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Original Article

DISPENZO: A Smart and Transparent IoT-Driven Ration Distribution Framework

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Abstract *- The Public Distribution System (PDS) is the fundamental system through which basic essential items such as food grains, kerosene and oil are distributed to the beneficiaries through fair price shops in India. Research gap-However, such a system has limitations in the form of poor measurement methodologies, manual entries, lack of transaction transparency. This imparts scope for corruption and mis-use of commodities. Existing technologically driven applications address one aspect or the other, such as user identification or partial automation, without integrating secure authentication, automated dispensing and continuous monitoring at a single platform, leaving a void in the fully automated digital ration distribution system. Proposed work-To mitigate these shortcomings, the current proposed system, DISPENZO: Smart Ration Distribution System, is developed. It is an IOT-based automated system for safe authentication with regulated ration distribution. The system is developed in order to reduce manual intervention, increase transparency of ration distribution and enable the digital monitoring of inventory and transactions. It also incorporates the environment sensing for commodity preservation and monitoring of the quality of stored goods for making them eco-friendly. Methodology-The main controlling unit is the ESP32 microcontroller, which is connected with various modules such as the MFRC522 RFID reader (RC522) for card-based authentication, R307S fingerprint sensor for biometric authentication. Grain measurements are precise with the use of a load cell integrated with the HX711 amplifier module, whereas stock levels are determined using the HC-SR04 ultrasonic sensor. Environmental parameters are sensed using the DS18B20 temperature sensor and the LM393 3.3V-5V Soil moisture sensor module. The grain dispensation is carried out using the MG995-180-degree rotational servo motor (PWM-Controlled) and DC 3-6 V mini micro submersible water pump via a 2 Channel relay module powered by a 3.7 V Lithium-ion battery. Outcome- The implemented system successfully helped to assist accurate distribution of ration stock, keep a check on storage status of food commodities and also helps to keep track of transaction details by use of Firebase and Blynk platform. The prototype, which is developed here, confirms that the integration of authentication, automation and remote monitoring into a single system is achievable.*

Keywords *- Automated ration distribution, Cloud Monitoring, Internet of Things (IoT), Public Distribution System, Sensor-Assisted Dispensing, Smart authentication.*

1. Introduction

Introduction to present-day problem-Food security continues to be a leading socio-economic issue within the developing countries, more particularly in India, as a large segment of the population is dependent on the food subsidy distribution schemes. The Public Distribution System (PDS), which represents one of the largest food security systems in the world, is the largest public sector system supplying the food requirements of over 800 million people through around 500,000 fair price shops [1].

The PDS plays an integral role in ensuring that vital food grains are readily accessible and affordably priced while simultaneously fighting poverty, hunger and malnutrition. In India, the passage of the National Food Security Act (NFSA) 2013, which provided food entitlements to over 80% of the population in the country, helped to expand this system [1]. Although the PDS has seen changes from a universal allocation scheme to a more targeted distribution model, it is currently rife with operational inefficiencies. One of the main sources of food grain leakage is through corruption and poor supervision at every point in the supply chain [2].

Errors are common in both inclusion (undeserving beneficiaries receiving benefits) and exclusion (deserving beneficiaries being denied benefits). Studies have shown that about more than 20% households have no ration cards, thus reducing their access to food grains [3]. Inefficiencies in the distribution process, like a lack of regular supply, low-quality food grains, and a lack of monitoring of fair-price shops, are also prominent [3]. Other issues in the supply chain include insufficient storage space, poor transportation of ration goods and delays in delivery due to various logistical constraints [2]. Lack of automated monitoring of every transaction in the supply chain leaves opportunities open to corruption and mistrust in the entire process.

Solutions to present day problems-Technology based interventions such as digitization of ration cards, Aadhaar-based authentication, and implementation of Electronic Point of Sale (EPoS) systems are being employed to tackle these shortcomings.

Unfortunately, the technology being implemented is largely piecemeal, dependent on the physical infrastructure in place, and is not fully automated in terms of dispensing of ration goods, especially in rural and remote areas lacking adequate connectivity [2].

Research gap-Thus, a clear discrepancy persists between digital identity verification and actual ration distribution, leading to further inefficiencies and malpractices.

The proposed system, The proposed Dispenzo - Smart Ration Distribution System aims to address the above-mentioned drawbacks of the current PDS through integration of automation, IoT-based dispensing and authentication systems.

The aim and advantage of the proposed system, as opposed to previous efforts Dispenzo directly addresses the accuracy of quantities and automation, and ensures the minimization of leakages with real-time tracking and minimized human involvement, ensuring transparency.

The Dispenzo smart ration distribution system bridges the gap between digital verification of eligibility and physical dispensation of ration products efficiently.

It increases the levels of accountability and trust of the beneficiaries towards the existing system through automation and intelligent monitoring, helping to achieve food security for all. This research aims to demonstrate how technological innovation can significantly improve the efficiency and reliability of public welfare systems like the PDS.

Section 2 deals with the literature review and problem formulation, Section 3 deals with the implemented methodology, technical details of the physical components used and their specific application in the developed system. Section 4 deals with results and their analysis, followed by conclusions and future directions.

2. Literature Review

Many systems have been developed for ration distribution management. This section aims to study the existing models and understand their objectives, methodologies, implemented tools and used technologies. It further targets to highlight their challenges and frame the problem definition and objectives for the experimental model that is built.

The literature review is tabulated in Table 1. Based on Table 1, the following have been some of the main problems identified in the existing system

a) There is a likelihood of some inaccurate counting and measurement of ration commodities since weighing is manually done.
b) Manual records being maintained lead to difficulty in monitoring, and there are various issues like misinterpretation, misuse, or malpractice occurring during the dispatch of rations.

To counter these issues, various recent researchers have tried to implement Radio Frequency Identifier (RFID) authentication, biometric authentication, and microcontroller-based dispensing mechanisms to automate distribution, which has increased efficiency in some of the above aspects, but these seem to work in isolation with a weak digital monitoring component. Some of the issues found from studies are-

a) It fails to display real-time transactions and stocks.
b) Poor integration with a connected network for a centralized mechanism
c) Lacks the quality monitoring component that would keep track of conditions like temperature, humidity, and risks associated with potential spoilage, affecting the food items being stored.

Therefore, there is a need for a more integrated system that combines secure authentication, automated dispensing, and quality monitoring.

The proposed DISPENZO: Smart Ration Distribution System *aims* to address these limitations by implementing an IoT-enabled framework that assists controlled ration dispensing while improving transparency and operational efficiency. The novelty of the implemented system is-

a) To design and develop an automated ration distribution system that reduces dependence on manual processes in the Public Distribution System.
b) To implement secure authentication and sensor-assisted dispensing mechanisms for the regulated distribution of ration commodities.
c) To enable digital monitoring of transactions and inventory levels using connected technologies to improve transparency.
d) To improve operational efficiency in ration shops by reducing manual errors and simplifying distribution procedures.

