

# Development and analysis of a smart cold storage system for fruit warehouses

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**Abstract.** This research explores the innovative integration of traditional refrigeration systems with Object Detection via Artificial Intelligence. It leverages the use of an AI algorithm to optimize the temperature and enhance the overall efficiency of the system. This research presents a smart, eco-friendly cold storage system for fruits and vegetables to remain fresh for a longer period. Following the incorporation of Object Detection for intelligent temperature control for this system which will further improve the energy efficiency. The Object Detection component of the project uses computer vision to recognize objects within the cold storage and dynamically change the temperature to ensure optimal preservation based on the kind and number of contents. It will also provide information related to the state of the product (for example, if an apple is stale or fresh). The whole information will be accessible via the internet so we can access the data of the cold storage any time anywhere. The temperature and state of the fruits will also be displayed on the lcd. The practical application of this project is to be used in the agricultural and transport industry for long-term efficient storage of different objects in any compartment.

**Keywords:** Object Detection, Refrigeration, Cold Storage, Artificial Intelligence

## 1 Introduction

The demand for energy-efficient and technologically advanced systems has never been greater in a society that is continually advancing towards sustainable and eco-friendly solutions. Cold storage systems are used for the preservation of a variety of fruits and vegetables. Post-harvest diseases destroy 10-30% of the total yield of crops and in some perishable crops, especially in developing countries, they destroy more than 30% of the crop yield [1-2]. Pakistan is the developing country, where 35-40 percent post-harvest losses are in fruits and vegetables. In these losses 15-20 percent are at the time of management harvested crop, 5-8 percent at harvesting and 10-12 percent loss in vegetable and fruits when it transports [3].

This system tackles these issues by maintaining appropriate temperature levels within a cold storage through a refrigeration cycle with 4 main components Compressor, Condenser, Evaporator and Capillary tube. Furthermore, it features a one-of-a-kind object recognition mechanism to adjust temperature settings based on the stored contents, assuring accuracy and energy efficiency. Object detection will also be used to display real time information like its temperature and the state of the contents (stale or fresh) of the cold storage and the stored contents. The temperature and the state of the fruit will then be displayed on the LCD and be accessible via the internet. The cooling system is powered

by alternating current electricity, which circulates a refrigerant to collect and release heat. The refrigerant in the evaporator takes heat from the interior air or the refrigeration room and cools it. This project blends sustainability, energy efficiency, and artificial intelligence to promise a breakthrough in cold storage technology that will benefit agriculture, food preservation, and healthcare. This project is a perfect blend of traditional technology and new technology which can increase efficiency and in the long term help us save energy. This project embodies innovation, responsibility, and a commitment to building a better world for generations to come.

## **2 Methodology**

### **2.1 Refrigeration System**

#### *2.1.1 Design of cold storage compartment*

Rigorous calculations were undertaken to ensure the seamless integration of the 18 by 18-inch cooling storage space, a critical dimension for preserving perishable goods. The creation of a detailed frame played a strategic role, providing structural support to the entire cooling storage system. Every component, including compressors, control systems, condensers, thermostats, and evaporators, underwent careful consideration and placement. Factors such as heat exchange dynamics, energy efficiency, and spatial constraints were thoroughly accounted for in this intricate design phase. The result was a thoughtfully crafted system poised to deliver optimal functionality and performance in the preservation of fruits.

#### *2.1.2 Fabrication of the cold storage system*

A robust framework was skillfully constructed with a wooden base and strategically placed pillars at each corner, providing support for the subsequent assembly. The four walls were carefully crafted using a combination of 3 mm acrylic sheet and plywood. Once shaped, these walls seamlessly fit into the frame, enclosing the storage area from all four sides. For optimal thermal insulation and reduced heat losses, an inventive top lid was crafted using a combination of acrylic sheet, with a 1-inch thermophore sheet strategically placed between them to enhance heat retention. To further reinforce the structure against heat dissipation, all four sides were meticulously covered with a 1-inch thermophore sheet, completing a comprehensive approach to minimize thermal losses within the storage unit. This meticulous construction enables easy removal of the walls when needed for analysis, providing both practicality and efficiency in examining the enclosed Phase Change Material.

