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Innovative Water Distribution Systems: Raspberry Pi Based Adaptive Water Vending Solutions

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Abstract

Technology has advanced to the point that many complex equipment and gadgets are now indispensable tools for humankind. Among these, automated vending machines have become a mainstay, simplified a variety of tasks, and greatly increasing productivity while reducing the need for human involvement. These devices, which have numerous inputs and outputs, can dispense snacks, cold beverages, coffee, tea, water, and more to meet the needs of a diverse clientele. The government of India's "Rail Neer" project features specialized vending machines known as "Water Vending Machines," which are widely present in railway stations, especially in India. These devices give clean and hygienic fluids, which improve public health and convenience for tourists. Within train grounds, the water vending machine effectively supplies inexpensive, clean drinking water. Its design is limited, though, in that each transaction results in the dispensing of a predetermined volume of water. When consumers insert water bottles that are partially filled or of different sizes, this causes problems. As a result, extra water that the vending machine dispenses in these circumstances can be wasted. To properly handle this problem, this study offers an adaptive algorithm that is built into the machine's design. Our goal is to put in place a system that can scan the bottle and collect vital information about its weight and height. With the use of this data, we will be able to determine the ideal time for the machine to dispense water, resulting in effective use and reduced water waste. With Raspberry Pi 3 serving as its processor, the adaptive water vending machine prototype that is shown in this paper has been successfully developed.

Keywords: Raspberry Pi 3, ultrasonic sensor, water sensor, load cell, HX711, solenoid valve, relay circuit

INTRODUCTION

Portable drinking water provision is essential for railway stations to uphold passenger well-being and health standards. Various methods, including municipal taps, tube well taps, railway-provided water purifiers, packaged drinking water, and water dispensers, currently supply water [1]. However, with a growing emphasis on hygiene and health, establishing standardized protocols for portable drinking water provision by Indian Railways is imperative both at stations and on trains.

In pursuit of this goal, Indian Railways has implemented water vending machines, facilitated by the government under the "Rail Neer" project, to provide pure drinking water at reasonable prices on station platforms and within trains. Figure 1 illustrates a recent water vending machine [2] consisting of components such as a water tank, coin insertion mechanism, coin recognition system, water inlet, outlet nozzle, selection buttons for water

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quantity, and a bottle placement base [3]. Various water quantity options are available at different prices. Operationally, a coin-operated water dispenser relies on coin detection. Upon coin insertion, the coin sensor assessed the validity of the coin based on its thickness, diameter, and fall time. The CH-926 multi-coin selector, which is capable of accepting up to six-coin types simultaneously, is commonly utilized owing to its reliability. This selector identifies coins based on material, weight, and size while maintaining stability despite environmental fluctuations. Utilizing different channels for coin denominations enhances the accuracy.

Users initiate the process by inserting a coin, after which the machine recognizes the coin and the selected option, and water flows from the outlet nozzle. However, inefficiencies occur when the selected water quantity exceeds the user's bottle capacity, resulting in waste. For example, if a user has a 250 ml partially filled bottle intended for a total capacity of one-liter and selects the one-liter option, only 750 ml of water is needed, resulting in 250 ml of water wastage. Similarly, opting for one-liter with a 750 ml bottle leads to wastage.

Thus, the primary objective of this study is to reduce water waste at the individual machine level, contributing to national water conservation efforts. Even with modest cuts per machine, addressing these inefficiencies could result in significant water savings.

PROPOSED ADAPTIVE WATER VENDING MACHINE

Methodology

Current water vending machines suffer from significant drawbacks related to water wastage owing to their non-adaptive nature. To address this issue, several features must be incorporated to make the machine adaptive. Our machine is considered adaptive because it operates based on an adequate dataset [4]. Nevertheless, such a data set may not be accessible during the early period of operation. In such cases, it is necessary to create a dataset containing information, such as the height and weight of the water bottle, along with the time required to complete the bottle [5]. The operational process of the adaptive machine began with an initial check to determine whether a bottle had been placed on the base. This confirmation is made possible by utilizing an ultrasonic sensor that detects the presence of a bottle. Simultaneously, the user selects the size of the bottle placed using a push-button interface, indicating whether it is a standard 1-liter size, 500 mL, or any other possible volume.

