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Arduino-Based Baby Bath System with Accurate Water Level and Temperature Control

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ABSTRACT

Infant bathing can be challenging for parents due to safety and temperature control concerns. This study aimed to develop and evaluate a fully automated baby bathtub system featuring water level and temperature control using an Arduino Mega 2560 microcontroller. This system was designed to ensure a safe and comfortable bathing environment for infants while providing convenience for parents. The methodology involved designing and assembling key components, including a 4x4 keypad, relays, water level, and temperature sensors. The system underwent comprehensive testing to evaluate its functionality and accuracy. The results showed that the system maintained a consistent water level of 9 liters and controlled water temperature within a narrow range. For example, when the actual water temperature was 37.8°C, the sensor reading was 37.5°C, demonstrating a minor deviation of 0.3°C. Overall, temperature deviations ranged from 0.5°C to 1.0°C from the setpoint. The total operation time for preparing the bathtub, including heating and filling, ranged from 15 to 20 minutes. All components functioned correctly during testing, confirming the system's reliability and accuracy. In summary, the automated baby bathtub system successfully meets its design objectives, offering a safe, efficient, and user-friendly solution for infant bathing while assuring parents of its safety and ease of use.

INTRODUCTION

Maintaining an appropriate water level in a baby bathtub is essential for several reasons. First, it is crucial to ensure the safety and comfort of infants during bathing. Appropriate water levels minimize the risk of drowning or discomfort, which are significant concerns for infant safety [1]. The use of technology such as ultrasonic sensors can aid in monitoring and controlling water levels to prevent overflow and ensure safety [2]. Second, maintaining the correct water level is essential for preventing accidents such as slipping or falling, which could harm the baby [3]. Furthermore, maintaining an optimal water level can enhance the bathing experience by providing adequate support and comfort for infants, which is crucial for their psychological and physical well-being [4]. Third, the water level in a baby bathtub is vital to ensure proper hygiene and skincare for infants. While bathing with water alone may be effective, using mild liquid baby cleansers can be superior in cleansing and conditioning the skin [5], [6]. These cleansers can also help prevent conditions such as diaper dermatitis [6]. Finally, the concept of maintaining water levels in a baby bathtub can be linked to broader scientific methodologies, such as the bathtub approach used in various studies related to coastal flooding and inundation modeling [7], [8], [9], [10]. This methodology emphasizes the significance of water levels for baby care and scientific modeling and risk assessment in coastal areas. By understanding the importance of water levels, parents and caregivers can ensure the safety, comfort, and well-being of infants during bathing, and scientists can use this concept to develop more accurate models for coastal flooding and inundation.

Although water temperature during bathing is crucial for an infant's well-being, it is essential for high-risk infants, as researched [11]. An appropriate water temperature is essential for preventing heat loss through various means, such as radiation, conduction, and evaporation [12]. This is particularly significant for premature infants more susceptible to temperature changes. Swaddle bath techniques, as mentioned in [13], partially wrap the baby in a soft cloth or blanket during the bath to reduce heat loss and stress and help maintain thermal stability. These techniques can help maintain thermal stability, and it is recommended that the first bath be administered only when the baby is stable.

In addition, the water temperature can influence the comfort and general experience of the baby during the bathing process. A study conducted recommends taking special precautions when bathing newborns to avoid the risk of hypothermia [6]. Applying swaddle bathing techniques has been demonstrated to be

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beneficial for maintaining a baby's body temperature [14]. Furthermore, research indicates that limiting the bath duration can prevent cold stress and minimize exposure to soap, emphasizing the significance of maintaining control over water temperature [15].

Furthermore, the consequences of water temperature on newborns extend beyond comfort. It can also influence physiological parameters and the duration of crying. Research has shown that stimulating the palmar grasp reflex, an involuntary response in which an infant instinctively grasps an object placed in the palm during bathing contributes to maintaining physiological stability and decreasing crying times in babies. This reflex is a key indicator of neurological development in newborns and provides a sense of security when engaged in care routines. This directly connects water temperature, bathing techniques, and infant well-being. [16]. This underscores the intricate relationship between water temperature, bathing practices, and babies' overall experience.

