Automatic Water Pumping System with Adjustable Water Level Thresholds

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Abstract

The development of an automated water pumping system has been presented in this paper, designed to operate effectively even at low water levels, specifically below 30 centimeters. This capability distinguishes it from conventional automatic water pumps commonly available, which often face limitations regarding the minimum water level for operation. The designed system enables users to adjust the initial water level threshold down to a minimum of 5 centimeters, making it suitable for applications in shallow water sources or areas requiring rapid drainage to prevent damage to property. The system incorporates a sensor for detecting and measuring water levels, with a servo motor enabling dynamic adjustment of the sensor's height. Data from the sensor is transmitted to a microcontroller for processing, which then precisely controls the on/off state of the automatic water pump via a relay. Users can monitor system information through an OLED display, remotely access data, and control the system via the Blynk application. Experimental results have confirmed the robust stability of both the water level threshold control and the pump operation.

Keywords: Automatic Water Pump, Low Water Level, Adjustable Threshold, IoT

1. Introduction

The critical importance of effective water management and the mitigation of water-related disasters are highlighted by various research efforts. The impact of flash flooding on urban transportation networks necessitates multi-scale assessment frameworks for better management [1]. Similarly, the development of monitoring and early warning systems for flood invasion into critical infrastructure like subway tunnels is crucial for preventing casualties [2]. In industrial settings, managing alarm floods, which can overwhelm operators during critical events, requires sophisticated online analysis techniques [3]. Furthermore, precise water level monitoring is essential in diverse applications, ranging from agriculture, where contactless systems using image recognition are being developed for efficient crop management [4, 5], to coordinated emergency response in interconnected electricity and drainage networks during rainstorm disasters [6]. The assessment of groundwater vulnerability, particularly in regions reliant on it as a primary freshwater source, also underscores the need for accurate water level and quality monitoring [7]. Advanced techniques like image-based water level estimation using single cameras are being explored for robust and accurate measurements in various environments [8].

Building upon these advancements, this paper details the design and evaluation of an automatic water pumping system with adjustable water level thresholds, addressing the limitations of existing systems by enabling operation at very low water levels and offering user-configurable thresholds for diverse applications.

2. System Design

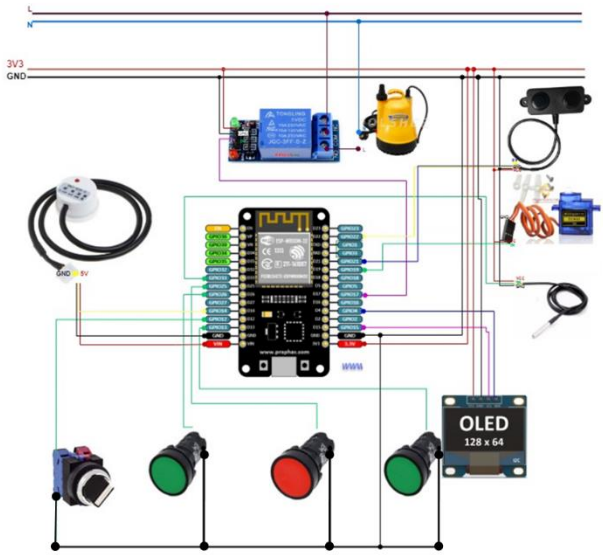

Fig. 1 Automatic water pump system structure

The automatic water pump system structure shown in Fig. 1 comprises a main processing unit, an ESP32 microcontroller. It coordinates water detection from a Non-contact Water Level sensor and an Ultrasonic sensor. A waterproof temperature sensor is installed to measure the water pump's temperature during operation. Processed data is displayed on an OLED screen. A rotary switch allows selection between Auto/Manual operation modes. Two push buttons control the rotation direction of a servo motor to increase or decrease the measurement height of the Non-contact Water Level sensor. Additionally, there's a push button for turning the water pump on or off in Manual mode. The water pump's on/off function is controlled via a relay.

2.1 System Structure

The operational flow of the automatic water pumping system with adjustable water level thresholds is illustrated in Fig. 2. The system initiates operation by measuring values from the water level sensor and the waterproof temperature sensor. This data is then used for decision-making and display purposes. Measurement data is displayed via the Blynk application and an OLED screen,

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enabling users to continuously monitor the system's status. User can select the system's operating mode between Auto and Manual.

