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An Optimal Smart Tank Juice-level Monitoring System for Beverage Industries: A Case Study of Raha Beverages Company Limited, Arusha, Tanzania

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** Regular Paper*

***Abstract*:** Poor monitoring of levels in juice tanks is among the challenges that beverage industries face when pumping liquid from one tank to another. This leads to spilling fluids, faulty juice tests, and industrial accidents. To keep track of the liquid level in a tank, various approaches have been used. Existing technologies are costly and not interactive, and the majority do not benefit individuals with physical disabilities when manual monitoring is needed. The purpose of this paper is to present an optimal smart tank juice-level monitoring system that can be used in beverage industries. The system is able to monitor the juice level within a tank and regulate a pump using voice commands via Alexa and the Amazon Echo Dot. The proposed system was tested and validated, with key findings being that the developed prototype prevented overflowing, accidents, and changes in juice flavor during the dilution process. This paper contributes to the body of knowledge for food and beverage industries in that engineers and operators of beverage industries can monitor the level of juice in a tank, as well as enhance communication when pumping juice from one tank to another in real time.

***Keywords*:** Smart tanks, Level-monitoring system, Beverage industries, Automatic pumps, Liquid overflow

1. Introduction

Some beverage industries are facing problems from juice overflow, accidents, and altered taste of the final product owing to manual monitoring of tanks. This manual monitoring is an ineffective way to determine the level of juice in a tank and to know when to switch off the pump in order to properly measure the liquids involved in the dilution process before fermentation [1]. Operator error can result in failure to provide correct information on the level of juice within the tank in time to prevent such problems, so the proposed system can warn an operator and avoid repeating the mistakes. If they happen again, the operator might be fired [2].

Local beverage industries in Tanzania face challenges caused by manual control of storages levels for liquids. There is no proper way of monitoring tank levels, and no interactive way of communicating with the pump. Totes, receptacles, or containers and tanks are not only for storing fluid; they also need to be monitored for proper stock levels. Tanks work as temporary depositories for liquid until they are transferred to another industry setup, especially for industries like gas and oil, water, chemicals, and beverages [3]. In beverage sectors, huge tanks are installed to facilitate juice and wine storage until it needs to be pumped from a boiling tank to a fermentation tank. Those tanks are joined by a pipeline network to facilitate movement of liquids to various stages of the production line and to transfer liquids at the required time.

This paper presents use of the Alexa voice interface to control a pump with voice commands instead of running to switch off the pump. The operator commands Alexa, via Amazon's Echo Dot, to switch the pump off or on remotely without physical contact with the switch. Alexa is a popular control for home appliances such as lights, fans, and other devices [4].

The main objective of this study is to develop an optimal smart tank juice-level monitoring system and to control a pump using voice commands.

The following specific objectives were followed to achieve this.

1. Identify system requirements for developing an optimal smart tank juice-level monitoring system.
2. Design and develop an optimal smart tank juice-level monitoring system.
3. Validate the developed system

This paper consists of five sections. After the introduction in Section 1, Section 2 reflects related work. Section 3 presents the methodology used in the study. Section 4 covers results and discussions. Finally, the conclusion and suggested future research are presented in Section 5.

2. Related Works

This section introduces a variety of research and system reviews of different liquid-level monitoring systems, such as fuel/oil, water tank, and beverage tank monitoring systems, particularly juice tanks.

2.1 Level Monitoring Context

Level monitoring is a process of monitoring the foundation movement in a structure to determine precise levels. It plays a crucial role for today's automotive oil, water, and gas-pressure levels, and in the beverage industries. Pumping oil into a tank requires a level-monitoring system to prevent overflow, measuring it using a pressure sensor [5]. It is also helpful in industrial manufacturing to know the level and the quantity of liquid inside a tank, which results in the same quality and liquid levels in all tanks and bottles [6]. The next sections discuss various liquid-level monitoring systems.

