ARCADA

Smart Fridge Project

Automating Inventory Management with IoT Technology

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1 Introduction

The Smart Fridge project is a system designed to automate inventory management of products within a refrigerator. By integrating ultrasonic sensors with an ESP8266 D1 Mini microcontroller, the system monitors canned products across three rows inside the fridge. The fridge's shelf is tilted to work as a gravity-based shelf. The products are chosen to be round for easy distance tracing with the tilted shelf. The collected data is displayed via a web-based interface, enabling users to track inventory levels in real-time.

The project has many aspects to it. It includes programming, 3D-printing, electronic circuit design and testing. Through 3D-printing and testing, many prototypes were constructed until the final version was established. The report outlines the development process including all implementations, challenges and outcomes.

2 Project Description

2.1 Project Objectives

The main goal of the project is to develop a reliable system for detecting the presence or absence of canned products on a shelf within the fridge. The shelf will have a gravity-based loading system, meaning that the products must be round. To ensure product detection, HC-SR04 ultrasonic sensors are implemented and connected to an ESP8266 D1 Mini microcontroller.

2.1.1 Mounting System Design

To get reliable readings on the product distances the ultrasonic sensors need to be stable. A secure method for mounting the ultrasonic sensors onto the fridge's interior shelf needs to be designed. A solution for this is to make 3D-printed custom brackets for mounting each sensor securely while maintaining good positioning for accurate readings. The brackets are designed to hold the sensors at specific angles and heights, ensuring a good field of view of the cans. The ESP8266 D1 Mini microcontroller will also need to have a 3D-printed box for it to be mounted into the fridge. This will tidy the fridge up and make it look more professional.

2.1.2 3D-Printed Components

3D printing is used to create all necessary structural parts, including sensor brackets and any additional support structures required for organizing wires and securing the ESP8266 D1 mini. The material used in 3D printing is polylactic acid (PLA).

2.1.3 Web-based Interface Development

Implement a user-friendly web interface that allows users to monitor inventory levels remotely via Wi-Fi. The interface provides visual feedback on the status of each row and alerts when any of the row's stocks are empty. The microcontroller is programmed to work in a specific network and to access the web interface one needs to be connected to the same network. The controller can always be programmed to another network if needed.

2.1.4 ESP8266 D1 Mini

The microcontroller is an ESP8266 D1 Mini version 2.2.0. It is based on the ESP-8266EX microcontroller and is a compact Wi-Fi development board. It is designed for Internet of Things (IoT) applications, offering integration of Wi-Fi connectivity and microcontroller capabilities in a small form factor. The board supports digital I/O, analog input, and standard communication protocols such as I2C, SPI, and UART, making it suitable for a wide range of sensors. (WEMOS)

2.1.5 HC-SR04 Ultrasonic Sensors

The HC-SR04 sensor is a popular cost-effective ultrasonic sensor used for distance measurement. It works by transmitting and receiving sound waves. It emits a pulse and measures the time it took for the pulse to reach an object and return from it.
Sensor specifications:

- Operating current 5V DC
- Current consumption 15 mA
- Measuring range 2 cm – 400 cm
- Operating frequency 40 kHz

When the sound wave comes back to the sensor, the Echo pin turns on and stays on for as long as the wave takes to go to the object and back. This time is used to calculate the distance. Below is the formula for the calculation that the sensor does to measure the distance to an object.

$$d = \frac{t \cdot 343\frac{m}{s}}{2}$$

For the project 3 ultrasonic sensors are placed on the back of a shelf. The products have their individual lanes on the shelf and the lanes all have their own ultrasonic sensor that tracks the distance for the specific product that belongs to the corresponding lane.

2.2 Project Scope

The project scope was very unclear in the beginning but became clearer the further the project developed. The primary focus was clear, and it was to develop a functional, cost-effective smart fridge by using IoT technologies. The smart fridge is designed for an environment where students and teachers can purchase the selected product from a shared refrigerator. The main goal is to produce an automated inventory tracking system for the fridge by using ultra sonic sensors. The sensor readings are then informing an ESP8266 mini D1 microcontroller mounted into the fridge that based on the distance reading of the specific sensor, how many products are available in that lane. The data is then transmitted wirelessly to a web interface which will inform the user how many products are available and the cost of them. The shelf itself will be slightly tilted with the purpose that the round shaped products would automatically roll down to the edge of the fridge which ensures stable readings. All the equipment used for the project is available from Arcada University of Applied Sciences.