Additionally, studies have demonstrated that tub bathing can improve thermoregulation in late preterm infants, suggesting that careful management of water temperature is vital for maintaining normothermia [17]. The recommended bathing temperature for infants is typically approximately 37°C, and deviations from this range can lead to discomfort or health risks [18].

The impact of the water temperature in the bathtub extends beyond its direct influence on the baby. Research has demonstrated the significance of water temperature in preserving skin integrity, as using specific temperatures in bathing newborns is safe and effective in maintaining skin health. [18]. By controlling water temperature, parents can avoid potential skin issues and ensure the well-being of their child, thereby highlighting the broader implications of temperature control during bathing.

Additionally, how newborns are bathed can affect the frequency of hypothermia. A randomized controlled trial conducted in Uganda demonstrated that bathing newborns shortly after birth increased hypothermia, even when warm water was used, highlighting the importance of correct bathing techniques and water temperature in preventing unfavorable results. [19]. This highlights the importance of maintaining an appropriate water temperature to protect newborns from potential health hazards.

This paper presents the development of a novel baby bathtub with automatic water level and temperature control features utilizing an Arduino Mega 2560. This innovation aims to enhance the safety and comfort of babies' bathing experiences. The system effectively regulates the water level to prevent excessive submersion or inadequate water levels, ensuring baby safety. Moreover, the temperature control feature maintains a consistent and ideal water temperature, reducing the likelihood of overheating or exposure to cold temperatures. Incorporating automated features into the bathtub minimizes human error risk, thereby providing parents with a dependable and convenient solution to safeguard their babies during bathing.

METHODS

The fundamental objective in designing and constructing the baby bathtub was to devise an automated system regulating water level and temperature. An Arduino Mega 2560 was used as the central control unit to achieve this objective. This device supervised the entire process, filling the water and ensuring the desired water level was maintained in the heating tank and baby bathtub. The K-0135 water level sensor was used to track the water levels. At the same time, the operating time of the heating element was controlled to ensure that the water temperature reached the specified setpoint, which could be adjusted through a 4×4 keypad. Temperature changes were displayed on an LCD screen for real-time monitoring. The procedure employed in this study encompasses several essential stages.

In the initial stages of the research, Ponorogo Regency's medical service institutions became the subjects of field studies aimed at collecting data and information on the guidelines and requirements for baby bathtubs that adhere to medical standards. The primary goal of these studies was to ensure that baby bathtub designs were safe and compliant with medical recommendations. Furthermore, the research team conducted literature reviews to amass data and information from scholarly sources, including journals, books, and other pertinent materials. This literature review aimed to obtain information that would aid in the design and execution of an automated baby bathtub and temperature control system.

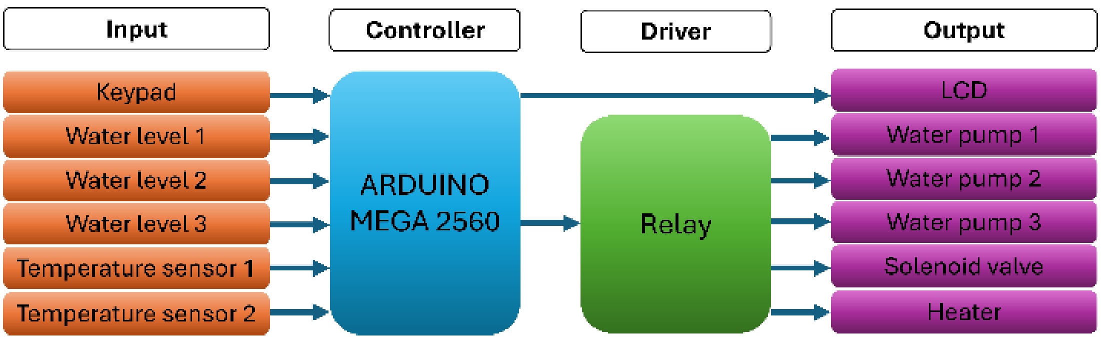

Figure 1. Block Diagram of The System

The creation of the baby bathtub commenced following the completion of the data-gathering stage, during which the system design, block diagram, hardware configuration, software development, and component selection were developed. Figures 1 and 2 show the baby bathtub's system block diagram and preliminary design, respectively.