Table 1. Literature review of the existing ration distribution systems

Year & Ref	Objective of the built system	Tools and technologies used	Challenges encountered
2025 [4]	To develop an AI and IoT-based smart ration distribution system that ensures secure, transparent, and automated delivery of food grains using multi-layer authentication, real-time monitoring, and intelligent decision-making.	Artificial Intelligence, Raspberry Pi / Arduino, RFID, Fingerprint and facial recognition, Voice assistant, Load cell sensors, Cloud database	Introduces high system complexity, lacks cost-effective deployment strategies, and does not address the practical challenges of large-scale implementation
2024 [5]	To develop a secure and scalable blockchain-based ration distribution system that leverages post-quantum cryptography and hardware security modules to enhance transparency, prevent fraud, and ensure efficient and reliable food distribution.	Blockchain (Hyperledger Fabric, Raft Consensus), Post-Quantum Cryptography (Dilithium-Kyber), Hardware Security Modules (HSM, PKCS11), Chaincode (Smart Contracts), Go + Gin Framework (Backend), Machine Translation,	Introduces high architectural complexity, depends on advanced infrastructure and cryptographic mechanisms, and lacks focus on cost-efficiency and practical deployment feasibility in real-world public distribution environments.
2024 [6]	To develop a machine learning-based inventory optimization system using ABC classification that improves demand prediction, inventory control, and overall supply chain efficiency.	Machine Learning Algorithms (Random Forest, SVM, KNN, Naïve Bayes, Decision Tree), ABC Inventory Classification (Pareto Principle), Python (Sklearn Library), Database Management System (DBMS).	Does not address real-time integration with physical distribution systems and lacks automation in dispensing mechanisms.
2023 [7]	To design an automated grocery distribution system using RFID-based authentication and hardware-controlled dispensing to reduce manual errors, prevent misuse, and improve efficiency in ration distribution.	Arduino Uno (ATmega328), RFID Card & RFID Reader, Flow sensor (for liquids), Load cell + HX711 Amplifier (for solids), Servo Motor & Solenoid Valve, Web-based Interface (database + monitoring).	Relies solely on RFID-based authentication, lacks advanced fraud detection and real-time analytics, and does not address scalability or integration with larger ecosystems.
2023 [8]	To develop an automated ration distribution system using RFID and biometric authentication to ensure secure user identification and accurate dispensing.	RFID reader, fingerprint sensor, load cell, IR sensor, microcontroller, and dispensing system.	Limited IoT connectivity and centralized monitoring; the system mainly focuses on authentication and dispensing.
2022 [9]	To design an automated ration shop that minimizes manual work and ensures transparent ration distribution through digital tracking.	Arduino Mega 2560, load cell with HX711, Node-MCU Wi-Fi module, LCD display, web portal, relay and pump.	Implementation cost is high, and system scalability for large PDS networks is not addressed.
2022 [10]	To develop an automated ration vending machine using RFID-based authentication to reduce corruption, eliminate manual intervention, and ensure efficient and accurate distribution of ration commodities.	Arduino Uno (ATmega328P), RFID Tag & RFID Reader. Keypad (for authentication), Servo Motor & Relay, LCD Display, Local Database System	Lacks real-time monitoring and centralized database integration, and does not incorporate advanced security, scalability, or intelligent fraud detection mechanisms
2022 [11]	To design an automated ration vending machine using RFID, biometric authentication, and sensors to reduce corruption, eliminate manual intervention, and enable transparent and reliable ration distribution.	Raspberry Pi 4, RFID reader & smart cards, Fingerprint sensor, GSM Module (OTP Verification), Load cell (weight sensor), Servo motor & relay, MySQL database, Python (Thonny IDE)	Lacks large-scale deployment validation, centralized government integration, advanced analytics, and intelligent fraud detection mechanisms.
2022	To design a blockchain and IoT-based	Blockchain (Private Ethereum	Lacks focus on cost-effective

[12]	smart ration shop system that ensures transparency, prevents corruption, and enables secure, traceable, and real-time monitoring of ration distribution.	Network, Smart Contracts), IoT (Asset Tracking using QR Codes), Raspberry Pi (Embedded System), Web3 API & Node.js Backend, Cloud & REST APIs.	large-scale deployment, and does not fully address practical challenges such as integration with existing PDS infrastructure and real-world operational constraints.
2022 [13]	To develop an automated ration distribution system at the panchayat level using RFID authentication and an automatic dispensing mechanism to reduce corruption, eliminate manual errors, and ensure accurate distribution of commodities.	ARM7 LPC2148 microcontroller, RFID (EM-18 Reader & smart Card), GSM module (OTP-based verification), Solenoid valve (for liquids), DC gear motor (for grains), Keypad & LCD display, Embedded system design	Relies on basic RFID and OTP authentication, lacks centralized monitoring, scalability, and integration with digital ecosystems, and does not incorporate advanced analytics
2021 [14]	To implement a smart public distribution system using RFID smart cards to ensure accurate measurement and transparent ration allocation.	RFID EM-18 reader, Arduino UNO (ATmega328P), load cell, servo motor, database.	Does not include biometric verification or advanced IoT monitoring features.
2021 [15]	To develop an IoT-based automated ration distribution system that uses biometric authentication to ensure secure, transparent, and efficient delivery of subsidized commodities while reducing fraud and manual intervention.	Raspberry Pi, Fingerprint (Biometric) module, Android application, DC motors & Hydraulic valves (for dispensing), Minutiae-based, Fingerprint algorithm	Lacks scalability due to reduced accuracy with larger datasets, exhibits measurement errors in dispensing, and does not incorporate real-time monitoring and advanced fraud detection
2021 [16]	To propose a blockchain-based conceptual framework for the Indian Public Distribution System that enhances transparency, reduces leakage and corruption, and ensures efficient tracking of food grain distribution across the supply chain.	Blockchain (Distributed Ledger Technology), RFID (for tracking grain movement), Biometric authentication (Aadhaar-based), Decentralized database systems, Consensus mechanisms (proof of authority), Mobile applications (for FPS demand and tracking)	Remains conceptual without real-world implementation, depends heavily on infrastructure such as internet connectivity and technical expertise, and does not address practical deployment challenges or cost-efficiency at scale.
2020 [17]	To analyze inefficiencies in existing food subsidy systems using Value-Focused Thinking (VFT) and propose a blockchain-based prototype that ensures transparency, accountability, and efficient delivery of subsidized food.	Blockchain (Hyperledger fabric, Hyperledger composer), Smart contracts, Angular 7 (frontend), Value-Focused Thinking (VFT) methodology, Distributed Ledger Technology, Consensus Mechanism	Lacks real-world deployment validation, does not address cost and scalability challenges for nationwide implementation, and depends heavily on stakeholder participation and infrastructure readiness.
2019 [18]	To replace traditional ration cards with RFID-based smart cards for automated authentication and controlled distribution.	RFID tags, PIC microcontroller, GSM module, load cell, IR sensor	Lacks IoT integration and centralized real-time monitoring of ration inventory.
2018 [19]	To create an IoT-based ration distribution system to reduce corruption and automate ration delivery.	RFID smart card, GSM communication, microcontroller, and solenoid control circuit.	User interface and authentication security are limited; biometric validation is absent.
2016 [20]	To develop a smart card-based e-PDS system integrated with biometric authentication and a centralized web server to improve transparency, reduce corruption, and enable efficient monitoring of ration distribution.	Smart card system, Fingerprint (Biometric Authentication), Web-based Server & database, GSM/SMS notification system, GUI-based web application, Centralized Cloud Database	Lacks automated dispensing mechanisms, advanced data analytics, and intelligent fraud detection, limiting its effectiveness in ensuring end-to-end automation and scalability.