2.2 Fuel Monitoring Systems

Research presented in [2] and [7] revealed that 90% of individuals struggle when manually managing and monitoring fuel usage from tank storage. Consumers want to ensure that the number of liters put into their fuel tanks matches the quantity recorded on the receipt if gasoline transfer is done manually. These systems were created to track the amount of fuel in the tanks, interact with the user, and relay the level to the tank's owner to ensure that what was ordered and what was received are the same. These systems use a probe that cannot be immersed into liquid intended for consumption by people, because the probe can rust. Furthermore, they use the Arduino Uno Microcontroller, which is expensive and requires an external shield to be connected to the internet.

2.3 Water-level Monitoring Systems

Some researchers have developed smart water tanks that measure water levels using a probe sensor within the tank, and that sends data to Arduino Uno for analysis, which then sends data to the cloud for visualizing [8-12]. Furthermore, some of this work is done after sensing, so the data sent to Arduino Uno for processing include notification messages or generate an alarm for the operator when the tank is too low or too full in order to prevent accidents. In case the system fails to actuate and automatically switch off the pump, it uses a *Short Message Service* (SMS) to alert the operator to physically switch the pump off. However, these systems were developed for water tank monitoring (not for juice) and they use an expensive microcontroller (the Arduino Uno), which needs an external shield to be connected to the internet, and some do not perform automatic pumping. Moreover, some systems use a probe to measure the level of water, which is not good for immersing into a liquid intended for consumption by people because it may rust, negatively affecting their health.

2.4 Beverage Industries

In beverage industries, juice and other products need to be monitored and automated by providing easy distribution to make the supply chain more effective [13].

Level-monitoring systems have been used in brewing industries. The majority of beer tanks are equipped with devices for measuring levels within the tanks, but those devices come into contact with the beer. They require special attention when cleaning the tanks, which is why one project developed an ultrasound system, sensor, or probe attached to the tank's exterior in a noninvasive manner [14].

Level-monitoring systems have been used by industries that produce wine. Wine levels are detected using an ultrasonic sensor measuring the distance between a wine-level buoy and the top of the tank. The data are shared via the Arduino board and are then uploaded to the cloud to be visualized [15]. Manual control of wine ullage can lead to oxidation each time the tanks are opened, leading to ineffective results [16]. The level of wine must remain constant to maintain the taste. Other systems use an ultrasonic sensor placed inside the cask or tank, which keeps measuring the ullage within the tank [16, 17], measures whether the level of wine increases or not, and sends the data to Arduino Uno, where they are analyzed and visualized. Pambudi et al. [18] developed a system for automatic vending machines to sell juice. The machine considers different parameters, such as the level of juice in the reservoir, notifying the vendor when the level reaches a certain threshold. However, this system is integrated with two microcontrollers, which makes it complex and expensive, and it does not implement automatic pumping control or a proper way of visualizing the sensed data. The systems presented in [19] and [20] monitor the level of juice and other liquids within tanks, emitting an alarm when the liquid level changes. The systems use a radar sensor, which is a probe that can also rust and harm the health of customers who consume the products.

A level-monitoring solution developed by Biz4Intellia [21] allows an observer to monitor the level of juice in multiple large (*30 - 45 feet*) tanks/tankers in real time, sending notifications when the juice level reaches a threshold. The system also measures the temperature of the juice stored within the tank.

It uses a wireless ultrasonic sensor to measure the

Table 1. System hardware requirements.

No.	Hardware	Specifications
1	Node MCU	ESP8266
2	Container	Rounded containers (2), storing 14 liters (28cm length)
3	Pipe	Black pipe (2m)
4	Level sensor	HC-SR04 ultrasonic sensor, range: between 2cm and 4m
5	Buzzer	Piezoelectric
6	Relay	5V module
7	LCDs	16x2 I2C module
8	DC pump	Micro-submersible (12V)
9	Speaker	Amazon Echo Dot

amount of juice in the tank, and sends the data to the cloud for visualizing, which eliminates the need for someone to climb into the tank to check the juice level. The system costs US$1000 to US$2000, which makes it expensive and not affordable by small-scale industries.

Different technologies have been developed to monitor different liquids within tanks and measure their levels. Existing level-monitoring systems, whether they measure water, gasoline, beer, wine, or juice within a container, can be adopted to measure the level of juice within tanks. However, there is no easy, interactive, and low-cost technology (affordable to local beverage industries) that can be adopted to measure juice tank levels. Based on the above works, existing systems that measure levels of liquids within tanks/reservoirs are expensive, complex, offer no automatic pumping control, and use a probe for the sensing that can have a negative impact on people's health if it rusts and contaminates the juice.