In the scope:

- Inventory monitoring using HC-SR04 ultrasonic sensors
- ESP8266 D1Mini as microcontroller
- Wi-Fi is used as a wireless communication method

- 3D-printing for lane separators, mounting brackets and microcontroller box.
- Shelf design with polycarbonate plate and a slightly tilted shelf
- Web-based interface for product management and tracking
- Choosing the products
- Testing and correcting the system
- Documentation which will be uploaded to Github.

Out of scope:

- Integration of a payment system
- Security features
- Advanced web interface

2.3 Product Detection Logic

For the detection of the cans, three HC-SR04 ultrasonic sensors were used to measure the distance between the sensors and the cans. When a can is removed the sensor detects a longer distance which means a change in stock. The microcontroller receives the readings and updates the status of the lane to the website. To reduce false readings a simple averaging filter is used. This ensures that the system can track how many cans are remaining.

3 Methods

3.1 Sensor Implementation

When integrating the HC-SR04 ultrasonic sensors with the ESP8266 D1 Mini microcontroller, voltage compatibility issues were discovered. The HC-SR04 sensors operate at 5V, while the ESP8266 D1 Mini operates at 3,3V. Directly connecting the sensor's Echo pin (output) to the microcontroller could potentially damage it, as they are not designed to handle 5V signals. To fix this challenge, we added a resistor-based voltage divider to safely reduce the output voltage from 5V to 3,3V. This is described in chapter 3.1.1.

3.1.1 Voltage Divider Circuit

A voltage divider circuit was constructed using two resistors, R1 and R2, connected in series between the 5V output of the HC-SR04 sensor and the input pin of the ESP8266 D1 Mini. Standard resistor values of R1 = 1 kΩ and R2 = 2 kΩ was chosen, which matches the maximum resistor tolerance. This configuration ensures that the output voltage is reduced to around 3,3V, making it safe for the ESP8266 D1 mini. (Instructables)

$$V_{in}\frac{R1}{R2} = V_{out} \; = \; 5V \cdot \frac{2k\Omega}{1k\Omega + 2k\Omega} = 3{,}33V$$

3.1.2 Circuit Diagram

The circuit diagram below shows the voltage divider circuit and how everything is wired. The diagram fully matches the real wiring with the GPIO pins. It was created using Wokwi, an online diagram simulator tool meant for IoT appliances. The application had a large quantity of microcontrollers and component options but lacked the D1 Mini version of the ESP 8266. The program had an ESP8266 which was chosen to the initial circuit diagram knowing that it was the wrong one. This meant that the ESP8266 had to be later replaced with the D1 mini by using Adobe Photoshop. The wiring had to also be modified to connect to the right pins of the D1 mini controller.