2015 [21]	To design an embedded automated ration distribution system that dispenses grains automatically using electronic measurement.	AT89S52 microcontroller, load cell, ADC circuit, keypad interface, and solenoid valve.	No digital authentication, IoT monitoring, or real-time data tracking features.

3. Methodology

This section describes the methodology, procedure and functionalities of the components used in the experimental set-up. To fulfil the above set of objectives, an initial survey was conducted to understand the difficulties faced by the customers who visit the ration shops to buy rations.

Section 3.1 discusses the results of the conducted survey. Section 3.2 discusses the flow of the experimental setup along with the description of the block diagram, and Section 3.3 gives the technical information related to the circuit diagram and pin connections for the entire developed set-up.

3.1. The Survey Learning

A survey was conducted to understand user requirements and challenges in the existing ration distribution process. The responses helped in identifying the need for authentication, accurate grain measurement, and system transparency. The total number of participants in the survey were 31. The survey was based on the following questions- The average waiting time of the customers at the ration shop, overall satisfaction with the current ration distribution system and a quantitative listing of the problems faced while collecting ration. Figures 1, 2 and 3 show the results obtained from the survey related to the above three questions.

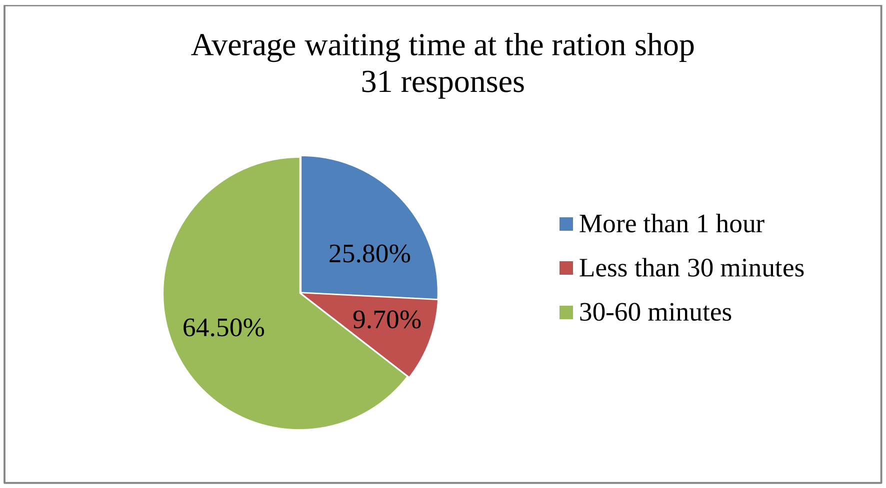

Fig. 1 Average waiting time at the ration shop

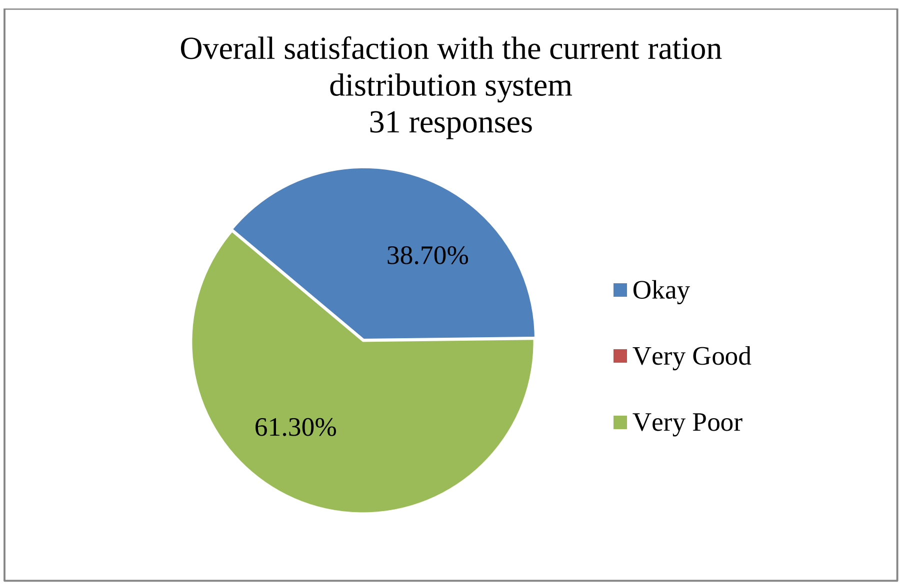

Fig. 2 Overall satisfaction rating of the customers

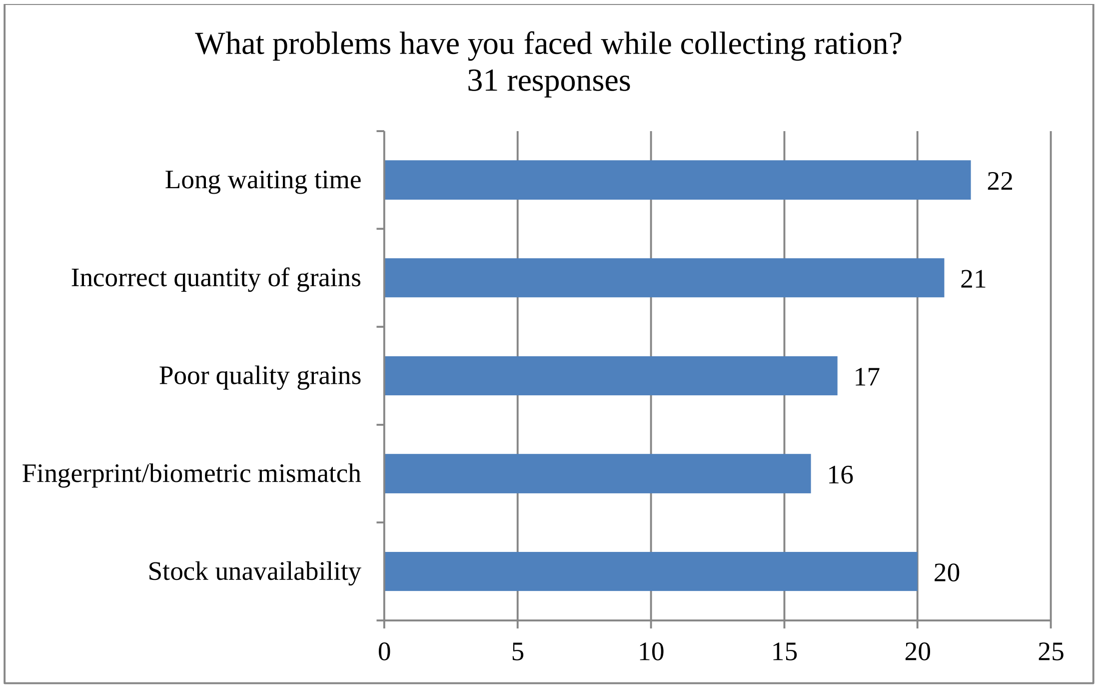

Fig. 3 Quantitative listing of the problems faced by the customers