This paper presents a prototype with which an operator is able to view and communicate with the system, and interact with it. The level of juice in the tank is shown on a *liquid crystal display* (LCD) and is visualized via the cloud. When the juice reaches the desired level, the system automatically switches the pump off and generates an alarm. By using voice commands, the operator is able to control the pump before the juice reaches the set threshold. For example, when the juice reaches a certain level, the operator can ask Alexa to turn off the pump. This is a fun and easy way to keep track of the juice level in the tank at an affordable price.

3. Materials and Methods

3.1 System Requirements

3.1.1 Hardware Requirements

Table 1 lists the hardware components that were used during prototyping.

3.1.2 Software Requirements

While developing this system, the C programming language was used [22]; features included low-level memory access, a simple set of keywords, and a clean style. The code was written in the Arduino *Integrated Development Environment* (IDE), which is compatible with the ESP8266 module [23].

ThingSpeak was used to visualize and analyze data sent via the microcontroller from sensors or actuators. The ThingSpeak service is a platform that enables online analysis and visualization of data [24]. The Alexa app was used in this project for communication through the Amazon Echo Dot. A Sinric Pro cloud was used to create the interface for communication between physical and virtual online pumps.

3.2 Block Diagram

The developed system has three main parts. The sensing unit determines the level of juice within the tank and sends the data to the processing unit. The processing unit using the ESP8266 acts as the core of the system, because all sensors and actuators are connected to it. The actuating unit changes the processed data into human readable and understandable form; for instance, the level of juice is shown on a liquid crystal display, a buzzer sounds an alarm, and a relay switches the pump on or off. Fig. 1 is a block diagram of the developed system.

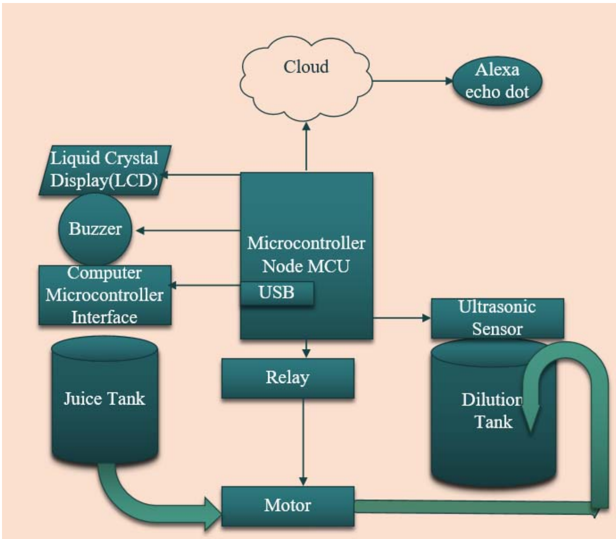


Fig. 1. Block diagram.

3.3 Voice-controlled Smart Tank Juice-level Monitoring System using Alexa on Amazon's Echo Dot

The Amazon Echo Dot is a voice-activated gadget that can be controlled from far. Alexa, a voice-activated intelligent personal assistant, responds to users through the gadget. Upon command, Alexa communicates with the user, plays music, sets alarms, delivers weather forecasts, and provides other real-time information. Other devices users have installed, such as lights, fans, and so on, can be controlled through the Echo Dot [25]. The purpose of this paper is to provide a low-cost method of controlling a pump, and an interactive way of monitoring the level of juice in tanks. Alexa and the Echo Dot were used to construct a method to connect with the *microcontroller unit* (MCU). When an operator needs to switch a pump off or on, it is done via voice command and relayed responses to the operator's requests.

3.4 System Flowchart

The system's flowchart, shown in Fig. 2, explains the operations and activities completed through sequential phases and the links between the activities. After turning the system on, the sensors and actuators begin to communicate with one another. The ultrasonic sensor continuously senses the juice level within the tank, sends data to the microcontroller for analysis, and signals the actuators. Once there is an increase of juice in the tank, the LCD keeps displaying the percentage level. When the level reaches 100%, the relay switch stops the pump automatically, and the alarm sounds for the operator, indicating the tank is full.