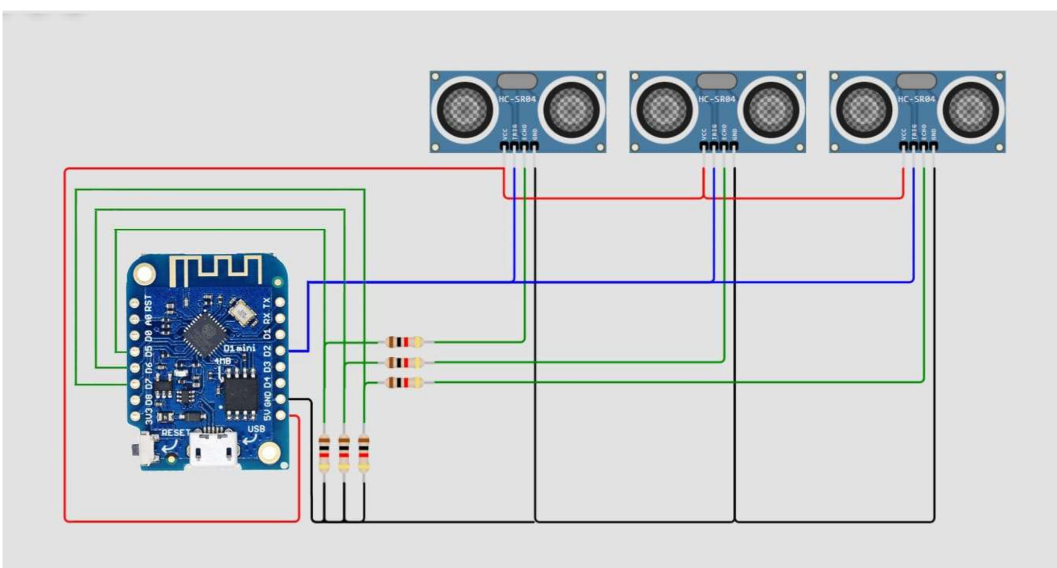

Figure 1: The wiring diagram between the HC-SR04 sensors and the ESP8266 D1 mini controller.

3.2 Smart Shelf Design

The sensors were mounted directly onto the fridge shelves for testing. However, the shelf's bars interfered with the sensors readings, giving inaccurate results. To fix this, we installed a black polycarbonate plate over the shelf and cut square openings for the sensors. This minimized interference, improved accuracy, and provided a clean look. Testing confirmed good detection of canned products across all rows.