From the above responses, it becomes very clear that more than 60% of the customers agreed that the average waiting time at the ration shops is between 30 to 60 minutes and were not very satisfied with the current ration distribution system. Also, long waiting time and unavailability of stock was the major concerns cited at the ration shops.

3.2. The Experimental Setup

The flow diagram of the experimental setup is given in Figure 4, and the block diagram of the proposed DISPENZO: Smart Ration Distribution is illustrated in Figure 5. Figure 4 represents the flow diagram for the developed automated dispensing and monitoring system for ration distribution, DISPENZO: Smart Ration Distribution. The entire system is divided into two parts: the part that users have access to and the other part that the admin has access to. The user can access only the authentication module, whereas the admin has access to the grain measurement and dispensing system and the environment monitoring system. Both systems are further connected to an ESP32 microcontroller that acts as a central controller and helps collect the data from different modules. It shows how the ESP32 microcontroller integrates authentication modules, sensors, dispensing mechanisms, and cloud connectivity. The functionalities of the individual units are described below-

1. ESP32 Microcontroller-The ESP32 microcontroller is the main controller of the system. It receives data from the authentication modules and sensor, processes the data, and controls the actuators, such as the servo motor and relay.

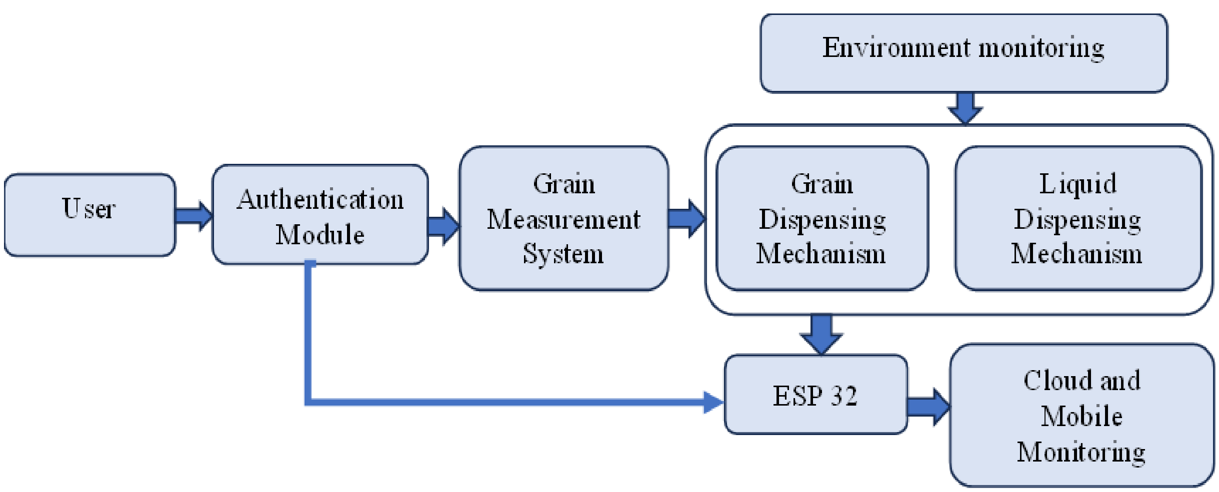

Fig. 4 The flow diagram of the experimental set-up

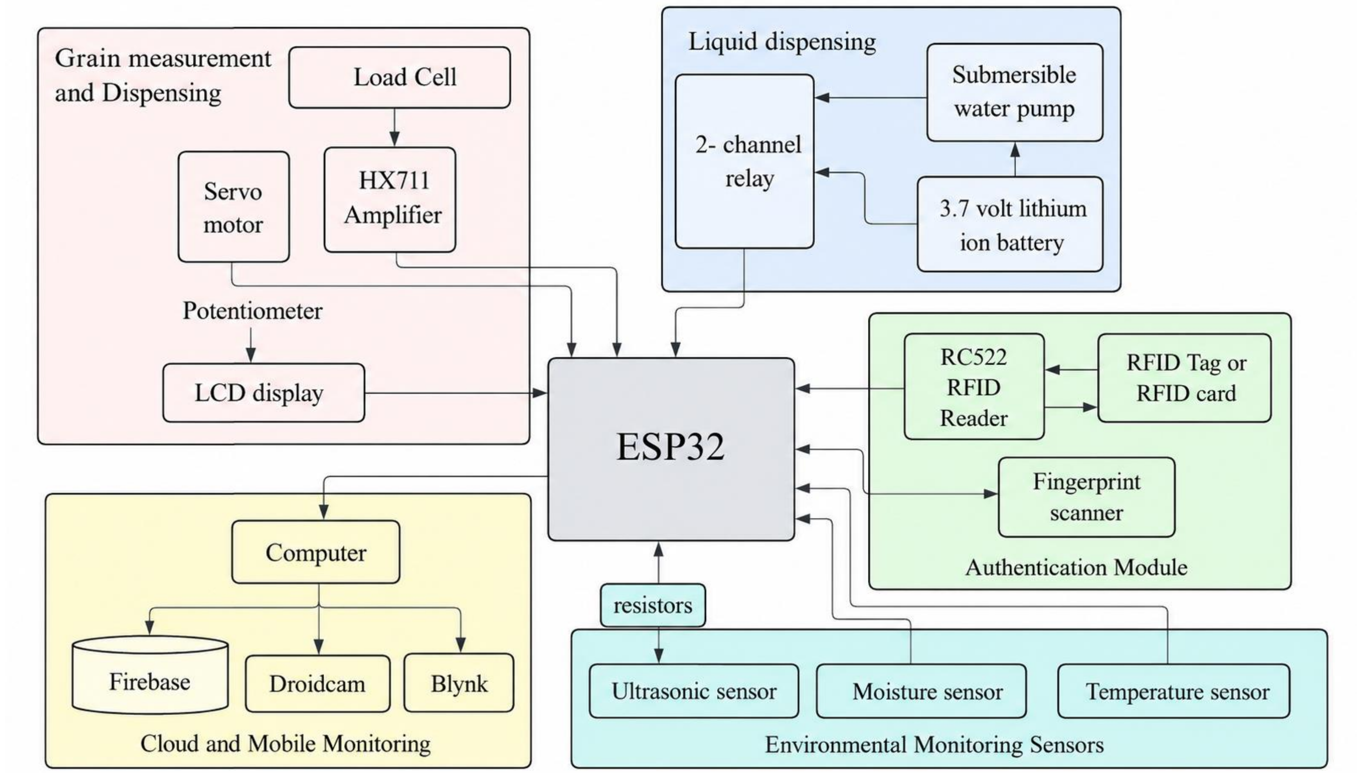

Fig. 5 Block diagram of the developed system

2. Authentication Module (AM)-The authentication system is integrated to enable only the authorized users to use the facility. The system uses an RC522 RFID module and an R307S fingerprint sensor for authentication.