Furthermore, the sensed data are sent to the cloud for further analysis, and once an operator gives a command to Alexa to switch the pump off or on, the Echo Dot automatically sends the command to the cloud and checks if that device is available. Once the device is found, the system executes the suggestion; otherwise, Alexa replies that the pump cannot be found.

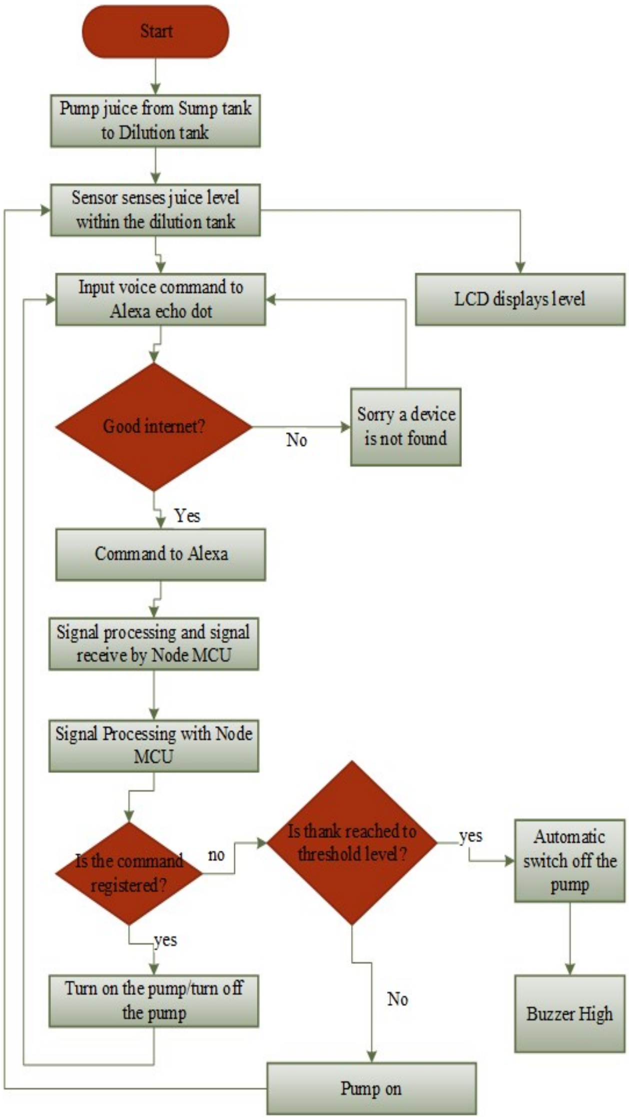


Fig. 2. System flowchart.

3.5 Component Integration

Fig. 3 shows a circuit diagram of the developed system. The ESP8266 12E chip comes with 17 *general-purpose input/output* (GPIO) pins, which convey input, output, or act as both input and output, depending on the configuration. The 5V ultrasonic sensor, trig pin, echo pin, and ground pin were connected to VU, D3, D4, and ground pins of the board, respectively. The trig pin provides output, while the echo pin is set for input. The buzzer is connected to the D8 and ground, set for output. The relay switch data pin was connected to D7, set for output, and connected to the pump to control it (either high or low). In the 16x2 I2C LCD module, only four pins are connected to the ESP board. The *serial data* (SDA), *serial clock* (SCL), and ground pins are connected to D2, D1, and ground, respectively. The Amazon Echo Dot, shown in B, wirelessly communicates with the system through the Alexa app.