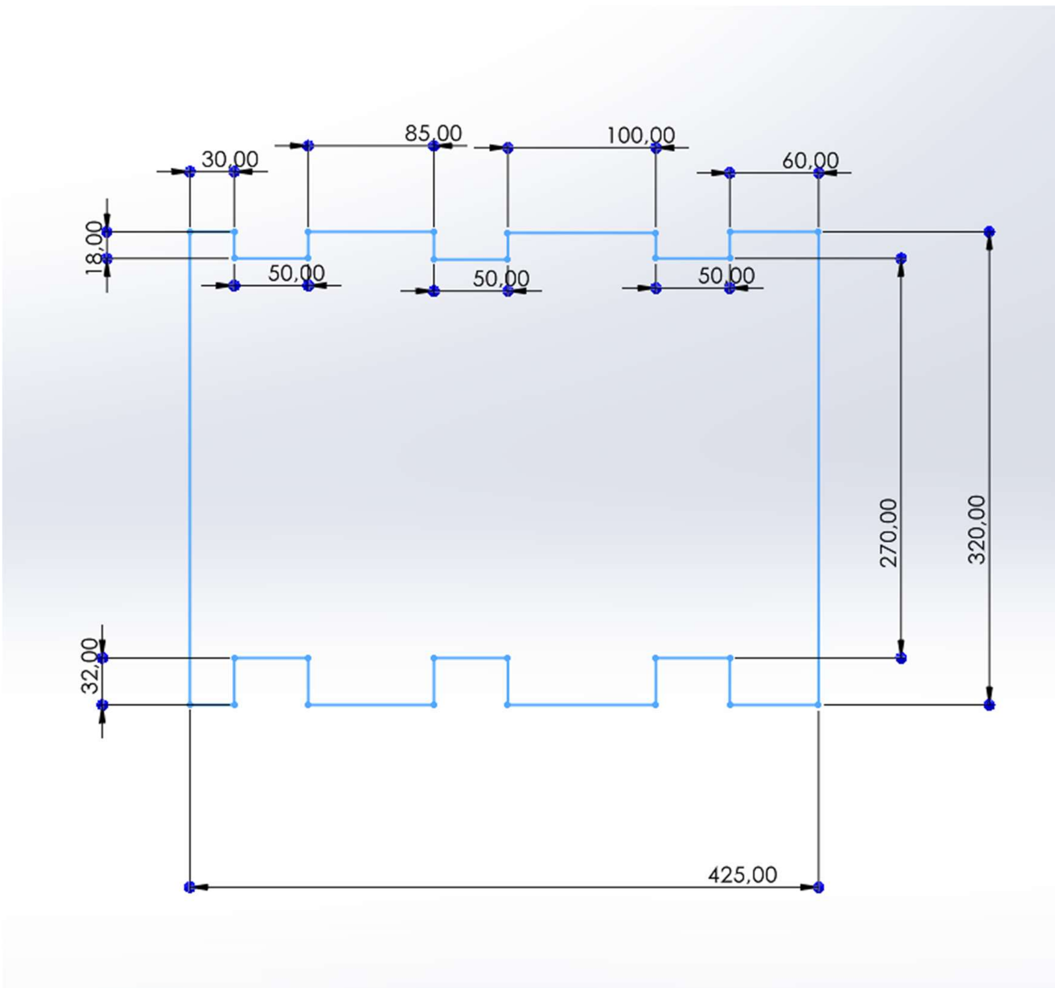

Figure 2: The dimensions of the polycarbonate plate that was designed to be placed on top of the shelf.

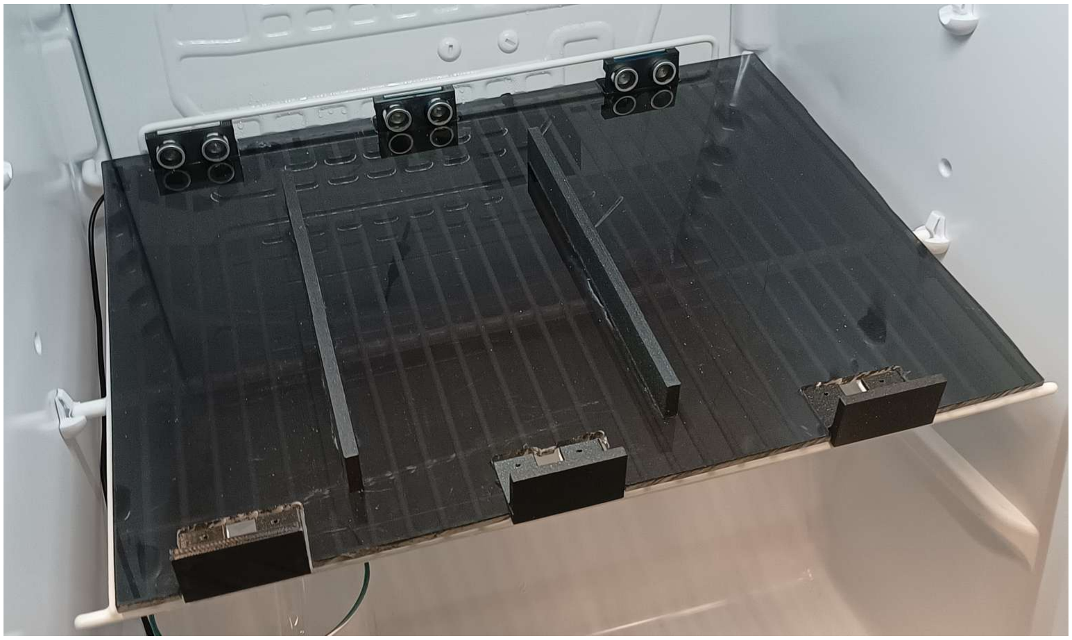

Figure 3: The design of the completed shelf.

3.3 Wi-Fi and Web Interface

The web interface will run locally, and it is hosted by the ESP8266 D1 mini microcontroller. The web interface has a simple design with inventory status on the products. It visually shows the product name and a small picture per specific product meaning that if there are 3 Coca cola cans in the fridge, it will be shown in the webpage as 3 small Coca cola cans. It also shows the amount in numbers.

Figure 4: The layout of the web interface.

3.4 Testing and Calibration

When designing the parts there were numerous test prints where parts were created using different designs and dimensions and checking their compatibility with the smart fridge interior.

One significant challenge was to achieve the correct spacing between the sensors and the cans while avoiding interference from the fridge's internal structure. Several prints were necessary to refine the bracket designs, including features like angled supports and adjustable mounts to support slight variations in shelf dimensions.