a) RFID reader (RC522)-The RC522 RFID reader is used for card-based authentication. When a user scans the RFID card, the reader captures the unique ID and sends it to the ESP32 for verification. If the ID is valid, the user is authenticated.
b) Fingerprint scanner (R307S)-The R307S fingerprint sensor provides biometric authentication. The user places their finger on the sensor, which captures the fingerprint and compares it with stored templates. If a match is found, the ESP32 confirms the user identity.

3. Grain Measurement System (GMS)-The grain management system is a critical subsystem of the developed module and helps to measure the exact amount of grain required by each customer. It consists of the following parts-

a) Load cell (20 kg)-The load cell measures the weight of the dispensed grains by converting the applied mechanical force into a small electrical signal.
b) HX711 amplifier-Since the load cell generates very small signals, the HX711 amplifier is used to amplify and convert the signal into digital data that can be read by the ESP32. This enables the system to measure the exact quantity of grains dispensed, prevent over- dispensing and maintain accurate distribution records.

4. Grain Dispensing Mechanism (GDM)-The grain dispensing mechanism helps to dispense the exact amount of grain required by each customer. This module works in coordination with GMS. It fundamentally consists of a servo motor MG995 (180-degree rotation). The servo motor controls the grain dispensing gate. When a user is authenticated, and a dispensing command is given, the ESP32 sends a Pulse Width Modulated (PWM) signal to the servo motor, the servo rotates to open the grain outlet, grain flows out, and the servo closes the outlet once the required weight is reached.

5. Liquid Dispensing Mechanism (LDM)-The LDM is used to dispense the required amount of liquid. It consists of- submersible water pump (DC 3-6 V mini micro), used for dispensing water and a relay module. Since the pump requires higher voltage and current, it cannot be directly controlled by the ESP32. Therefore, a 2-channel relay module (5V) is used as a switching device. A 3.7 V lithium-ion battery provides the external power supply for the pump. When the ESP32 sends a control signal to the relay, the relay switches the external power supply. The pump turns ON or OFF accordingly.

6. Environmental Monitoring Sensors (EMS)- -It is assumed that the grains aimed for distribution will be kept in the godown. The godowns are prone to accumulate moisture and

experience rise and fall in temperature. The EMS helps to track the temperature and moisture of the grains stored in the godown. The system helps to maintain proper storage conditions and ensure consistent food quality. The EMS system consists of-

a) Temperature sensor (DS18B20)-The temperature sensor monitors the temperature inside the grain storage container. This helps prevent grain spoilage caused by high temperatures.
b) Moisture sensor (LM393 3.3V-5V)-The moisture sensor measures humidity levels in the grain storage area. Excess moisture can lead to fungal growth or grain damage.
c) Ultrasonic sensor (HCSR04)-The ultrasonic sensor is used to measure the level of grains in the storage container by detecting the distance
d) between the sensor and the grain surface. It helps in real-time inventory monitoring and alerts when the grain level becomes low.

7. Display System- The built-in display system helps to provide real-time feedback to the end users. It consists of a Liquid Crystal Display (LCD) display (16 x 2 without I2C) and a potentiometer connected to the LCD to adjust display contrast for better visibility.

8. Cloud and Mobile Monitoring (CMM)- The CMM is built to transmit the captured data from all of the above-mentioned modules to a Firebase database. This is done using the Wireless Fidelity (Wi-Fi) of ESP32. The data captured on the cloud can be viewed through the dashboard, while the Blynk app is used for notifications and alerts. This increases the transparency of the system.

9. Grain Quality Monitoring using Computer Vision- It might happen that the grain contains impurities that need to be monitored. Impurities increase the weight of the dispensed grains, thereby affecting the overall actual quantity given to the customer. A smartphone camera, linked to Droid Cam, captures video feed from the top surface of the grains. The video feed is then processed to recognize impurities in the grain using basic computer vision techniques.

3.3. The Technical Specifications

The circuit diagram of the proposed DISPENZO: Smart ration distribution explains the hardware connection details of the ESP32 microcontroller with the respective sensors, authenticator modules, and actuators used in the proposed system. It explains how the load cell, RFID reader, fingerprint sensor, ultrasonic sensor (HCSR04), relay module, and servo motor are connected with the controller to facilitate the automated process of grain dispensing. Figure 6 shows the complete circuit diagram of the built-in systems, and Table 2 highlights the pin connections between various components used in the developed system.