4. Results and Discussion

4.1 System Setup

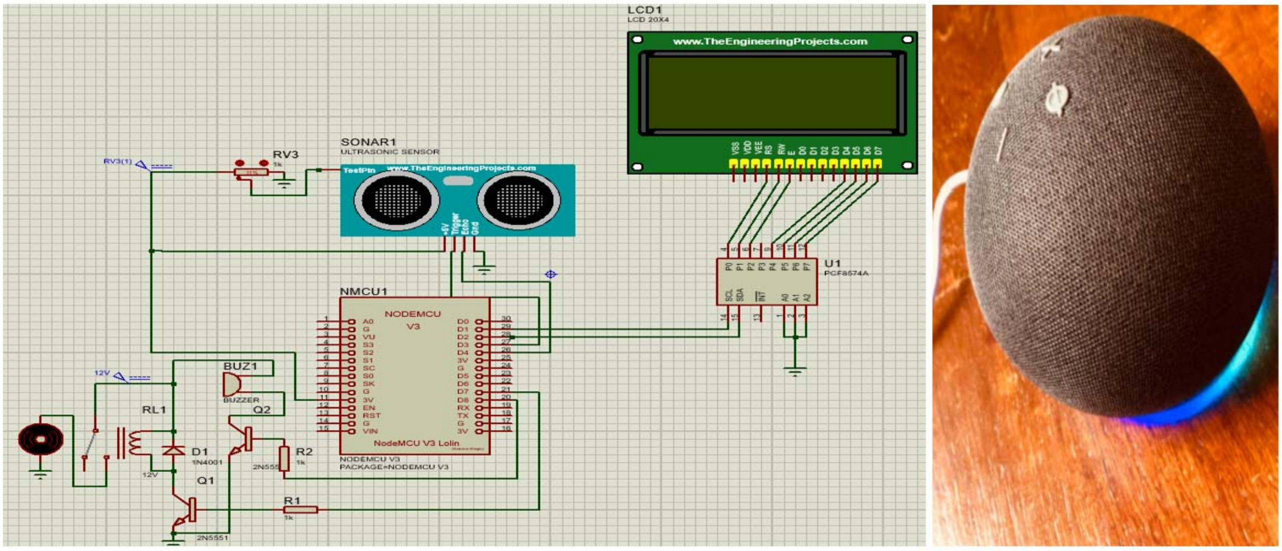
This study was carried out at the *Raha Beverage Company* (RABEC) Limited, Arusha, Tanzania. According to interviews and observations within this company, communication was poor. The proposed system provided more advantages than the existing ways of communication during juice transfer from one process to another, where someone climbed into the tank, checked the level of juice, and then ran fast to switch off the pump. Other systems implemented abroad [21] within highly developed industries are complex, very expensive, cannot be afforded by local beverage industries as well as in residential tank-level monitoring systems. System requirements are shown in Tables 2 and 3.

4.1.1 Functional Requirements

Functional requirements shown in Table 2 specify what the system does, how it reacts to specific input, and how it operates in a specific environment [27].

4.1.2 Non-functional Requirements

Non-functional requirements shown in Table 3 describe system performance, its usability, and the effectiveness of the entire system [28].



(a) (b)

Fig. 3. (a) The circuit diagram; (b) Amazon's Echo Dot.

Table 2. Functional requirements.

No.	Requirement	Description
1	Monitor juice level within the tank	The system must monitor the level by using an ultrasonic sensor.
2	Display juice level in the tank on an LCD	The LCD must continuously display the percentage.
3	Sound alarm when juice reaches the threshold	The system must generate a sound when the juice level reaches a threshold or when the level is too low.
4	Visualize data via the cloud	The system must send data to the cloud to be visualized.
5	Communicate via Alexa and the Echo Dot	The pump should be switched off and on by voice command.

Table 3. Non-functional requirements.

No.	Requirement	Description
1	Power consumption	Lower power consumption by switching the system off when the plant is not functioning.
2	Efficiency	Perform tasks effectively.
3	Performance	Perform tasks without delay.
4	Security	Security must be ensured by placing it somewhere safe.
5	Response	The system must respond in real time.
6	Flexibility	The system must be easy to use.

4.2 Hardware Components

Fig. 4 shows how the system hardware is integrated, powered, and begins working.