Figure 1. Existing water vending machine.

The machine then employed a load cell to measure the weight of the bottle. This weight measurement is crucial because it enables the machine to calculate the precise time required to complete the bottle with water. By utilizing data from the load cell, the machine gained a comprehensive understanding of bottle capacity.

The information gathered was cross-referenced with a database that already existed after the measurement step. If a match is found, the machine follows the preconfigured parameters and proceeds accordingly. However, if the data for a specific bottle are not present in the database, the machine initiates a series of calculations based on the gathered specifications. This ensured that the machine could accurately dispense an appropriate amount of water into the bottle without any prior information. Additionally, to prevent potential overflow, the machine incorporated a water level sensor. The sensor continuously monitored the water level within the bottle during the filling process. If the water level approaches the brim of the bottle, the sensor triggers a mechanism that halts the filling process, thereby preventing spillage or overflow.

Furthermore, measurements obtained during each operation were recorded and added to the database for future reference. This continuous updating of the database ensures that the machine can adapt and optimize its operations over time based on the data collected from each interaction.

Hardware Components of Proposed System

The proposed system utilizes the following hardware components: The working principle and specifications of the components used in the proposed system are described below.

Ultrasonic Sensor

An ultrasonic sensor was used to measure the distance to an item using ultrasonic sound waves, as shown in Figure 2. It functions by emitting and receiving ultrasonic pulses through a transducer, which enables it to gather information about an object’s proximity. These pulses, composed of high-frequency sound waves, propagate towards the surfaces and create distinct echo patterns upon reflection. By assessing the time interval between the transmission and reception of the ultrasonic pulse, the sensor can determine the distance to the target.

Typically, when operating at a frequency of 40 kHz, the sensor emits an ultrasonic pulse into the surrounding environment. This pulse bounces back towards the sensor when it comes into contact with an obstruction or an item. By calculating the travel time of the pulse and considering the speed of sound, the sensor accurately computed the distance to the object. The existence of items within the detection range of the sensor can be detected using this method.

Load Cell

The load cell shown in Figure 3 serves as a transducer, converting the force into a measurable electrical output.

Figure 2. Ultrasonic sensor.

Figure 3. Load cell.

Among the various types available, strain gauges are most commonly used. Strain-gauge load cells offer accuracy ranging from 0.03% to 0.25% of the full scale, making them suitable for a wide range of industrial applications.

In this specific application, a “single-point shear beam load cell” was employed. Instead of measuring the bending force, this type of load cell is intended to measure the shear force imparted to the beam. It is frequently employed in situations involving side loads, including weighbridges and commercial weighing systems.

The shear force refers to the force acting parallel to the cross-section of a structural element, while a bending moment occurs when an external force causes the element to bend. The utilization of a single-point shear beam load cell aligns with this concept. These load cells are frequently utilized on small to medium platform scales, featuring platform dimensions ranging from 200x200mm to 1200x1200 mm. Their single-point design allows for flexibility and ensures accurate reading, even when the weight distribution is uneven.

The load cell operates by converting force or weight into an electrical signal using strain gauges attached to the body. Under a load, the load cell undergoes a slight deformation in shape. The strain indicators, which also distort in tandem with the body to detect this deformation, cause voltage changes. The magnitude of this voltage change is directly proportional to the applied initial force or weight, which enables its calculation.