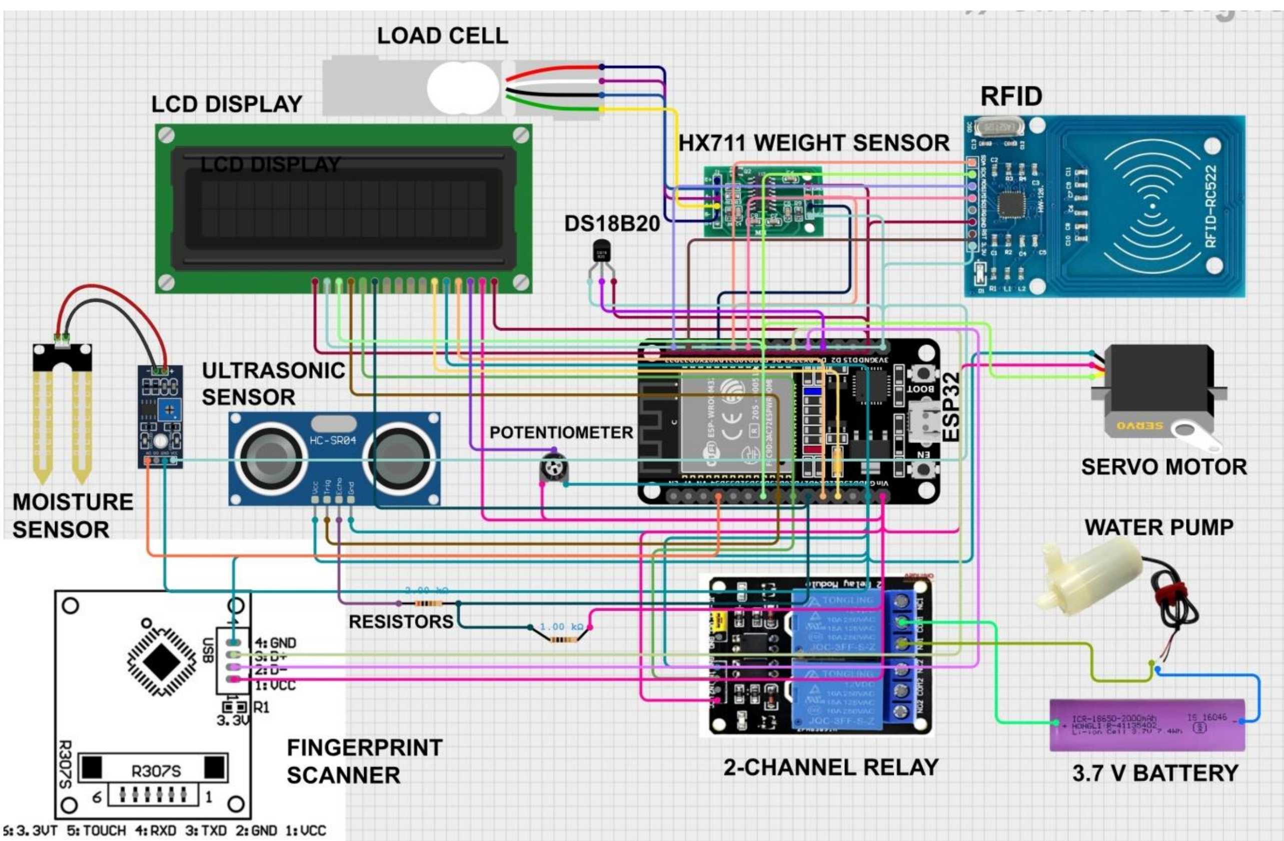

Fig. 6 Circuit diagram

Table 2. The pin connection is related to the circuit diagram

Servo motor		**Finger print sensor**		**Loadcell**	
Component pin	ESP32 Pin	Component pin	ESP32 Pin	Component pin	ESP32 Pin
Servo Signal	GPIO 13	TX (Sensor)	GPIO 16	DT	GPIO 4
VCC	5V	RX (Sensor)	GPIO 17	SCK	GPIO 2
GND	GND	VCC	5V	VCC	5V
		GND	GND	GND	GND
2 Channel relay		**Moisture sensor**		**LCD**	
Component	ESP32 Pin	Component	ESP32 Pin	LCD Pin	ESP32 Pin
Relay IN	GPIO 26	Analog Output	GPIO 34	RS	GPIO 21
VCC	5V	VCC	3.3V	E	GPIO 22
GND	GND	GND	GND	D4	GPIO 4
				D5-D7	GPIO 17-15
Ultrasonic sensor		**Temperature sensor**		**Pump**	
Component	ESP32 Pin	Component	ESP32 Pin	Connection	Goes To
TRIG	GPIO 25	Data	GPIO 27	Battery (+)	Relay COM
ECHO	GPIO 32	VCC	3.3V	Relay NO	Pump (+)
VCC	5V	GND	GND	Pump (-)	Battery (-)
GND	GND	Resistor	4.7 kΩ VCC- Data		
HX711		**Loadcell**		**RC522 RFID**	
Component	ESP32 Pin	Load Cell Wire	HX711 Pin	Component pin	ESP32 Pin
DT	GPIO 4	Red	E+	SDA (SS)	GPIO 14
SCK	GPIO 2	Black	E−	SCK	GPIO 5
VCC	5V	White	A−	MOSI	GPIO 23
GND	GND	Green	A+	MISO	GPIO 19

4. Results and Discussions

This section discusses the module-wise outputs with the help of neat screenshots of the implemented project.

4.1. Module-Wise Results and Discussions

This section deals with the physical hardware implementation and testing of the Dispenzo prototype system. The images demonstrate the hardware setup, grain and liquid dispensing mechanism, and integration of sensors and control modules using the ESP32 microcontroller. Figure 7 is an image of the entire experimental setup of the built system. Figure 8 shows the automated grain dispensing mechanism that comprises a servo motor, a load cell and a collection tray controlled by a control unit.

The above assembly permits the regulation of measured grains flowing through the dispensing mechanism. The automated liquid dispensing mechanism shown in Figure 9 comprises a container with a submersible pump and connecting tubes to a collecting container. A battery-operated pump, which is controlled via a relay, is used in this arrangement to control the flow of the liquid. Figure 10 shows the RFID-based authentication, which controls access of a user card through scanning at the RFID tag of the system, which on verification of the user, permits dispensing of the respective material.