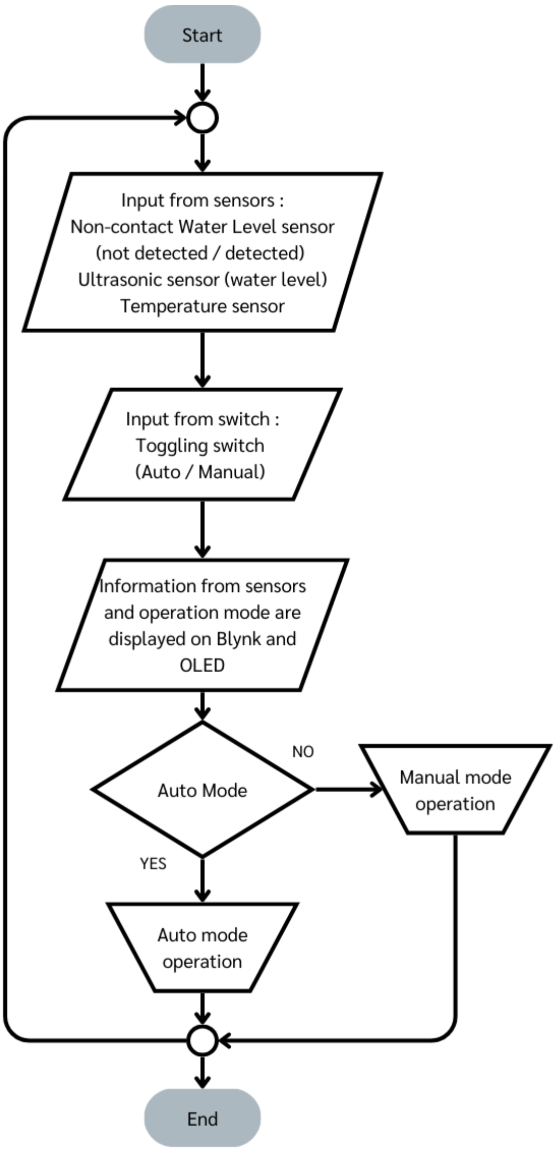

Fig. 2 Flowchart of automatic water pumping system and control via smartphone

From Fig. 3, in Auto mode, the system automatically controls the water pump's operation. It checks the water level against predefined thresholds. If the water level is within the desired range, the system will activate the relay to turn the water pump on. Conversely, if the conditions are not met, the system will deactivate the relay to stop the water pump.

From Fig. 4, in Manual mode, the user desires to control the water pump themselves. They can use the On/Off switch to manually activate or deactivate the water pump as needed.