HX711 ADC

The electrical signals produced by the load cell typically have low amplitudes, usually only a few millivolts. Therefore, they require amplification before they can be processed further. This is where the HX711 weighting sensor module, shown in Figure 4, plays a crucial role. The module incorporates an HX711 chip, which is a 24-bit high-precision analog-to-digital converter (ADC). With two analog input channels, the HX711 chip allows a programmable gain of up to 128 on these channels. Consequently, the HX711 module amplifies the weak electrical output from the load cells. Subsequently, this amplified and digitally converted signal was transmitted to the microcontroller, enabling the derivation of accurate weight measurements.

Raindrop Sensor

A nickel-coated board in the shape of lines serves as the raindrop sensor, as depicted in Figure 5, which operates based on resistance. When the board is dry, the resistance is high, resulting in a corresponding high voltage, according to Ohm’s law (V=IR). However, because water is an electrical conductor, its presence lowers resistance when raindrops land on board. This connectivity between the nickel lines in parallel leads to decreased resistance and a voltage drop across the board.

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Figure 4. HX711 ADC.

The operation of the raindrop sensor module was straightforward. The exposed copper paths on the sensor function as variable resistors, with the resistance varying based on the quantity of water present on the surface. These paths are typically unconnected, but become bridged through water, resulting in reduced resistance. Resistance is directly correlated with water content, higher water content results in lower resistance and better conductivity. The sensor creates an output voltage depending on the resistance level, indicating the presence or absence of rain.

The control sensor and rain-sensing pad, which can communicate with any microcontroller, make up the raindrop sensor modules. The module creates an output voltage proportional to the resistance of the sensing pad, which is supplied by an analog output pin. This signal was also transmitted to an LM3 93 high-precision comparator for digitization, with the digitized signal available at the TTL digital output pin. This raindrop sensor was utilized to prevent water overflow in various scenarios, including the creation of an initial database. If water overflow occurs while initializing the system or in any other situation, the sensor immediately halts the flow of water upon detecting the water droplets. Thus, the sensor plays a crucial role in preventing overflow incidents and ensuring system integrity during database creation and other operations.

Working Principle of Proposed System

Whenever a water bottle was placed on the base within the machine, its presence was detected using an ultrasonic sensor, as illustrated in Figure 2. The ultrasonic sensor was mounted on top of the structure, facing the base where the water bottle was placed. The sensor is controlled using software, and the distance (d) between the sensor and base is provided to the machine to make further decisions [6]. The ultrasonic waves emitted by the sensor operate at a velocity (V) of 340 m/s in air [7]. When the sensor initiates the propagation of waves, any encountered obstacles reflect the waves to the sensor receiver. Obstacle detection notifies the controller of a finite value. A measured height of 0 indicates that no water bottle is present on the base. Conversely, a finite height value indicated the presence of a water bottle. These finite values are not stored in the database.

To create the dataset, a solenoid valve was opened, allowing water to flow freely, while a parallel timer was activated. The solenoid valve depicted in Figure 6 is electronically controlled by varying the input voltage from 12 volts to 36 volts. In this machine, a half-opened solenoid valve is utilized and supplied at 24 volts using a relay circuit. Once the bottle was fully filled, water overflow was detected using a raindrop sensor positioned on the base, as shown in Figure 5.

Figure 5. Raindrop sensor.

Figure 6. Solenoid valve.

The raindrop sensor functions as a switching device [8–12]. To detect the presence of water. This function is based on the idea that the switch is generally closed when water is available. The sensor consists of nickel-coated lines and operates based on the principle of resistance. Upon detecting the water, the free flow of water through the solenoid valve was halted, and the timer was stopped. The timer count, representing the time until water overflows, was adjusted by subtracting a few seconds to determine the time required to complete the water bottle.

The dataset also includes the weight of the fully filled bottle measured using a load cell. A transducer that transforms a force into an electrical signal is called a load cell. In this machine, a strain-gauge load cell was utilized for its accuracy and cost-effectiveness. A single-point shear beam load cell, depicted in Figure 3, is employed, providing analog output. To convert the measured weight into digital form, an HX711 ADC was used. The HX711 converter was designed for weighing the scales, as shown in Figure 4 [13]. Once the weight measured by the load cell is converted into a digital form, the data are stored in the dataset as the weight of the fully filled bottle. This process ensures the creation of height, time, and weight data for water bottles that are not present in the dataset.