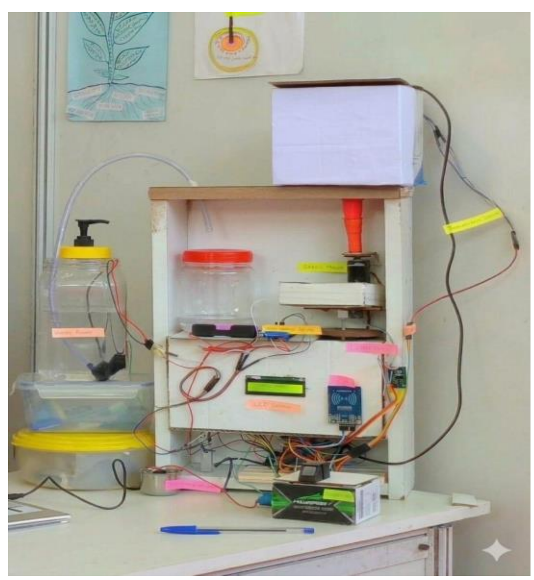

Fig. 7 Experimental set-up of the dispenzo system

Fig. 8 Grain dispensing system

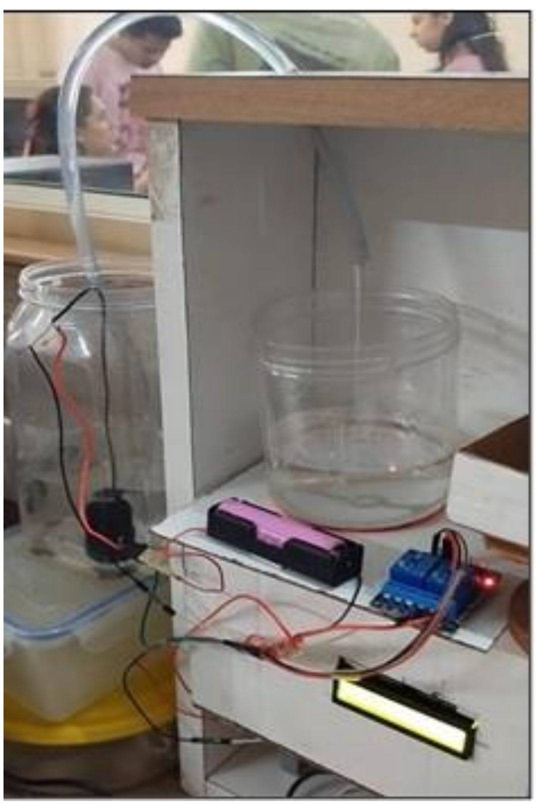

Fig. 9 Liquid dispensing system

Fig. 10 Authentication system using an RFID card

A software interface was developed to authenticate the user using an RFID card. The interface enables the end user authentication through RFID scanning and provides an administrative dashboard for monitoring beneficiaries, system parameters, and distribution records. This dual functionality system for both the customer and shop owner helped to improve system transparency and efficient management of the ration distribution process. Figure 11 shows the landing page of the software interface. The landing page of the system integrates voice assistance, an RFID-based scanning mechanism, and admin login options, providing an intuitive and accessible entry point for both users and administrators. The system currently provides support for six languages to interact with the system, including English, Hindi, Marathi, Tamil, Telugu and Kannada. In case the user loses the RFID card, the built-in system provides additional support that integrates a fingerprint authentication interface using a fingerprint sensor, as shown in Figure 12. The admin dashboard is shown in Figure 13.

Fig. 11 RFID card scanning interface

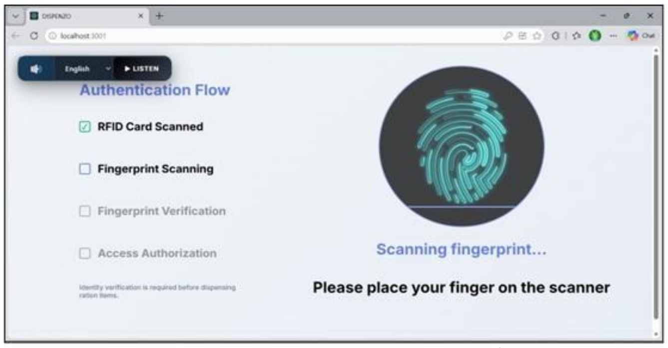

Fig. 12 Fingerprint authentication interface

A biometric interface that guides the user through fingerprint verification based on fingerprint ID stored in the databases, step-wise, ensuring secure and accurate user authentication before access is granted. The administrator page has facilities for checking the total of beneficiary customers, their details like name, phone number, family members and weight threshold. The DISPENZO 2.0 system implements a comprehensive role-based admin control centre accessible through password-protected authentication. Upon successful login, authorized personnel gain access to a multi-functional dashboard organized into three primary modules: User management module, Real-time monitoring module and Analytics module.

Figure 13 represents the interface on which administrators access the system to manage all the beneficiaries that were registered in the system. It is the beneficiaries' database and the system of controlled access in the DISPENZO 2.0 administration interface. In this page, administrators view a list of all registered beneficiaries along with important information from each profile, such as the Unique Identifier (UID), full name, phone number, number of family members, and the setting for weight threshold per individual ration (in grams).

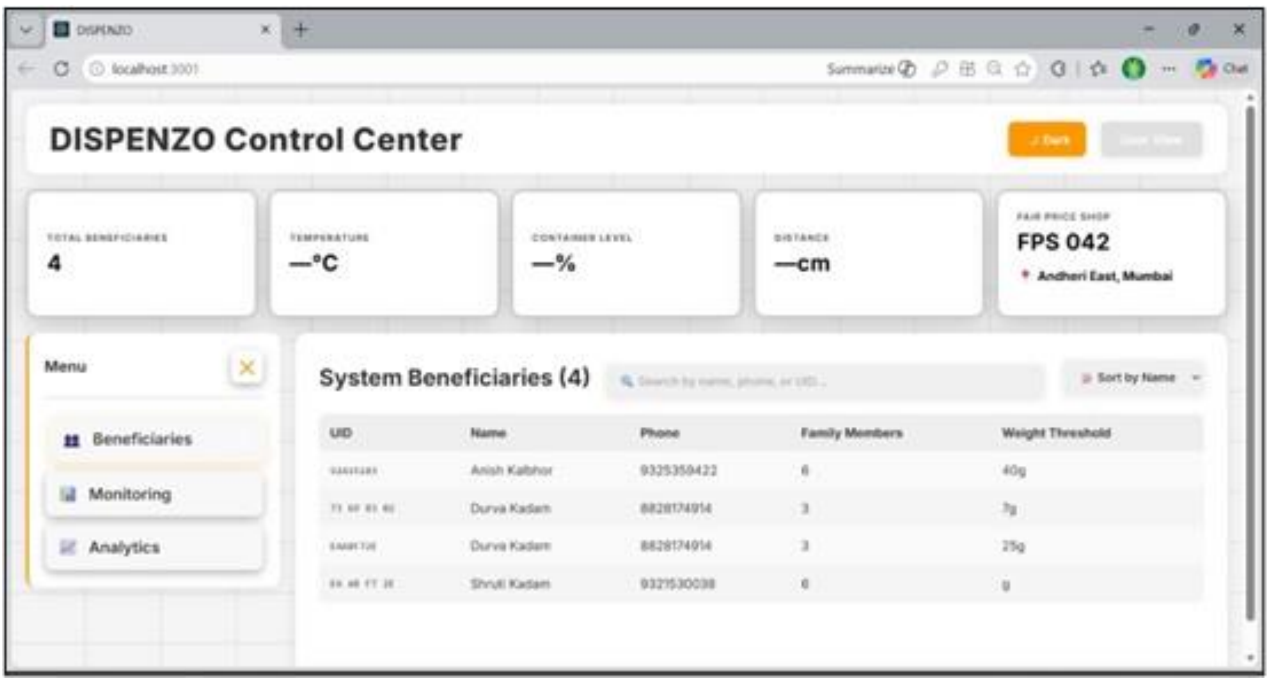

Fig. 13 The administrator dashboard

Further, the administrator is also provided with an analytical interface represented in Figures 14, 15 and 16, which provides transaction statistics, system performance metrics, and inventory insights related information through graphical visualizations over a period of time. Data for analysis is obtained from the Dispenzo2.0_Variation_Dataset.csv file, which contains timestamped transactions, grain dispensed quantities, the authorized quotas per individual, stock levels, environment (temperature, humidity) and power consumption, and the time to dispense. Figure 14 is the overview dashboard where the user will get operational KPIs at a high level. Operational KPIs are total transactions (number of times the item dispensed), success rate (% of successful transactions) and average transaction time (in ms). The dashboard renders two primary visualizations: a transaction success rate trend line graph that maps daily success percentages over time, and an item distribution doughnut chart that breaks down the proportion of grain versus liquid dispensed across all successful transactions. This dashboard allows the admin to quickly check the reliability of the system and the trend of the types of commodities being dispensed at the chosen time range (e.g. 7-day, 30 day or custom time range).