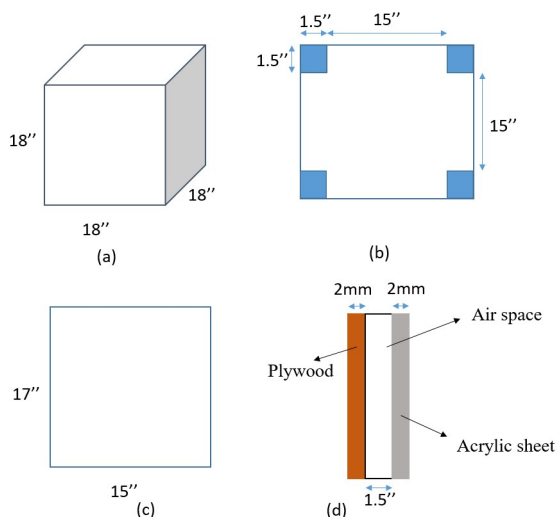


Figure 1 (a) 3-D view of cold storage compartment; (b) Top view of the compartment ; (c) Front view of the wall; (d) Side view of the wall with Acrylic sheet, plywood and air spacing

**Table1** Specification of the Components

Components Name	Specification
Compressor	TL103G Danfoss compressor with cooling capacity of 321 watts at evaporator temp “10°C”
Condensor	Lentgh= 30 feet Dia= 5mm
Evaporator	Lentgh= 24 feet Dia= ½ inch
Capillary tube	Length = 10 feet
Refrigerant	R-134a

The authors[4] used vision transformers for fruit defect detection. For apple fruits, the Internal Feeding Worm data set of the Comprehensive Automation for Specialty Crops research project [5] was used. It contains 5858 images of apples with and without worm defects at the apple surface. Images were taken from four cultivations of apple trees from June to September, at different ripeness levels from green to red colored apples. They used this dataset for binary classification of healthy and damaged fruits. The dataset was comprehensive with varying lighting conditions. They achieved state of the art performance on this dataset using the architecture mentioned above.

The authors[6] presented an innovative IOT-based control system for Cold Storage Rooms in agriculture domain. The system remotely monitored the internal microclimate and parameters of the room, the aim was to enhance the life of date fruits. The components consisted of various sensors for

real-time monitoring, and control of compressor, ventilation, and humidification units, this ensured the optimal conditions and energy efficiency. The paper [7] utilized IOT to automatically collect real-time data of temperature, humidity, light intensity and CO2 concentrations, the data was then stored in Firebase. After that an Artificial Neural Network (ANN) was used for the classification of three classes good, unsatisfactory, and alarming. Forward Propagation of ANN model was used which then trained and validated the model's performance over set number of epochs. In preprocessing they normalized the dataset using min-max normalization technique and used a split of 70-30 for training and validation. The trained model is then integrated into an Android app for real-time inference on environmental parameters and status prediction of perishable items.

### 2.1.3 Object Detection Training and Inference

Machine learning on edge devices is becoming increasingly important as the need for autonomous systems is increasing across a variety of industries. Edge devices or micro controllers bring utility to systems by being easily deployable and cheap. By leveraging machine learning algorithms directly at the edge, devices can analyze and respond to data instantly without relying on cloud connections or external servers. This is especially important for applications that need to make quick emergency decisions, such as autonomous vehicles, industrial automation, and healthcare monitoring systems.

This system utilizes the inexpensive and durable ESP32 Cam module for detection of fruits. The Object Detection algorithm, the training, and annotation of dataset was done on Edge Impulse Platform [8].

For the collection of datasets, Kaggle was used [9] to search for fruits datasets that contained two classes of each fruits, like fresh and stale class of each fruit. A dataset according was chosen according to requirements. Kaggle is a popular platform for hosting datasets across various domains, including computer vision tasks like image classification. To gather images of fruits, you can search the Kaggle platform for relevant datasets using keywords such as "fruit images", "fruit classification", or specific fruit names like "apple", "banana", etc.