If the weight data of the placed bottle are already present in the dataset, a binary search algorithm is utilized to find the index of the weight in the "csv" file. Compared with linear-search methods, which have an O(n) time complexity, this technique has a time complexity of O(log n), which is much less. From the search operation, the weight and time required for the selected bottle size were obtained. According to the specified time in the dataset, the solenoid valve is opened for the required duration based on Equations (1) and (2).

$$\text{Weight(w)} = \text{Final weight - Initial weight from the dataset of bottle} \quad (1)$$

$$\text{Time required} = \frac{(\text{Weight (w)} * \text{Time from dataset})}{\text{Final weight from dataset}} \quad (2)$$

If the bottle is initially filled with water up to a certain level, it will also be filled for the calculated time using Equations (1) and (2).

System Integration and Firmware Development

The firmware development flowchart is shown in Figure 7. The System Integration diagram of the adaptive water vending machine is shown in Figures 7 and 8.

RESULT AND DISCUSSION

The hardware for the adaptive water beverage machines suggested in the current research was successfully installed. During the initial phase, an initial dataset was effectively created when a water bottle was placed, as listed in Table 1. This dataset contains crucial information regarding the size and height of the selected bottle, weight, and time-related data.

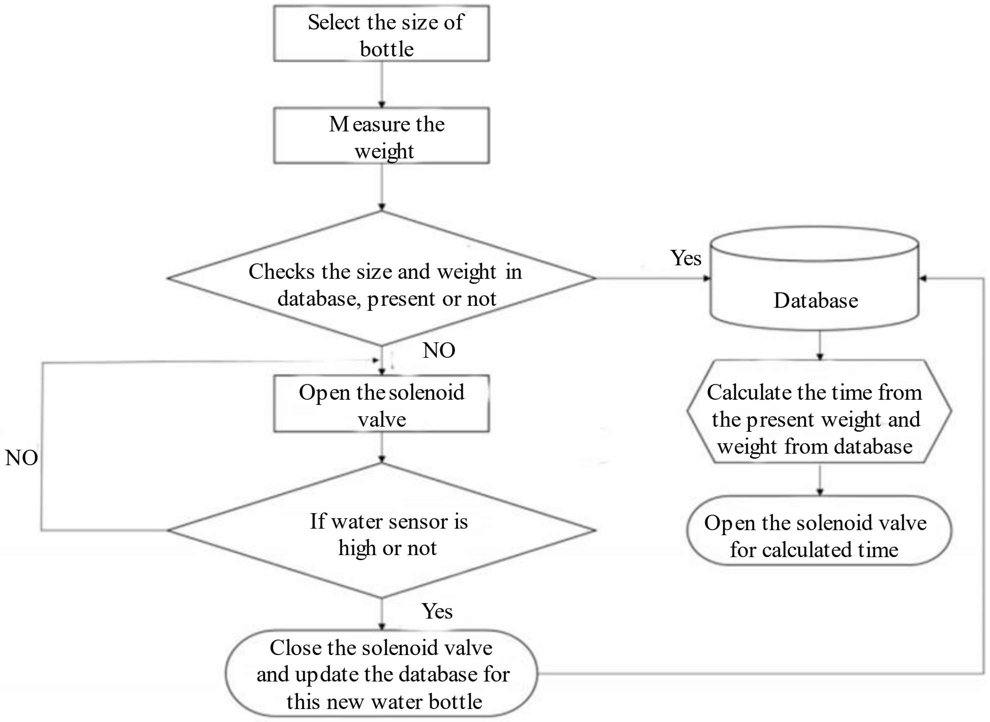

Figure 7. Flow chart of firmware development.