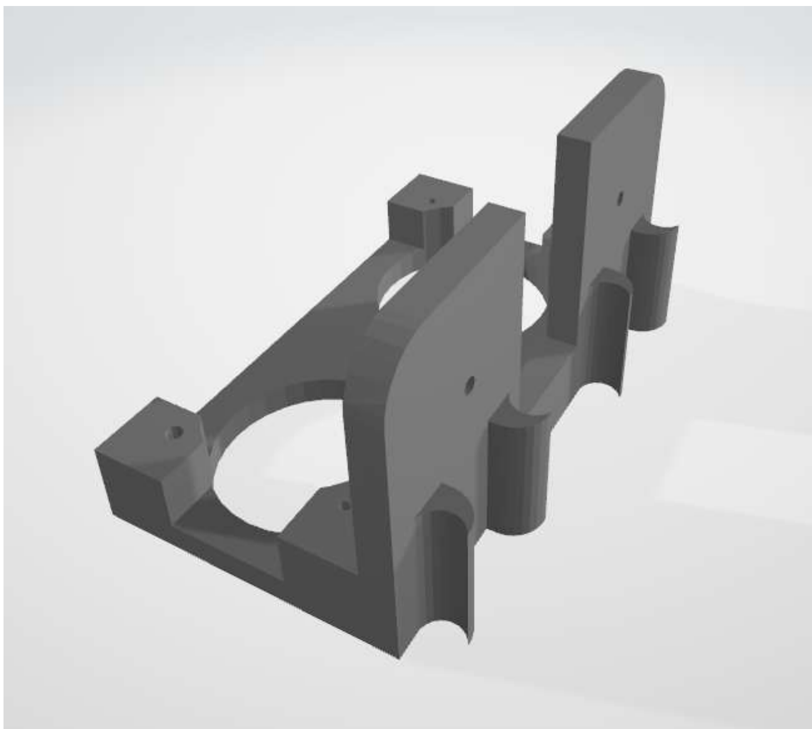

Figure 5: The final mounting bracket design.

4 Results

4.1 System Performance

The product detection logic was successful, meaning that the ultrasonic sensors detect each product in their own lane as planned. The sensors successfully detect the product quantity with each lane being monitored individually. Real-time data was transmitted to a web-based interface using Wi-Fi. Testing confirmed that the sensors reliably detect distance changes in their own lane and send that information to the web-based interface. The sensor mounting and the polycarbonate plate that was placed on top of the shelf to minimize interference worked as wanted. With the help of these implementations stable reading was ensured.

4.2 Inventory Monitoring

The chosen products for the fridge are:

- Coca-Cola can 0,33l
- Sega Fredo coffee can 0,235l
- Humble smoothie 0,25l

The products were selected as they are round, small, relatively cheap, and easy to sell. There was another choice of smoothie brand but that had to be changed because of its concave shape interfering with signals. The final product selection worked seamlessly with all products being round. Testing ensured that the inventory monitoring was working flawlessly when removing or adding the right products to/from their lanes.

Figure 6: How the fridge looks from inside. The smoothies on the right are not the final product on that lane, but this shows how tidy the fridge looks.

5 Discussion

The project was not all smooth sailing. There were many challenges starting from the beginning. The first challenge was a voltage compatibility issue. The ultrasonic sensors operate in 5V while the microcontroller operates in 3,3V. To solve this problem, we either needed to change the controller or to change the voltage coming out from the sensors. We decided to go with the latter option. We made a voltage divider calculation and soldered two resistances to each trigger output, 1kΩ and 2kΩ. This ensured that the controller received the correct voltage of 3,3V. However, initially we had issues with having a place to solder. The Arcada University of Applied Sciences school did not have any soldering station available for us to use whenever we needed to. We found our own way around it as Alfred Granqvist had a soldering station in his garage in Sipoo.