Once the dataset is collected the next step is to annotate it, 500 images of fresh apples and 500 images of stale apples were used and a bounding box was drawn on each sample. The quality of annotation can affect the training process, so it is necessary to create bounding boxes as close to the object as possible.

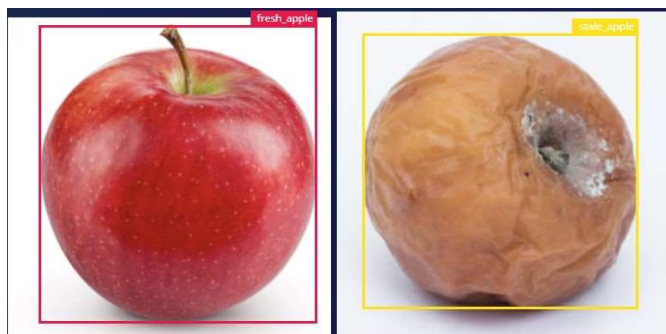


Figure 2 Annotated images of fresh (left) and stale apple (right)

Since the edge device used are resource constrained, a small but efficient object detection algorithm FOMO (Faster Objects More Objects) was utilized [10]. It is a fully convolutional network and can give 60 fps on Raspberry Pi 4, one difference between other object detection algorithm and FOMO is that it detects heatmaps and then creates a bounding box around it. The model is then trained using parameters, epoch 130, Learning Rate 0.002, Adam Optimizer. The next step is to import the trained model for inference on Edge device, the model was exported and then Arduino IDE was used to upload code on the device. The model was then tested and gave very good predictions.

#### 2.1.4 *Preprocessing*

Preprocessing steps such as image resizing, normalization, and labeling are crucial for preparing image datasets for any machine learning tasks. Image resizing involves adjusting the dimensions of images to a uniform size suitable for model input. In this model the original images were resized to 96x96 size for easy feature extraction. Normalization is the process of scaling pixel values within a certain range to improve model convergence and performance. Normalization scales these values to a range between 0 and 1 in most cases. Labeling involves assigning class labels or categories to each image in the dataset. For fruit classification, each image was labelled with the fruit type and classes as fresh apples and stale apples. Data augmentation techniques can be applied to increase the diversity and robustness of the dataset. Before training the model, the dataset is typically split into training, validation, and test sets. The training set is used to train the model, and the test set is used to evaluate the final model's performance. The dataset was split that contained 500 samples of fresh fruit and 500 samples of stale fruit into 80/20 split. Meaning 80% of the data was used for training and 20 % for testing.

#### 2.1.5 *Architecture*

Convolutional Neural Networks are the most successful type of Deep Learning used for Computer Vision tasks like object detection, classification etc. Following the success of CNN, we used a lightweight architecture FOMO [10] that can be used in low power micro-controllers. It is 1/8<sup>of</sup> the layers of MobileNet architecture.

##### Deployment

Model deployment and integration are crucial steps in bringing machine learning models to edge devices like the ESP32-CAM. This process involves deploying the trained model to the Edge Impulse platform, generating optimized model binaries for ESP32-CAM compatibility, and integrating the model into the ESP32-CAM firmware and hardware, including using the Arduino IDE for development.

After training the model using the labeled dataset and optimizing its performance, the next step is to deploy the model to the Edge Impulse platform. The model library was exported in Arduino IDE suitable files, after which Arduino IDE was used to deploy the model on esp32 cam.