The distance between the juice level and the ultrasonic sensor is measured with an ultrasonic sensor mounted on the top of the container; pins are linked to the MCU. The

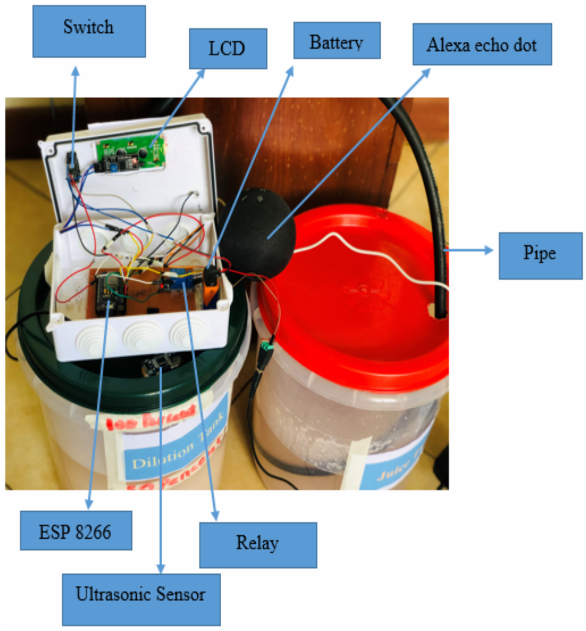


Fig. 4. System hardware interconnections.

ultrasonic sensor determines the distance, depending on duration and the speed of sound (331.4 m/s).

$$\text{Distance}(d) = (\text{duration} \times 331.4 \text{ m/s})/2 \quad (1)$$

The buzzer is connected to the MCU to generate a sound once juice reaches the threshold level. The I2C LCD displays the percentage of juice in the tank at any point throughout the filling procedure. A relay module is connected to the MCU and is attached to the pump, which is submerged in the sump juice tank from which juice is pumped, and is powered by a separate power supply. The Amazon Echo Dot is wirelessly connected to the system and able to communicate with it.

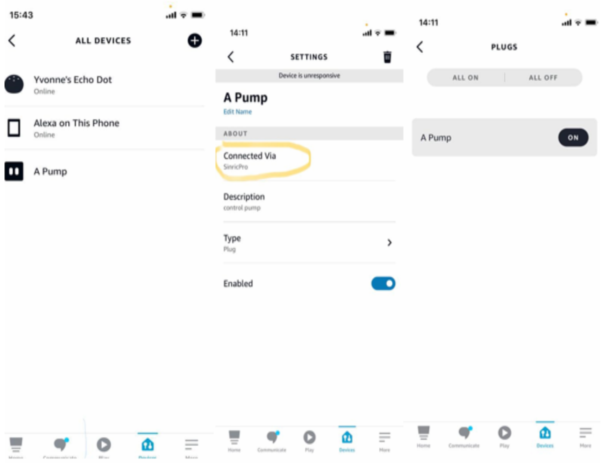


Fig. 5. From left to right, device configurations, pump configuration, and pump button.

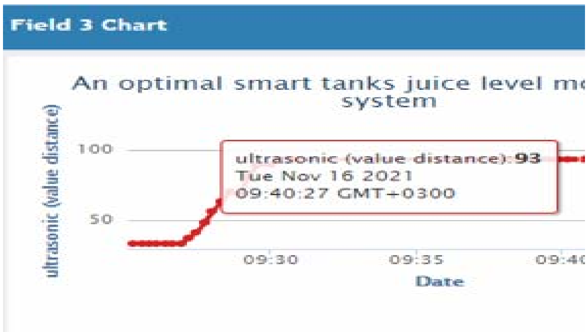


Fig. 6. Visualized juice level within the tank.

4.3 Software System Result

Fig. 5 shows how the pump is configured to the Sinric Pro and connected via Alexa. The Amazon Echo Dot is also configured through the Alexa app. If the system is not powered and not connected to the internet, a message pops up saying the device is unresponsive.

4.4 Data Visualization Result

Fig. 6 shows the percentage of juice sensed by the ultrasonic sensor and sent to the cloud for visualization. At any rise of the level in the tank, the system automatically sends data to the cloud.

Fig. 7 displays the buzzer state shown in the cloud. Bold indicates the buzzer's changed state, notifying the operator that the level reached the threshold, until operator switches the system off.

Fig. 8 shows results on the Sinric Pro dashboard from the pump. Once a pump is online, and the juice level within the tank is less than 100%, an operator is able to control the pump by calling Alexa to switch it off or on.

The commands used are:

"Alexa: switch OFF the pump" when a pump is operating, or "Alexa: switch ON the pump" when the pump is off.