Once the sensors were connected to the microcontroller, we did some testing with a simple code that would ensure that each sensor's trigger pin worked. We noticed that the measurements were way off. After hours of thinking we noticed that they only gave false readings when pointing the sensors at a far object or a very near one. After reading about the HC-SR04 sensors online, we found out that the sensors operate only over certain distances. After knowing this, we noticed that each sensor was working properly when testing within its distance limit margins. Next problem was that the microcontroller did not have the capacity to read all trigger pin outputs at the same time. We had to come up with a way to work around this. We implemented a time delay between each sensors' pulse, which solved the issue. After having the hardware problem solved, we had to come up with a way to mount them into the fridge. We had to figure out a way to connect the sensors and the microcontroller to the fridge. We designed multiple mounting prototypes for the sensors. We had difficulties designing it when using Solidworks but managed to get our visions through. The shelf is a metal shelf with ribbed metal bars. First, we needed to figure out how to attach it to the bars and we came up with 4 attachments on the bottom of the sensor bracket. This worked, but there were more issues. The attachments on the bottom were too tight, which meant that it was very difficult to push the sensor bracket to the end of the shelf. This was solved but slightly moving the attachments further away. We also had some material issues when 3D printing the brackets. We used Cura Ultimaker slicer which turned out to be way worse than Prusa slicer. The Cura Ultimaker slicer made the objects very thin and air-filled, while the Prusa slicer made more durable and dense prints. After installing the brackets on the shelf, we discovered a problem with the sensor readings. The sensors started reading wrong distances at >16cm distances. This turned out to be an issue with the shelf itself. The shelf's bars somehow reflected the signals which made the sensor read them wrong. We came up with an idea to implement a flat cover on the shelf's surface and we tested this theory by just inserting a carboard piece on top of the shelf. This worked perfectly. Knowing this, we searched around for a material that would fit our build in design. We found a black semitransparent polycarbonate piece that we needed to cut into the dimensions of the shelf. The plastic cover was also designed to be a sort of lock for the mounting brackets. This turned out to fit perfectly and look professional. The polycarbonate cover gave us more complications as we had designed lane dividers on the shelf. These dividers were designed to be a wall that keeps the products in their own lanes. The initial design had attachments at the bottom that were designed to attach to the bars on the shelf. As we built the cover, we did not need the attachments anymore. We had to come up with another idea. We ditched the attachments and just 3D printed simple walls which we then glued onto the assigned places on the polycarbonate cover. To ensure that the glue would attach to the lane walls, we scratched the surface on the polycarbonate cover where the pieces were to be glued on. The next challenge was to make the product choices. We decided to go with round products as they would work smoothly in a gravity-based loading system. This worked well and we bought 3 different product types. 1 lane for Coca-Cola cans, 1 for coffee cans and 1 for smoothies. All the products except one passed our testing. The smoothies were problematic. This was due to their design. They were concave to their form which reflected the signals incorrectly, meaning that the signal readings were unsuccessful. To correct this problem, we just had to choose another brand of smoothies that had a round but straight shape.

6 Conclusion

The smart fridge project started with many questions, and countless possibilities to enhance the outcome. To start with somewhat of a scope was a must, but the amount of work just piled on. There were many complications, issues that were solved through hard work, tears and sweat. We established a goal to limit the amount of equipment used and make it as simple and clean looking as possible. Through voltage division the goal was completed. This meant that it was necessary to wire all the sensors into 1 ESP8266 D1 mini controller. The great craftmanship of two fellow students made the wiring look outstanding. The main task was to build an automated inventory tracking for products inside the fridge, but the project's scope went beyond that. It included 3D-printing mounting brackets and lane dividers, sawing and designing a polycarbonate plate to fit perfectly into the fridge. The programming was the easy part of the project and was successfully done. There were many challenges along the way, but all were defeated. The polycarbonate surface was developed because of a challenge of sensor misreadings.

The final result worked great under testing. The system performs as it should, and the product choices were successful. The interior of the refrigerator looks tidy and professional. The final product is a great foundation for future improvements. There are a lot of improvements that can be made. Improvements like the payment system, added shelves and security.

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Figure 4: *The layout of the web interface.*

Figure 5: *The final mounting bracket design.*

Figure 6: *How the fridge looks from inside. The smoothies on the right are not the final product on that lane, but this shows how tidy the fridge looks.*

Sources

Instructables. (n.d.). *Modify Ultrasonic Sensors for 3 Volts Logic - prepar* . Instructables. Retrieved [20.02.2025], from https://www.instructables.com/Modify-Ultrasonic-Sensors-for-3-Volts-Logic-prepar/

WEMOS. (n.d.). *D1 mini* . WEMOS Official Documentation. Retrieved October 25, 2023, from https://www.wemos.cc/en/latest/d1/d1_mini.html