### 2.1.6 Evaluation Metrics

The metrics used for evaluation in this research are Accuracy and F1 Score

$$\text{Accuracy} = \frac{TP+FN}{TP+FN+FP+FN}$$
$$\text{F1 Score} = 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$$

## 2.2 Control Systems:

The overall system would consist of five components:

1. Arduino Uno
2. ESP32 CAM
3. ESP8266 Wi-Fi Module
4. DHT11 Sensor
5. Firebase
6. Relay

The system would function as follows:

First the algorithm running in the ESP-32 CAM microcontroller would use the camera module to recognize the type of fruit/vegetable and analyze if the fruit/vegetable is *fresh or stale*. After Classification it would pass this information to the Arduino Uno. The Arduino functions would be as follows:

- Measuring the inside and outside Temperature of the compartment using the DHT11 sensor.
- Receiving the classification information of the fruit/vegetable.
- Sending the temperature and classification data to a database via Wi-Fi Module for remote monitoring.
- Sending an alert message to the LCD display and buzzer unit in case of stale product detection.
- Controlling the temperature of the compartment by regulating the compressor through a relay connected to the Arduino.

### 2.2.1 Components:

#### 2.2.2 Arduino Uno:

The Arduino Uno is a microcontroller board based on the ATmega328P processor. The board features digital and analog pins, allowing it to interface with a variety of sensors and actuators. Arduino Uno is widely used in DIY electronics projects, offering an open-source platform for programming, and experimenting with different applications, from robotics to home automation.

#### 2.2.3 ESP32 CAM:

The ESP32 CAM is a compact and powerful development board that integrates the ESP32 chip and a camera module. This module enables IoT (Internet of Things) projects with image and video processing capabilities. It supports Wi-Fi connectivity and has various GPIO pins for additional sensors or peripherals. The ESP32 CAM is particularly useful in applications such as surveillance cameras, image recognition, and smart home devices due to its wireless capabilities and onboard camera.

#### 2.2.4 *ESP8266 Wi-Fi Module:*

The ESP8266 Wi-Fi module is a low-cost, compact device that provides Wi-Fi connectivity to microcontrollers and other embedded systems. It gained popularity for its ease of use and affordability. With built-in TCP/IP protocol stack, it allows devices to connect to the internet. The ESP8266 is widely used in IoT projects, enabling devices to communicate over Wi-Fi networks and access cloud services. Its small form factor and simplicity make it a popular choice for adding wireless capabilities to various electronics projects.

#### 2.2.5 *DHT11 Sensor:*

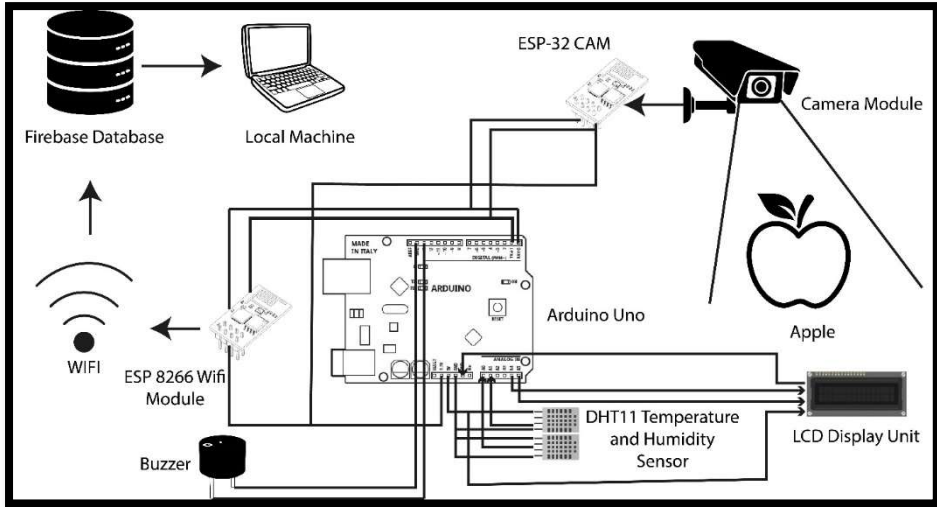
The DHT11 is a basic digital temperature and humidity sensor commonly used in electronics projects. It consists of a humidity sensing component and a thermistor for temperature measurement. The sensor provides a simple interface, usually through a single-wire digital communication protocol. Despite its low cost and simplicity, the DHT11 is reliable for obtaining temperature and humidity data, making it suitable for applications like weather stations, climate monitoring, and home automation projects.