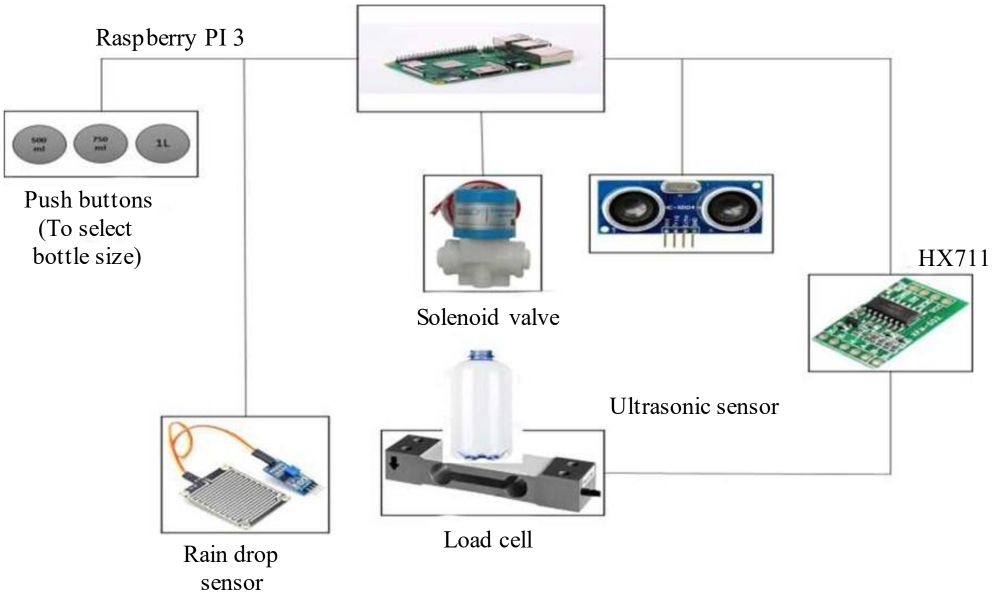

Figure 8. System integration diagram.

Table 1. Creation of initial dataset during pre-installation period.

Capacity	Height (cm)	Weight (g)	Time (sec)
500 mL	13	496	53
750 mL	19	730	84
1 L	25	980	95