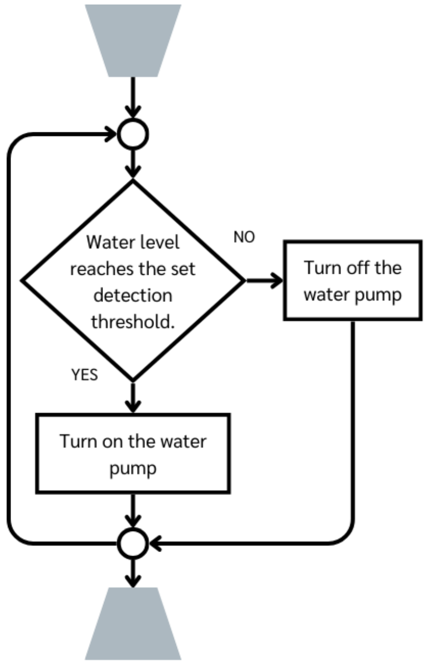

Fig. 3 Flowchart of water pumping system in Auto mode

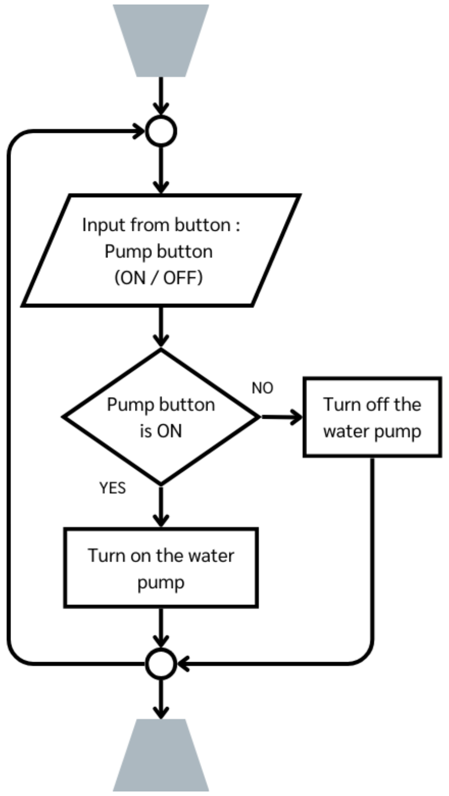

Fig. 4 Flowchart of water pumping system in Manual mode

The control mechanism of the servo motor rotating a pulley to adjust the position of the Non-contact Water Level sensor is illustrated in Fig. 5. It begins by receiving button press input. If the increase button is pressed, the servo motor rotates to move the Non-contact Water Level sensor upwards by 1 cm per press. Conversely, if the decrease button is pressed, the servo motor rotates to move the Non-contact Water Level sensor downwards by

1 cm per press. However, in the event that both the increase and decrease buttons are pressed simultaneously, or if neither button is pressed, the Non-contact Water Level sensor will not change its position. The system displays the height of the Non-contact Water Level sensor from the ground on the Blynk application, and this height also serves as the water detection threshold value.

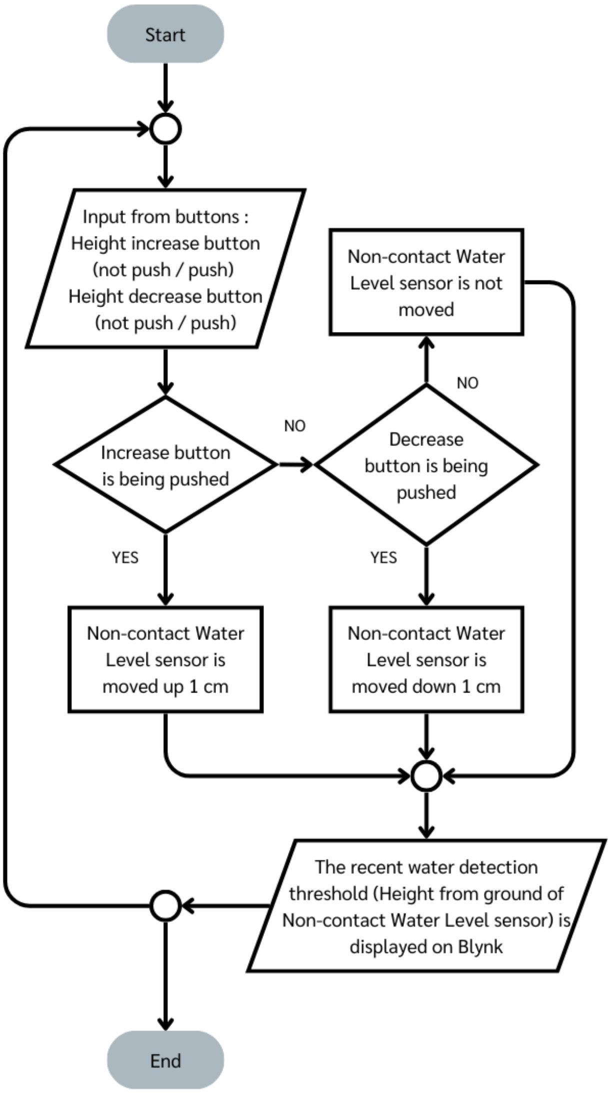

Fig. 5 Flowchart of servo motor control mechanism for adjusting water level threshold

2.2 Control Box

The details of the external water pumping system control box are shown in Fig. 6. There are a small OLED display and three types of control buttons, including a button to increase the water level threshold, a button to decrease the water level threshold, and a button to turn the water pump on/off. Additionally, there is a mode selection switch that allows toggling between automatic control, where the system operates based on the set water levels, and manual control, where the user can directly command the water pump. Notably, the on/off button for the water pump functions only in Manual mode. Inside the box, a 2P 30A 15mA Residual Current Circuit Breaker (RCCB) is installed to provide protection against electrical leakage hazards. The ESP32 board serves as the main controller of the system, receiving signals from various sensors and sending commands to the relay to control the water pump's operation. A 5V power supply board with 3-pin and 4-pin connectors is present for connecting to various devices within the system.