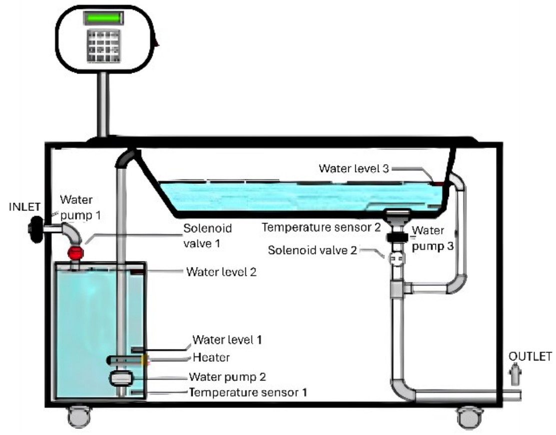

Figure 2. Design Layout of the Baby Bathtub System

Before the final design was implemented, each component in the system underwent individual testing to ensure proper functionality. The results of these tests were documented, including test images and performance tables for the components. Table 1 shows the elements incorporated in the construction of the automated baby bathtub, which boasts temperature regulation based on the Arduino Mega 2560.

Table 1. Components Used in the Baby Bathtub Design

Component	Specification	Function
Arduino	Mega 2560	Central control unit for system operations
Keypad	4×4 matrix	User input for setting water temperature
LCD	16×2	Displays temperature and system status
Relay	4 ch, 5V	Controls power to the heating element and other devices
Temperature sensor	DS18B20	Monitors water temperature for regulation
Water level sensor	K-0135	Measures water level in tank and bathtub
Solenoid water valve	12V DC	Controls water flow automatically.
Heating element	220V AC 600 W	Heats water to the desired temperature
Water pump	12V DC	Circulates water within the system.

Once the component testing was successfully concluded and its operational capabilities were verified, the design progressed to assembling the hardware and integrating all components based on the wiring diagram. Figure 3 presents a comprehensive illustration of the wiring diagram, depicting the assembly of each block in the system.

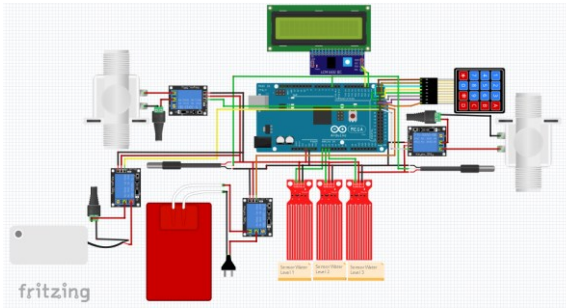

Figure 3. Wiring Diagram of the Baby Bathtub System

Following the construction of the system's physical components, an Arduino program was created per the software-planning flowchart. Coding was executed using the Arduino Integrated Development Environment (IDE) to ensure that the keypad, LCD, sensors, and drivers function according to the planned flowchart; coding was executed using the Arduino Integrated Development Environment (IDE). The resulting code was uploaded to an Arduino Mega 2560 microcontroller. The programming pseudocode of the baby bathtub system can be seen in Appendix A.

The evaluation process for the automated baby bathtub with temperature regulation was conducted to verify its compliance with the original design specifications. All test outcomes, including visual representations and an extensive table, were documented meticulously. Finally, a report was prepared that encompassed conclusions and suggestions based on the design and realization of an automated baby bathtub with temperature regulation powered by the Arduino Mega 2560.

RESULTS AND DISCUSSION

This paper's results and discussion section focuses on the design's implementation, followed by the testing of individual components and the entire system. Each testing phase is conducted to ensure that all components meet the specified criteria and that the system functions optimally, as the design intends.

Figure 4. The frame of The Baby Bathtub

Implementation of the baby bathtub design

The device's frame was constructed using hollow iron measuring 2 cm × 2 cm with a thickness of 0.7 mm. It was 85 cm in length, 40 cm in width, and 100 cm in height. This structural design provides a sturdy and secure foundation for baby bathtub systems, ensuring durability and safety. The selection of the hollow iron aims to strike a balance between strength and weight, resulting in a robust and manageable frame. Figure 4 shows the baby bathtub

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frame and the precise measurements and assembly process of constructing the framework.

