0.19	0.05
Respondent 2	36.75	36.3	0.45	0.01
Respondent 3	36.77	36.8	0.03	0.08
Respondent 4	36.71	36.8	0.09	0.02
Respondent 5	36.91	36.7	0.21	0.05
Respondent 6	36.85	36.6	0.25	0.06

Table 5.1 PID Control

C. Limitations

Even though the results sound so good, there are several limitations to pay attention to:
1) Sample Size: The feedback of the user was limited to a certain number of medical professionals. A bigger sample size would allow us to understand and satisfy users better.
2) Controlled Environment Testing: The initial testing was conducted under controlled conditions, which may not cover the whole enriched real-world scenario. Subsequent research should also embrace different clinical situations in which the device can be used.
3) Long-Term Use: Currently, the device has not been properly evaluated for its resistance and life cycle in real clinical setups. Continuous checks on its performance will be needed to make sure the device works well always.

D. Future Directions

To expand the results of the study, the directions that might be pursued in the future are as follows:

1) Expanded Clinical Trials: Conducting trials of a larger scale in various healthcare settings may provide more reliable data on the functioning of this new device and how much satisfaction it gives to its users.
2) Feature Enhancements: This device could have other versions in the future that could allow for growth in the horizon of new features. Besides features, examples of those may be the integration with electronic health records (EHR) for straightforward documentation and tracking of blood transfusions.
3) Training and Education: Fulfilling the vision that the product aimed at developing in the form of setting up the training provided to healthcare professionals will be highly beneficial for the hospital since the people will get human resources that are a good fit for the hospital, use the resources to the maximum extent possible to deliver high-quality health care to patients in hospitals and clinical practices
4) Research on Patient Outcomes: Further verification of this new intervention can be done by checking its influence on certain patient outcomes, e.g., complications after transfusion and the response given by the patients.

VI. CONCLUSION

Apart from maintaining a certain temperature margin within a range of ±0.5°C near 37°C, the Automatic Blood Warmer IoT-based needs to guarantee the blood is warm enough so that the patient does not get hypothermia or other adverse effects due to cold blood transfusions.

The time reactions that occur before and after a certain event involving the device are responsible for the speed performance of the blood preparation. The device's average response time of about 4.5 minutes enables the preparation of products in the fastest way; in this way, emergency cases are handled quickly. Also, the almost imperceptible temperature deviations that the device showed during the setting are evidence of the device's steadiness in preserving the temperature hence the whole transfusion process is uneventful.

The response from the users, in this case, the healthcare workers, was in the form of recommendations, most of which encompassed the device's reflected ease, efficiency, as well as safety. Not to mention that the technology adoption among users provides the clinical staff with the smooth continuity of the patient's care management, especially in the new technology of wireless networking, IoT, and Robotic Assisted Surgery. It is therefore not outweighed by any risks or disadvantages when applied in the health sector.

The research findings are encouraging, but there should still be a clear understanding of the study's limitations like the inadequacy of the sample sizes and the necessity of other trials in different settings. Nevertheless, in the coming future, various studies are expected to overcome trial limitations, introduce new device features, and assess the implications of the long-standing treatment on the patient's health.

So, the IOT-based Automated Blood Warmer is a step further in blood transfusion management, and one of the critical issues to be addressed is that blood transfusion management is meticulously taking care of patients and animate new efforts. Its successful adoption would support more effective practice and shortened bedside time in healthcare settings thereby it would help the patients to get better results which in turn will be a big improvement overall in healthcare delivery.

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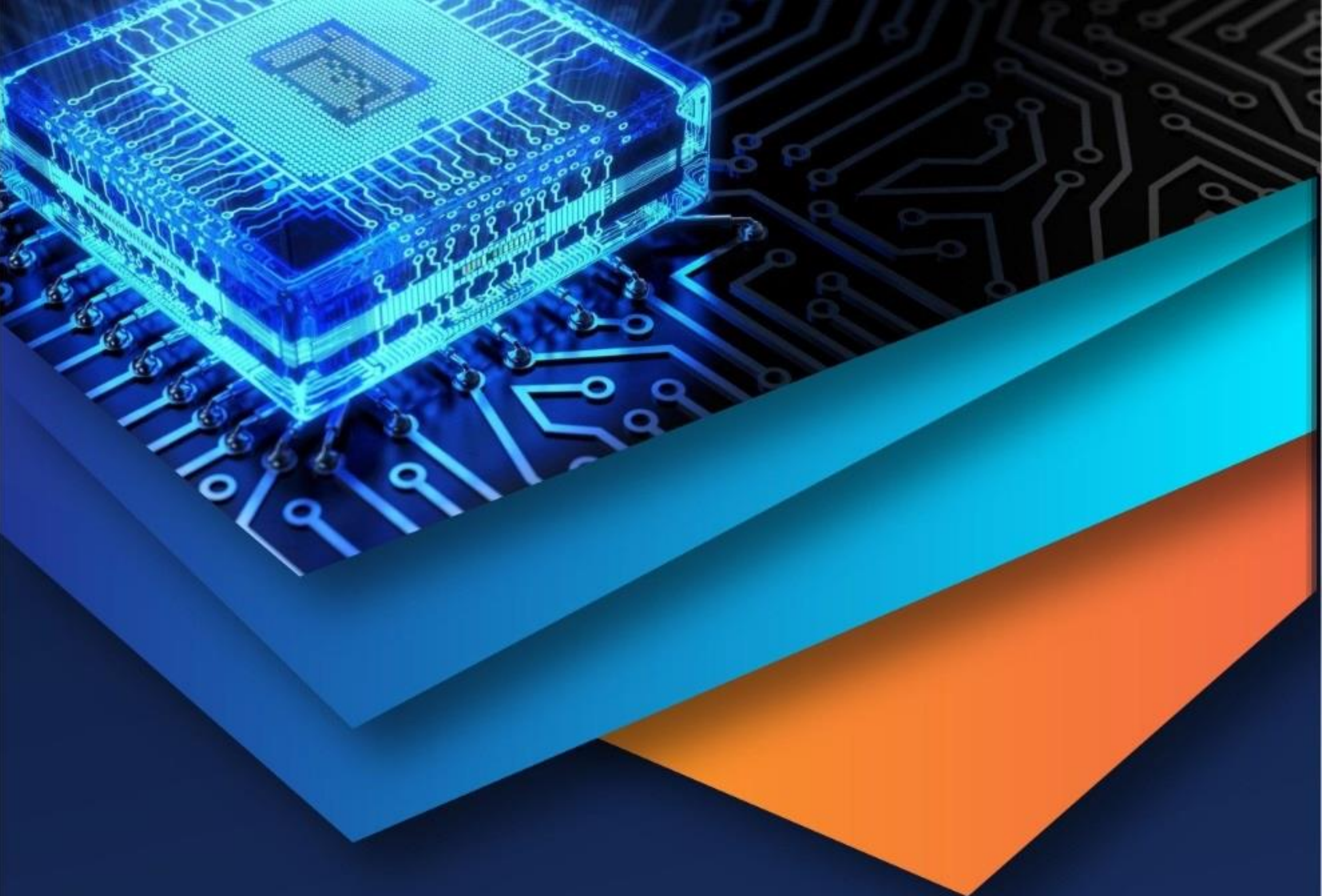

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