#### 2.2.6 *Firebase:*

Firebase is a comprehensive mobile and web application development platform provided by Google. It offers various services and tools, including real-time database, authentication, hosting, and cloud functions. Firebase facilitates the development of scalable and feature-rich applications by providing a backend infrastructure with easy-to-use APIs. The real-time database is particularly useful for applications that require instant updates and synchronization across multiple devices. Firebase is widely adopted for its seamless integration with both Android and iOS platforms, making it a preferred choice for developers building dynamic and collaborative applications.

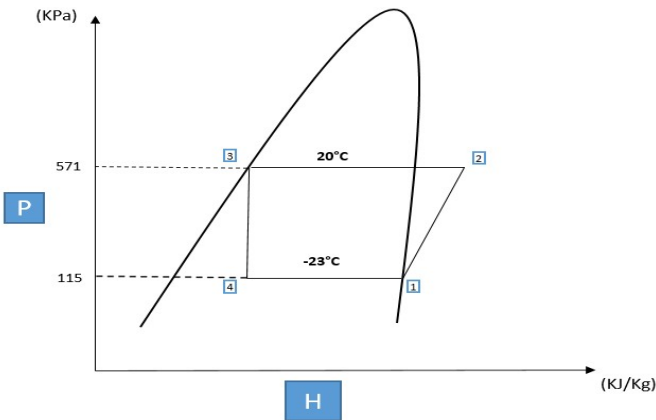
#### 2.2.7 *Relay:*

The relay acts as a switch which will be used to trip the compressor to reach the optimum temperature for cold storage. For example, in this case of apples the optimum temperature for storage is 8-12°C. The Arduino which conjunction with the relay and compressor to maintain this temperature aiding in long term preservation as well as energy efficiency.



*Figure 3 Schematic Diagram of Control System of cold storage with all the sensors and microcontroller*

### 3 Results And Discussion



*Figure 4 P-H Diagram of the cycle showing all the enthalpies, pressure and temperature*

Enthalpies:

$$H1=235.92 \text{ KJ / Kg}$$

$$H2=270.81 \text{ KJ / Kg}$$

$$H3= 79.32 \text{ KJ / Kg} =H4$$

Evaportaoor Refrigeration effect:

$$Q_e= H1-H4=156.6 \text{ KJ / Kg} \quad (1)$$

Condenser heat Rejected:

$$Q_c=H2-H3=191.49 \text{ KJ / Kg} \quad (2)$$

Compressor Heat:

$$Q_w = H_2 - H_1 = 34.89 \text{ KJ / Kg} \quad (3)$$

Mass Flow Rate:

Now the mass flow rate of the system is found by using the Refrigeration Capacity from the Compressor manual. Its value is 0.321 kilo-Watt.

$$Q_e = \dot{m} (H_1 - H_4) \quad (4)$$

$$\dot{m} = 0.321 / 156.6 = 2.04 \text{ g/sec}$$

Power:

$$W_{in} = \dot{m} (H_2 - H_1) = 0.07 \text{ Kw} = 70 \text{ watts} \quad (5)$$

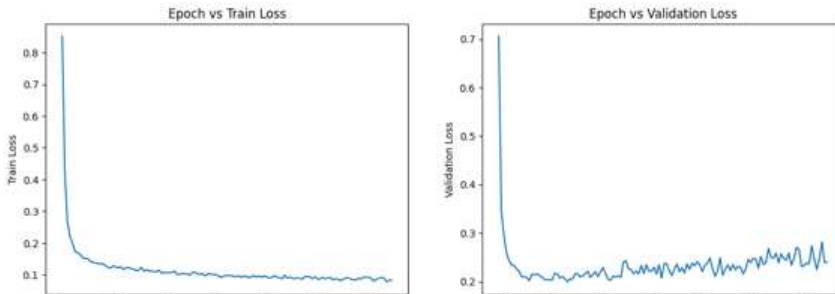
COP:

$$COP = \text{Refrigeration Capacity} / W_{in} = 4.58 \quad (6)$$

*Table 2 Cooling Capacity of System*

1	Cooling load requirement	68 watts
2	Cooling capacity of Compressor	321 watts
3	Evaporator temperature	10°C
4	C.O.P	4.58
5	Wattage	70 watts