The baby bathtub utilized in this study was made of a plastic material with a thickness of 0.7 mm. It was 69 cm in length, 41 cm in width, and 19 cm in height. The plastic material ensures that the tub is both lightweight and durable, providing a safe and comfortable environment for the baby. In addition, the plastic construction of the tub makes it easy to clean and maintain.

Figure 5. Baby Bathtub With An Automated Water Level and Temperature Control System Based on Arduino Mega 2560

The electronic circuits were constructed by connecting the pins of the Arduino Mega 2560 with the keypad, LCD, sensors, and drivers employed in the device by the wiring diagram depicted in Figure 3. This process guarantees that all the components interact effectively and perform as intended. Upon establishing these connections, all components were combined into a cohesive system, resulting in an automated baby bathtub device. This system relies on an Arduino 2560-based control mechanism to regulate water level and temperature precisely and reliably. Automation enhances the safety and convenience of the bathing process. Figure 5 shows the completed assembly of the device, showing the seamless integration of the electronic components with the physical structure. This comprehensive assembly process is vital for attaining the desired functionality and performance of an automatic water level and temperature control system in a baby bathtub.

Component and functionality tests

Component testing was performed to confirm that each element was operating correctly. Table 2 provides the test results for Arduino Mega 2560. The table shows that all ports were successfully detected during the testing process, the program upload procedure was completed without issues, and the serial monitor displayed the expected output. These results suggest that Arduino Mega 2560 operates normally and can execute its intended functions within the system. Ensuring the proper functionality of the Arduino Mega 2560 is critical because it serves as the central control unit for the automated baby bathtub system, managing the water level and temperature control processes. The successful testing of this component assures its dependability and capacity to integrate seamlessly with other elements in the overall system, thereby supporting the effectiveness of the entire design.

Table 2. Test Results of Arduino Mega 2560 Functionality

Test	Success	Failure
Port detection	Yes	No
Program upload	Yes	No
Serial monitor output	Yes	No

The subsequent evaluation of the 4 × 4 keypad revealed that this component usually operates, as the LCD accurately reflects each button pressed. This indicates that the keypad effectively communicates input commands to the system, ensuring reliable user interaction. The functionality of the keypad is critical for setting parameters, such as the desired water temperature within the automated baby bathtub system.

In addition to the keypad, a 4-channel relay was also tested, and the results demonstrated that this component operates as expected across all channels. Specifically, when the pin is set to low (0), the normally open (NO) status is off, and the normally closed (NC) status is on. Conversely, when the pin is set to high (1), the normally open status is on, and the customarily closed status is off. This consistent behavior across all channels confirms the relay's ability to effectively control various electrical components, such as heating elements and water pumps. The successful testing of both the 4 × 4 keypad and the 4-channel relay reinforces the reliability of the system's control mechanisms, ensuring that the automated processes function smoothly and according to the design specifications.

Table 3. Test Results of Water Level Sensors via LCD Display

Water level	Sensor 1	Sensor 2	Sensor 3
Empty bathtub	Water is empty	Water is empty	Water is empty
Full bathtub	Water is full	Water is full	Water is full

Table 3 shows the test results for the water-level sensors, which demonstrated accurate performance during testing. When the bathtub was emptied, all the sensors correctly indicated an empty status, which was displayed on the LCD. Similarly, when the bathtub was filled with water, all the sensors accurately detected the full status, and this information was also displayed on the LCD. These results confirm that the water-level sensors function as intended, providing reliable and precise measurements of the water level within the bathtub. Accurate detection by these sensors is crucial for automated water level control, ensuring that the system can maintain the desired water volume within the bathtub. The successful operation of these sensors is essential for the overall effectiveness of the baby bathtub system as it directly affects the safety and reliability of the water level management process.

Temperature sensor testing was conducted to evaluate the accuracy of the temperature readings from Sensor 1 (T1) and Sensor 2 (T2) in comparison to a reference measurement taken from a digital thermometer (T). As shown in Table 4, the readings from both sensors demonstrated a high level of accuracy, with differences (ΔT) ranging from 0.1°C to 0.7°C compared to the digital thermometer. This indicates that the sensors can effectively monitor the temperature within the system.

Table 4. Test Results of Temperature Sensors. T is the temperature reading from the digital thermometer, T_1 is the temperature reading from sensor 1, T_2 is the temperature reading from sensor 2, ΔT_1 is the difference between T_1 and T, and ΔT_2 is T_2 and T.