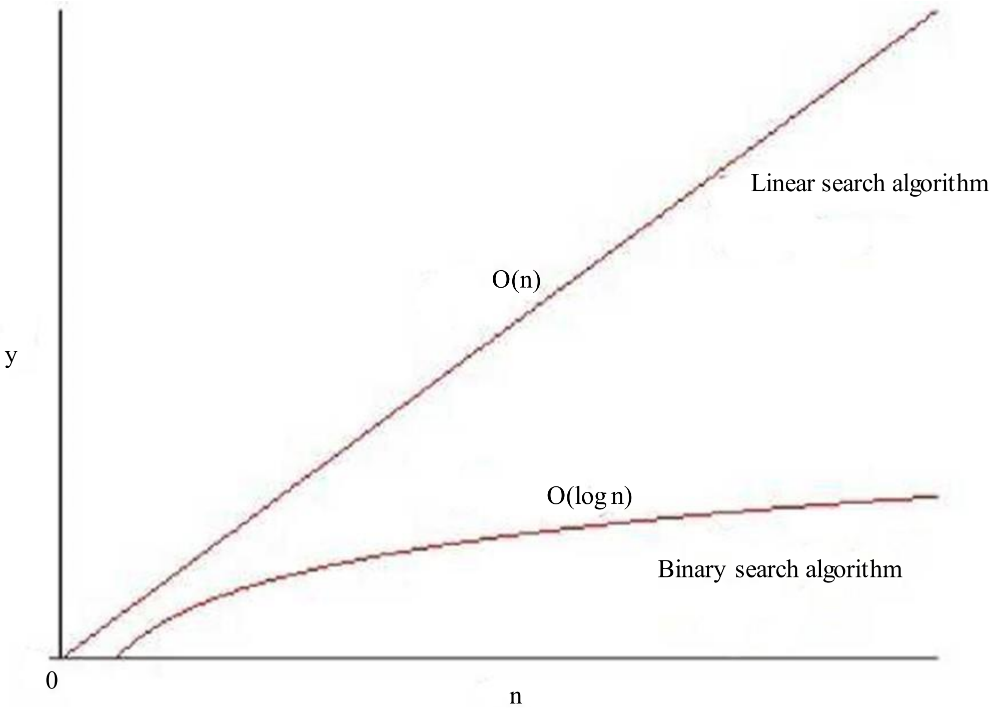

Figure 9. Binary search algorithm and linear-search algorithm-time complexity.

When a partially filled water bottle is placed, the machine retrieves the timing information from the dataset and opens the solenoid valve for the calculated duration only, thereby dispatching the appropriate amount of water. A binary search algorithm was employed to search for data in the dataset, as previously discussed. This algorithm efficiently finds the index of the weight in the 'csv' file, offering a time complexity of O (log n), which is notably lower than that of the linear-search algorithm with a time complexity of O(n). Through the search operation, the relevant data regarding the weight and time required for the given weight index are retrieved. Subsequently, the solenoid valve is opened for a specified duration according to Equations (1) and (2). A comparison between the results of the binary search algorithm and the linear-search algorithm is illustrated in Figure 9.

In our system, as the number of trials increased, the amount of data in the dataset also increased. This expansion in the dataset tends to enhance the accuracy of the machine and consequently reduces water wastage. By accumulating more data through repeated trials, the machine becomes better equipped to make informed decisions regarding water dispensation, thereby contributing to overall efficiency and conservation of water resources.

Scope of Proposed System

Standardized Size Bottle

The water vending machine was engineered to accommodate standard-sized bottles commonly found in the market, offering options for 500 ml, 750 ml, and 1 L capacities. By adhering to these standardized sizes, the machine ensures compatibility with the most common bottle sizes, facilitating convenience and ease of use for consumers.

Payment-free System

At present, the vending machine operates on a payment-free system, meaning that there is no mechanism implemented to calculate the cost based on the dispensed water amount. Users can access pure drinking water from machines without the need for monetary transactions. This payment-free approach simplifies the user experience by eliminating the need for coins, tokens, or digital payments, thereby enhancing accessibility to clean drinking water for all users, irrespective of financial constraints.

CONCLUSION

The implementation of an adaptive water vending machine represents a significant leap forward in technology and a crucial step towards fostering an eco-friendly world. Its adaptive nature is instrumental in preventing water wastage, a prevalent issue in existing systems, by dynamically adjusting its operations based on real-time data. Moreover, its ability to accommodate bottles of similar size eliminates the need to create new databases for a specific range of weights, thereby saving time and resources. This feature, coupled with its user-friendly interface, ensures accessibility to individuals from all walks of life, making it easy to use and widely applicable. The proposed system holds promise for widespread adoption and implementation from ordinary consumers to environmentally conscious individuals. In essence, the adaptive water vending machine not only signifies technological advancement but also demonstrates a commitment to sustainable practices. By addressing water wastage and streamlining the user experience, it catalyzes transitioning towards a greener, more sustainable future, positioning itself as a valuable asset in the journey towards environmental stewardship and conservation.

Future Scope

In the future, the adaptive water vending machine could incorporate several enhancements:

- *Utilization of cloud data storage for the dataset*: This allows multiple machines to access a single dataset simultaneously, thereby enhancing the overall accuracy and efficiency of the system.
- *Implementation of online payment methods*: Introducing online payment options would improve user convenience and make transactions easier and more accessible to consumers.
- *Development of a transaction application*: Creating a dedicated application for managing transactions would further streamline financial activities and provide users with a user-friendly platform for making payments.
- *Integration of an amount calculation system:* By incorporating an accurate billing and payment calculation system, the vending machine can ensure transparency and reliability in financial transactions, thereby enhancing the overall user experience.

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