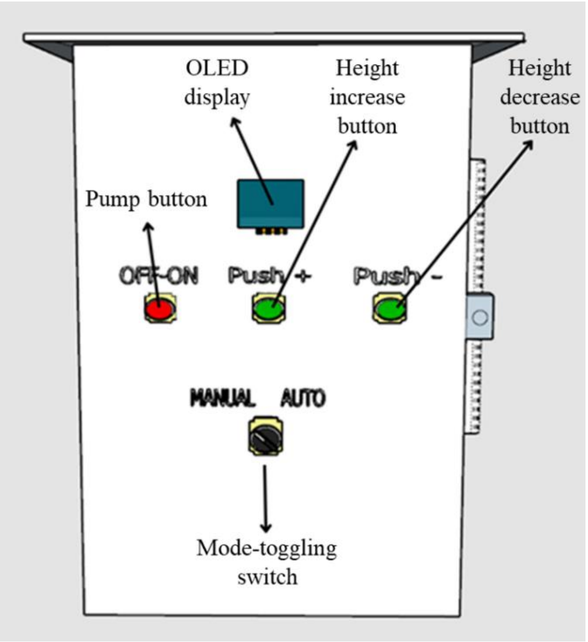

Fig. 6 Control box

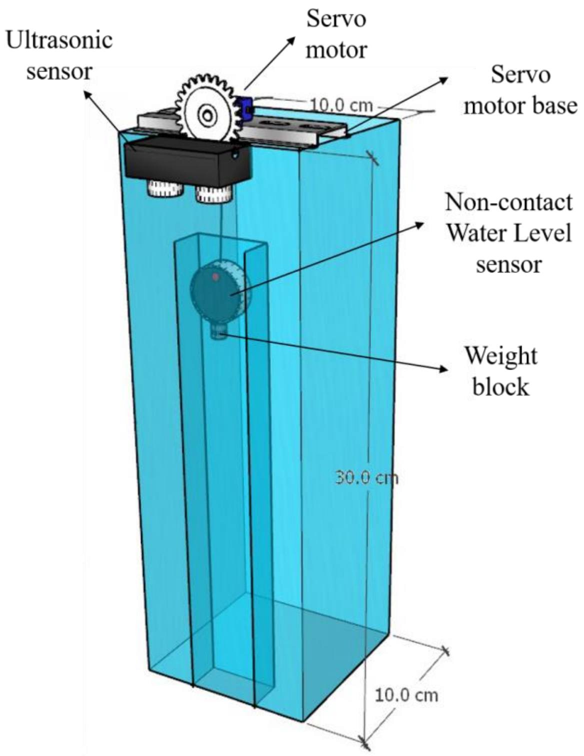

Fig. 7 Detection box

2.3 Detection Box

From Fig. 7, it illustrates a detection box which includes a servo motor for adjusting the position of the Non-contact Water Level sensor via a pulley and tendon mechanism, and an ultrasonic sensor mounted at the top to measure the water level using sound waves. Both sensors send data to the central processing unit to control the pump in Auto mode. The water level measurement box is made of transparent glass with dimensions of 10×10×30 cm. The Non-contact Water Level sensor weighing 50 g is attached to a weight block of 500 g. The spool has a diameter of 5 mm, and the motor's no-load speed is 0.12 s per 60 degrees.

2.4 User Interface on Smartphone

The menu screen on the Blynk application, as shown in Fig. 8, comprises: a work mode indicator (Auto / Manual), a water pump status indicator (On / Off), the water pump temperature, the current water level, the currently set water level detection threshold, a button to increase the height of the water level detection threshold, a button to decrease the height of the water level detection threshold, and a water pump on/off button that is only usable in Manual mode.