***T* (°C)**	***T*1 (°C)**	***T*2 (°C)**	**Δ*T*1 (°C)**	**Δ*T*2 (°C)**
30.1	29.5	29.5	0.6	0.6
34.7	34.0	34.5	0.7	0.2
35.6	35.0	35.5	0.6	0.1
36.7	36.5	36.0	0.2	0.7
37.8	37.5	37.5	0.3	0.3

However, slight inconsistencies were noted in the readings of the two sensors for specific measurements. These variations are likely due to the uneven mixing of hot water with the existing water in the system during measurement. When new hot water is added, blending thoroughly with the existing water may take some time, resulting in temporary differences in temperature readings between the two sensors.

Despite these minor discrepancies, the overall accuracy of the sensors is sufficient to meet the system's requirements, ensuring that the water temperature in the baby bathtub remains within the desired range. These findings validate the effectiveness of the temperature sensors in providing reliable and precise temperature control within the automated system.

The comprehensive testing process was then implemented to assess the functionality of the baby bathtub, which incorporated an Arduino Mega 2560-based automatic water level and temperature control system. The primary objective of this test was to confirm that the system functioned as intended and fulfilled the design criteria. Throughout the testing process, the device operates automatically from inception to conclusion after the user has specified the desired temperature setpoint and differential and subsequently presses the enter button or the "D" key on the keypad.

The process commenced with filling the heating tank with water, which was followed by heating the water to a controlled temperature. Subsequently, the heated water was distributed into a baby bathtub, where the water level was maintained at a depth of 7 cm. The water temperature was closely monitored and controlled to align with the setpoint, providing a comfortable bathing experience for the baby. This precise control guarantees that the water temperature is safe and soothing, assuring parents regarding the safety and dependability of the device.

The system also incorporates a highly efficient drainage mechanism that ensures that the bathwater is drained smoothly once the bathing process is complete. The successful operation of the device during this testing phase is a testament to its ability to automate the entire bathing process, including water heating, filling, and maintaining the desired water level and temperature. This results in a comfortable and secure bathing experience for the baby while also providing parents with peace of mind that the system is user-friendly and reliable.

Table 5. Test Results of The Overall System. T_{set} is the temperature setpoint, T_W is the water temperature in the bathtub, ΔT is the difference between the setpoint temperature and the water temperature, t_T is the time taken to fill the water tank, t_H is the time for heating the water, t_B is the time to fill the bathtub, and Σt is the total time for bathtub preparation.

***T*set (°C)**	***tT* (m:s)**	***t*H (m:s)**	***t*B (m:s)**	**Σ*t* (m:s)**	***T*W (°C)**	**Δ*T* (°C)**
35	1:32	12:24	1:23	15:19	35.5	0.5
36	1:35	14:07	1:25	17:07	37.0	1.0
37	1:36	15:56	1:27	18:59	38.0	1.0
38	1:35	17:23	1:22	20:20	38.5	0.5

The outcomes of extensive system testing are presented in Table 5. The testing involved modifying the initial temperature from 35°C to 38°C and measuring the time required to prepare the bathtub with a maximum water volume of 9 liters. The preparation time ranged between 15 min and 20 s and 20 min and 20 s. Most of this time was spent on heating the water, and the duration increased as the volume of water to be warmed increased. This indicates that water heating is the most demanding step in the system's operational procedures. Research suggests that the water temperature for a baby's bath should generally be maintained between 37 and 38°C. [11], [20]. This temperature range minimizes heat loss, which is particularly important for newborns who are more susceptible to hypothermia because of their limited ability to regulate their body temperature. [17], [21].

Furthermore, the testing revealed a slight difference between the initial and final water temperatures in the bathtub, with variations ranging between 0.5°C and 1.0°C. This discrepancy arises because of the time required for hot water from the heating tank to mix evenly with the water in the bathtub. Thus, there was a delay in the temperature sensors detecting the final water temperature, causing the heater to turn off later than intended. Consequently, the water temperature in the bathtub was slightly higher than the predetermined temperature.