The experiment was performed on the fruits dataset for object detection, on 96x96 input image size, with 80/20 training and testing split for 130 epochs, with batch size of 32. When learning features Adam Optimizer was used, with a Learning rate of 0.002, and quantized data from float64 data type to int8 data type.



*Figure 5 Train and Validation Loss Curves of machine learning model*

	BACKGROUND	FRESH APPLE	STALE APPLE
BACKGROUND	99.8%	0.0%	0.1%
FRESH APPLE	7.5%	92.5%	0%
STALE APPLE	0%	0%	100%
F1 SCORE	1.00	0.95	0.95

*Figure 6 Confusion Matrix illustrating the performance of the model*

Table 3 The Evaluation Metrics

Model Type	Accuracy	F1-Score
FOMO	92.27%	95.1%

## 4 Conclusion

Object detection paired with the traditional refrigeration system reduces the refrigerator's power usage and can be used to distinguish between stale and fresh apples, increasing the efficiency of the traditional refrigeration system and also improving the air quality inside the storage to reduce the amount of gases released from stale fruits. The total cooling requirement for the model shown above was 68 watts and a compressor with cooling capacity of 320 watts was used which maintained the cold storage at a temperature of 10°C. The time taken by the compressor to cool the storage to set temperature was 35 minutes. An artificial intelligence system will be used to recognize the type of fruit and determine whether it is fresh or stale. The accuracy of the model was 92.27% and F-1 score was 95.1% on test set. The test results show that the model is working properly against unseen data. The control system will further regulate the temperature within the cold storage facility based on the kind of fruit. The computer will display various information regarding the cold storage, such as internal temperature and humidity, as well as power usage, for ease of access.

## 5 References:

- [1] D. Seaver, "3311 Postharvest Technology of Horticulture Crops".
- [2] "Plant Pathology - 5th Edition." Accessed: Oct. 29, 2023. [Online]. Available: <https://shop.elsevier.com/books/plant-pathology/agrios/978-0-08-047378-9>
- [3] Staff, "Post-harvest losses in fruits and vegetables in Pakistan," AgriHunt - A Hunt for Agricultural Knowledge. Accessed: Oct. 29, 2023. [Online]. Available: <https://agrihunt.com/articles/pak-agri-outlook/post-harvest-losses-in-fruits-and-vegetables-in-pakistan>
- [4] M. Knott, F. Perez-Cruz, and T. Defraeye, "Facilitated machine learning for image-based fruit quality assessment," *J. Food Eng.*, vol. **345**, p. 111401, May 2023, doi: 10.1016/j.jfoodeng.2022.111401.
- [5] "Dataset." Accessed: Feb. 18, 2024. [Online]. Available: <https://engineering.purdue.edu/RVL/Database/IFW/index.html>
- [6] M. Mohammed, K. Riad, and N. Alqahtani, "Design of a Smart IoT-Based Control System for Remotely Managing Cold Storage Facilities," *Sensors*, vol. **22**, no. 13, p. 4680, Jun. 2022, doi: 10.3390/s22134680.

[7] H. Afreen and I. S. Bajwa, “An IoT-Based Real-Time Intelligent Monitoring and Notification System of Cold Storage,” *IEEE Access*, vol. **9**, pp. 38236–38253, 2021, doi: 10.1109/ACCESS.2021.3056672.

[8] <https://edgeimpulse.com/>

[9] <https://www.kaggle.com/>

[10] <https://docs.edgeimpulse.com/docs/edge-impulse-studio/learning-blocks/object-detection/fomo-object-detection-for-constrained-devices>