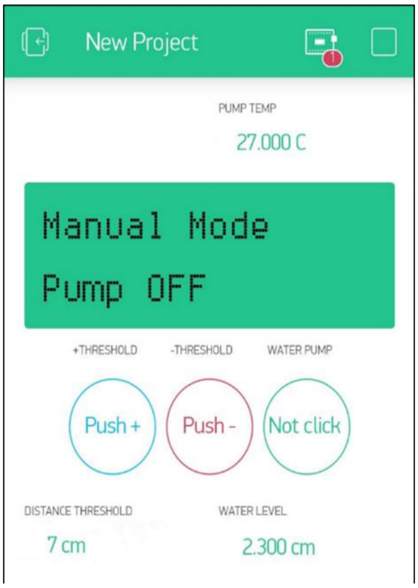

Fig. 8 Blynk gadgets

2.5 Motor Rotation Equation

First, we need to find the torque (τ) required for the motor to lift an object, use the following equation:

$$\tau = (m \cdot g) \cdot \left(\frac{d}{2}\right) \quad (1)$$

where τ is the torque (in N.m), m is the mass of the object (in kg), g is the acceleration due to gravity on Earth (approximately 9.81 m/s^2), and d is the diameter of the spool around which the string is wound (in m).

Next, we calculate the motor's loaded speed (ω). When a load is applied, the motor's speed decreases from its no-load speed along its Torque-Speed Curve, which is typically a linear relationship:

$$\omega = \omega_0 - k \cdot \tau \quad (2)$$

where ω is the actual angular velocity of the motor under load (in rad/s), ω_0 is the motor's no-load angular velocity (in rad/s), and k is a constant that depends on the motor's properties.

Once you know the motor's actual angular velocity from (2), you can calculate the vertical distance (h) the object is lifted using the relationship between the axle's rotation and the distance traveled:

$$h = \omega \cdot r \cdot t \quad (3)$$

where h is the distance the object is lifted (in m), t is the time taken to lift the object (in s), and r is the radius of the axle (in m):

$$r = \frac{d}{2} \quad (4)$$

Therefore, the final equation for finding the lifting distance is a combination of equations (2) and (3):

$$h = (\omega_0 - k \cdot \tau) \cdot r \cdot t \quad (5)$$

3. Results and Discussions

```
if (BUT_state1 == LOW || pinValue1 == 1) {
  myservo.write(speedForward);
  delay(distanceCM * timePerCM);
  myservo.write(stopServo);
  Serial.println("Servo+");

  adjustedThreshold -= 1;
} else if (BUT_state2 == LOW || pinValue2 == 1) {
  myservo.write(speedReward);
  delay(distanceCM * timePerCM);
  myservo.write(stopServo);
  Serial.println("Servo-");

  adjustedThreshold += 1;
} else {
  myservo.write(stopServo);
}
```

Fig. 9 Servo motor rotation control command set

Table 1 Experimental evaluation of servo motor rotation time and Non-contact Water Level sensor displacement

Delay Multiplier for Rotation	Servo Motor Rotation Time (seconds)	Measured Distance (cm) [Decreasing]
1	0.1	0.15
2	0.2	0.2
3	0.3	0.2
4	0.4	0.7
5	0.5	0.7
6	0.6	0.8
7	0.7	0.9
8	0.8	1
9	0.9	1.2
10	1	1.3

In order to control the increase and decrease in height of the Non-contact Water Level sensor, which sets the water level detection threshold, the operation of a servo motor mechanism rotating a pulley to move the Non-contact Water Level sensor up and down is required. The programming for this is shown in Fig. 9. Specifically, the command "delay(distanceCM * timePerCM);" controls the rotation cycle of the servo motor. Therefore, determining the value of the variable distanceCM, which dictates the amount of delay for the servo motor's rotation, is crucial. The variable timePerCM is defined as 100 ms.

According to Table 1, we focus on the object's release distance of 1 cm. The time taken for the release is used to calculate the damping constant according to (2). Then, we use (5) to generate a graph showing the relationship between the servo motor's rotation time and the upward movement of the Non-contact Water Level sensor.