The maximum deviation from the recommended bathing temperature, approximately 37°C, can vary based on individual infant responses and environmental conditions. Although specific studies do not universally define a maximum deviation, it is critical to recognize that even slight increases above the recommended range can lead to physiological stress responses. For example, excessive heat can exacerbate transepidermal water loss (TEWL), compromising skin barrier function, as indicated by Lund et al. [18]. This mainly concerns newborns whose skin is more susceptible to dehydration and irritation. Regarding maximum temperature deviations, although specific numerical thresholds are not universally established, it is advisable to avoid temperatures above 39°C to prevent overheating and associated risks such as hyperthermia or heat stress [22](Sarkar et al., 2010). Additionally, the literature emphasizes the importance of monitoring infants' behavioral cues during bathing, as signs of distress, such as crying, can indicate discomfort or overheating [11], [23]. With a typical bathing temperature set at 37°C and a maximum deviation of 1.0°C observed in the system, the water temperature remains safely below the upper threshold of 39°C, as recommended in prior studies to prevent risks such as

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hyperthermia or overheating. This demonstrates that the system is safe and reliable for bathing infants.

The slight temperature variation observed in the water results from the system's response time in adjusting the heater based on the sensor readings, which signifies the inherent delay in achieving temperature equilibrium as the warmer water mixes with the cooler water in the bathtub. Despite this minor fluctuation, the system maintained the water temperature within a narrow range of the desired setpoint, ensuring that the water was comfortable and safe for the baby.

In general, the operation of the system for regulating the water level and temperature in a baby bathtub with a maximum capacity of nine liters is highly effective, with only minor fluctuations in temperature that do not significantly impact the safety or comfort of the bathing process. These results indicate the system's dependability in fulfilling its intended purposes and provide evidence for a secure and convenient means of automating baby bathing.

CONCLUSIONS

The automated baby bath system, utilizing an Arduino Mega 2560 for water level and temperature control, has been proven to be reliable and effective in meeting its design objectives. Comprehensive testing confirmed the accurate functioning of all components, including the keypad, relays, water level sensors, and temperature sensors, allowing the system to efficiently automate the bathing process. With a maximum water volume of 9 liters, the system maintained the water temperature within a close range of the setpoint, ensuring a safe and comfortable environment for infants. Although minor temperature discrepancies of 0.5°C–1.0°C were observed, they were within acceptable limits, primarily owing to the natural delay in temperature equilibrium. The system's overall operation time of 15–20 min, influenced mainly by the water heating process, reflects its efficiency in preparing the bathtub for use. In conclusion, the system successfully delivers a secure and user-friendly bathing experience, making it a valuable tool for parents to focus on their infants' safety and comfort during bathing. Future research could explore the integration of additional features, such as adaptive temperature control based on real-time feedback from infant behavior or environmental conditions. Furthermore, extending the functionality of the system to include remote monitoring and control via smartphone applications could enhance the usability and accessibility for parents.

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APPENDICES

A. Pseudocode of the programming code in Arduino

```
Start
    Initialize Arduino Mega 2560
    Set the temperature setpoint and differential (Diff)

    Loop
        // Tank Sensor and Pump Control
        Read MAX Tank Sensor (LV2)
        If Tank Volume >= 7 Liters, Then
            Turn ON the Tandem Pump and Solenoid 1
        Else
            Turn OFF Pump 1 and Solenoid 1
        End If

        Read MIN Tank Sensor (LV1)
        If Tank Volume > 4 Liters Then
            Continue Process
        Else
            Return to Start Point (Restart process)
        End If

        // Temperature Control
        Read the Water Temperature Sensor
        If Water Temp < Set Point Then
            Turn ON Heater
        Else
            Turn OFF Heater
        End If

        // Sub Tank Sensor and Pump 2 Control
        Read Sub Tank Sensor 2
        If Water Temp < Set Point Then
            Continue Process
        Else
            Repeat Reading (Go back to Read Sub Tank Sensor 2)
        End If

        // Bathtub Water Level Control
        Read Bathtub Water Level Sensor
        If Bathtub Volume >= 9 Liters, Then
            Turn OFF Pump 2
        Else
            Turn ON Pump 2
        End If

        // Water Flow Check
        Check Water Flow
        If Flow is Sufficient, Then
            Turn ON Pump 3 and Solenoid 2
        Else
          Repeat Reading (Go back to Read Bathtub Water Level Sensor)
        End If
    End Loop
End
```


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