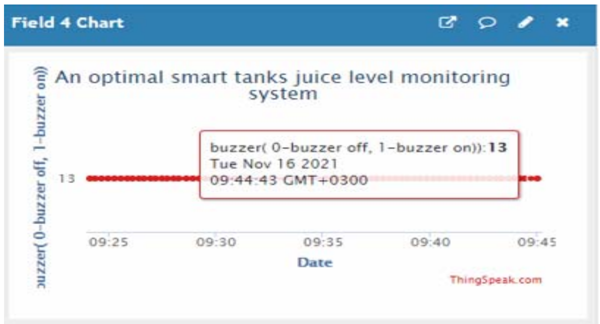


Fig. 7. Visualized buzzer state.

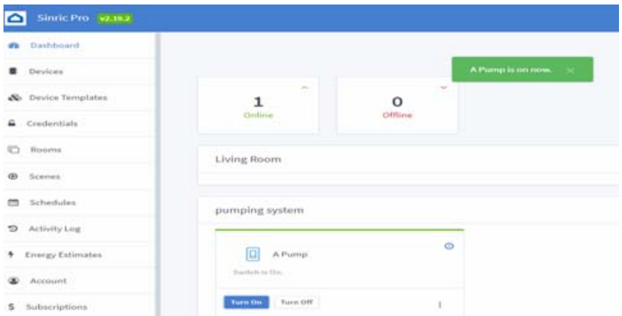


Fig. 8. Pump on the Sinric Pro dashboard.

4.5 Proposed System Simulation Setup

Fig. 9 illustrates the simulation setup from steps a to d. Step a shows juice flowing from the tank to a dilution container, and its level is displayed on the LCD in Step b. In Step c, the operator asks Alexa to turn the pump off. With each increase of juice level within the dilution tank, data are sent to ThingSpeak for visualization in the cloud, and for an operator to analyze how the level is changing within the tank, as shown in Step d. The distance on the chart shows the percentage of juice within the tank as measured by the ultrasonic sensor, that the pump was turned off at 81%, which corresponds to 11.34 liters within the container, and at the 22.68cm width of the container.

The distance measured by the ultrasonic sensor corresponds to the number of liters, as well as the width of container, as follows:

100% level → 14liters → 28cm (width of container)

General formula

$$= X\ level \rightarrow \frac{14liters}{100\%} \times X\% \rightarrow \frac{28cm}{100\%} \times X\% \qquad (2)$$

4.6 Validation of the System

The system prototype was tested and validated by pumping juice from one container to another, as shown in Fig. 10, scenario a to scenario c.

The sensors and actuators communicated with one another. The ultrasonic sensor continuously sensed the juice level within the tank, sent data to the microcontroller (ESP8266) for analysis, and sent signals to the actuators. Once there was a rise in the level of juice in the tank, the

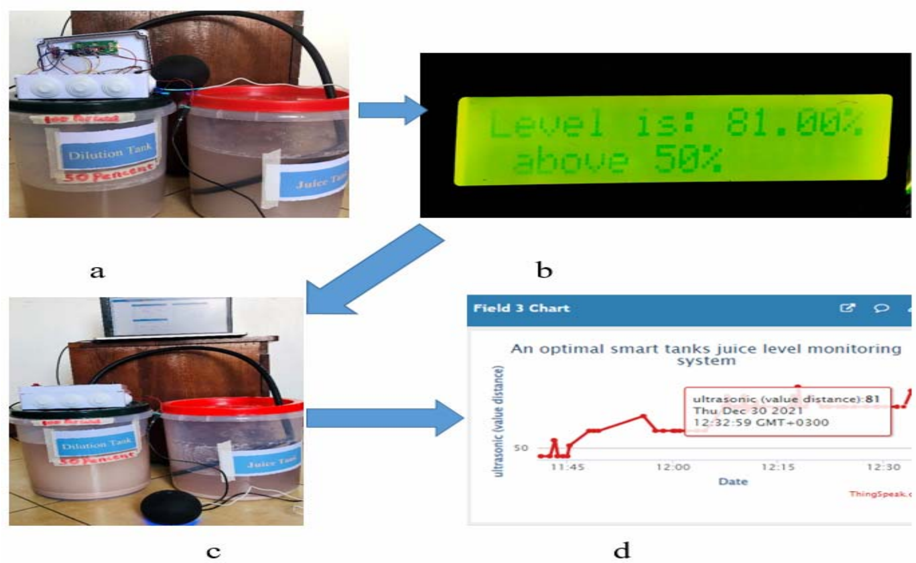


Fig. 9. (a) Pumping juice (level below 50%); (b) watching the percentage level displayed on the LCD; (c) Alexa switches the pump off; (d) the visualized level on ThingSpeak.