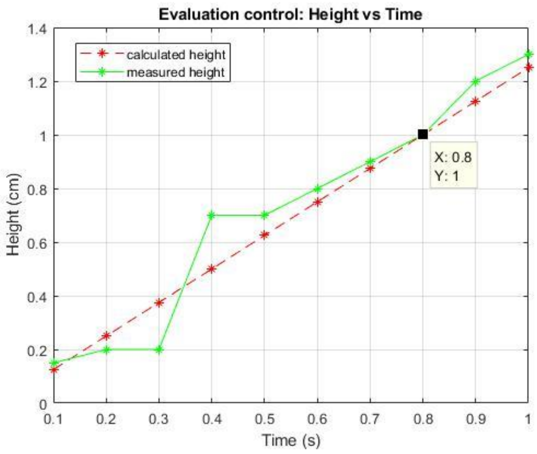

Fig. 10 The relationship between the servo motor's rotation time and the upward movement of the Non-contact Water Level sensor

From Fig. 10, a comparison between the calculated and measured lifting height of the Non-contact Water Level sensor is displayed. At a motor rotation time of 0.8 seconds, both the calculated and measured heights are equal at 1 cm. The consistent displacement during the sensor's downward movement confirms the pulley mechanism's stability, which effectively balances the upward motor-driven motion with the downward gravitational pull. With a servo motor rotation delay multiplier of 8, a 1 cm displacement is achieved, making it a suitable value for control. Therefore, the system is configured so that each press of the water level adjustment button corresponds to a 1 cm change in height.

Table 2 Cooperative analysis experimental results of Non-contact Water Level sensor and Ultrasonic sensor

No.	Scenario	Water Pump Operation (Auto Mode)
1	Non-contact Water Level sensor detected, Water level has not reached the threshold.	Pump does not work
2	Non-contact Water Level sensor not detected, Water level has reached the threshold.	Pump does not work
3	Non-contact Water Level sensor not detected, Water level has not reached the threshold.	Pump does not work
4	Non-contact Water Level sensor detected, Water level has reached the threshold.	Pump works

Next, the cooperative operation of the Non-contact Water Level sensor and the Ultrasonic sensor in Auto mode has been tested. This involved evaluating the consistency in their water status detection and the triggering of the water pumping system, to ensure that the system can process data from both sensors accurately and reliably.

Based on the results in Table 2, the system accurately coordinates the Non-contact Water Level and Ultrasonic sensors. The water pump activates only when the Non-contact sensor detects usage and the Ultrasonic sensor measures that the water has reached its threshold. This combined operation is accurate and effectively reduces pump activation errors in automatic mode.

Subsequently, the functionality of the control buttons in Manual mode for commanding the water pumping system has been tested to assess the stability of the water pump control button's response.

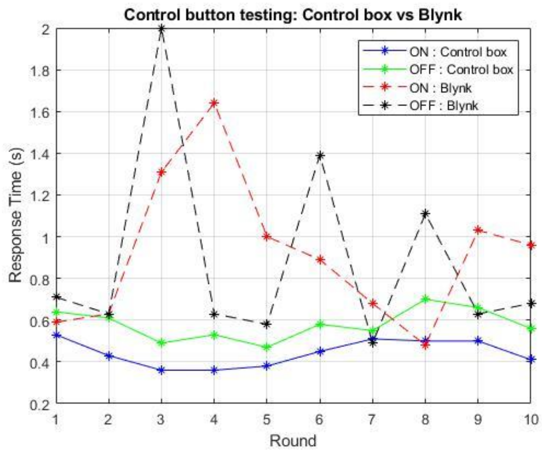

Fig. 11 Servo motor rotation control command set

From Fig. 11, it was observed that the on/off button for the water pump on the control box had a faster and more stable average response time for both turning on and off compared to the button on the Blynk application. The control box button showed an average response time of 0.443 seconds for turning on and 0.579 seconds for turning off, while the Blynk application button had an average response time of 0.921 seconds for turning on and 0.885 seconds for turning off. This indicates that controlling the water pump via the Blynk application is slower and has more fluctuating response times, which depends on the quality of the Wi-Fi signal. An unstable signal can lead to delays in button responsiveness. In contrast, the button on the control box exhibits a faster and more stable response due to its direct connection to the water pump's control system.

4. Conclusions

The Automatic Water Pumping System with Adjustable Water Level Thresholds allows users to set a minimum water level threshold of 5 cm for pump activation, with incremental adjustments of 1 cm up to a maximum of 20 cm. In automatic mode, the system demonstrates high accuracy in pump control due to the integrated operation of the Non-contact Water Level sensor and the Ultrasonic sensor. Furthermore, manual pump control functions effectively via both the physical buttons on the control box and the buttons on the Blynk application, which also provides continuous monitoring of the water level and pump status.

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