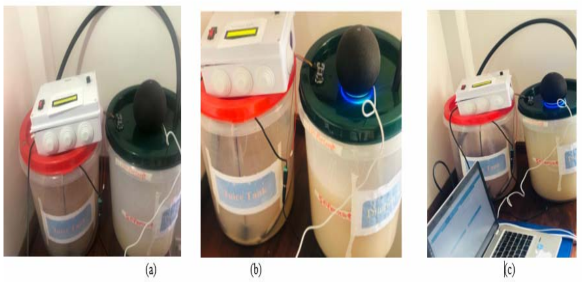


Fig. 10. The final system prototype.

LCD kept displaying the percentage. When the level reached 100%, the relay switch stopped the pump automatically, and the buzzer generated an alarm to notify the operator that the tank was full. Furthermore, the sensed data are sent to the cloud for further analysis after the operator commands Alexa to switch the pump off or on. The Amazon Echo Dot automatically sent the command to the cloud and checked if that device was available; once the device was found, the system operated as commanded; Otherwise, Alexa replies that the pump was not found. Moreover, once the tank was full, Alexa ignored all commands from the operator.

Table 4 shows how the status of the juice level within the tank is displayed on the LCD (which corresponds to the value from the cloud) and at which level the buzzer generated its sound, and when the pump switches off.

Table 4. Juice levels within the tank.

No.	Level	Status (juice within the tank)	Buzzer	Pump	Amount of juice (liters)
1	0 %	Empty tank	Low	High	0
2	50%	Half tank	Low	High	7
3	< 50%	Below 50%	Low	High	< 7
4	> 50%	Above 50%	Low	High	> 7
5	100%	Full (threshold)	High	Low	14

4.7 Discussion

The developed system is cost-effective, interactive, provides automatic pumping, and the pump can be controlled by voice commands from a distance. All of these features make it unique, compared to existing systems, which can perform only one feature but miss others.

This proposed system uses the ESP8266 microcontroller, which can connect to the internet without an external shield, and uses ultrasonic sensors that measure liquid levels in a contactless manner, whereas existing systems use the Arduino Uno and a probe sensor. The Arduino Uno microcontroller is expensive and requires an internet shield to send data to the cloud, which makes the system expensive. Moreover, the sensor probe is mostly used to sense fuel levels within a tank, and makes contact with the liquid. If used to sense the level of juice, it can negatively affect the health of people who consume the product, because a sensor probe can rust after a time.

For instance, Masetti et al. [16] developed a system that uses an ultrasonic sensor to detect the level of wine, but uses the Arduino Uno, which requires an external shield, making the system expensive and complex compared to the ESP8266. The system by Cañete et al. uses an ultrasonic sensor for ullage monitoring, known as a smart cork for measuring wine level [17]. But it only does level measuring; there is no pumping system. Yet another system was designed to monitor juice levels within the tank, which was interactive and provided data in real time [20]. However, it is expensive. The proposed system's functionality is more efficient and less expensive than the existing systems described in the related works section.

5. Conclusion and Future Research

Automation in industry makes activities simple, and reduces human involvement in the processes. Reduced human interference in industrial processes raises awareness and eliminates human-error-related mishaps.

The goal of this paper is to present a cheap and improved method of juice-level monitoring in tanks, and the use of voice commands to control a pump at any time. The system can also be implemented by other companies that monitor fluid levels in tanks. For future research other devices, such as lights and fans for industry, will be added to the system to be controlled by the Amazon Echo Dot to save energy, providing a smart industry, and applying a machine learning model to detect anomalies, thus ensuring security.

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Conflicts of interest

The authors declare they have no conflicts of interest.

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