Fig. 14 Analytics overview dashboard

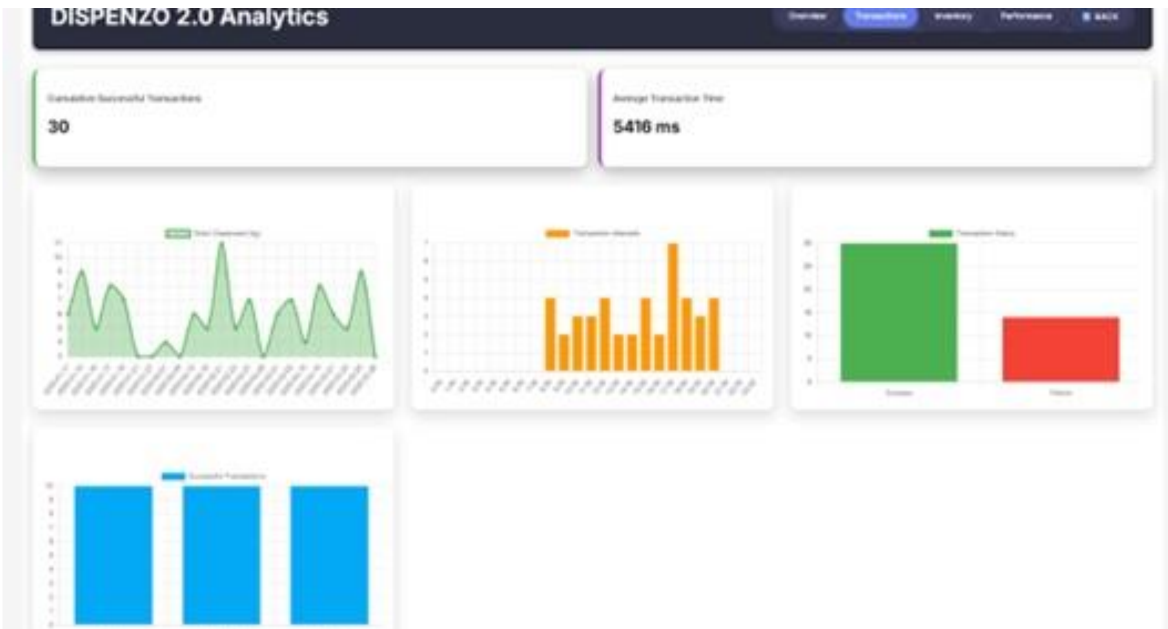

Fig. 15 Transaction analytics dashboard view

The transaction analytics dashboard provides deep insights into dispensing transactions through multiple temporal and categorical perspectives, as shown in Figure 15. There are multiple transaction summary cards, including line graphs to show daily ration dispensed, a column chart to show hourly transaction volume, and bar charts which show success & failure rate and transaction success. It will be useful for the admin to know about system bottlenecks, peak times and reasons of transaction failure. Figure 16 shows the inventory dashboard, which provides an overview of stock management and distribution efficiency metrics across designated ration distribution centres.

The view features a centre selector dropdown allowing administrators to analyse centre-specific (e.g., Gorai centre, Borivali centre) data. Summary cards display critical inventory KPIs: Total grain allotted (authorized stock quota), total grain distributed (actual dispensed amount), remaining grain stock, and distribution efficiency percentage (calculated as distributed/allotted × 100). There is a dual series bar chart to compare allotted grain vs distributed grain monthly, and a line graph showing the monthly distribution trend. This dashboard will help the admin monitor depletion of stock, allocate resources and understand the efficiency of each center's ration distribution.

The project has used Firebase Cloud Firestore as the database for the implemented system because it allows us to easily setup the real-time database. The structure of the database is shown in Figure 17. The database is structured into multiple collections, including:

a) Customer Collection: Stores information like name, address, email, RFID card number, fingerprint ID, no of family members, and allotted amount for each ration distribution center.
b) Inventory Collection: Maintains records of available stock, including quantity levels and updates after each transaction.
c) Transactions Collection: Logs all ration distribution events with timestamps, user identification, and dispensed quantities.

Each customer document has a schema which stores details like name, email, address, card number (RFID), fingerprint ID, no. of family members, issued date and allocated amount. Firebase provides us a way to synchronize all this information from the hardware system (ESP32 with Wi-Fi connectivity) to the admin interface and vice versa in real time. This enables seamless synchronization, remote monitoring, and secure data handling.

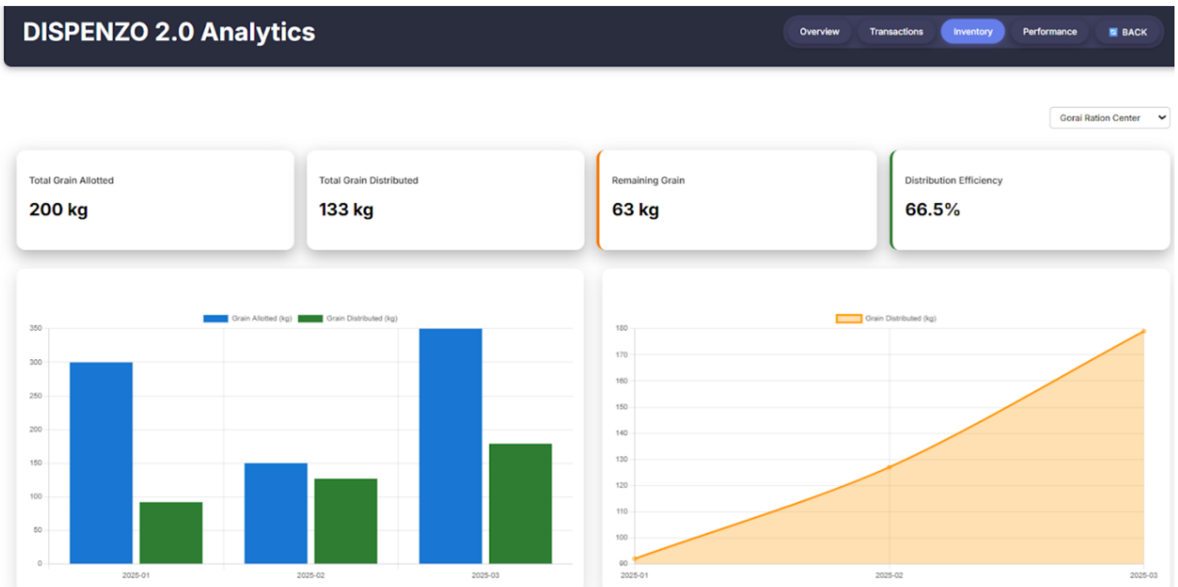

Fig. 16 Inventory analytics view

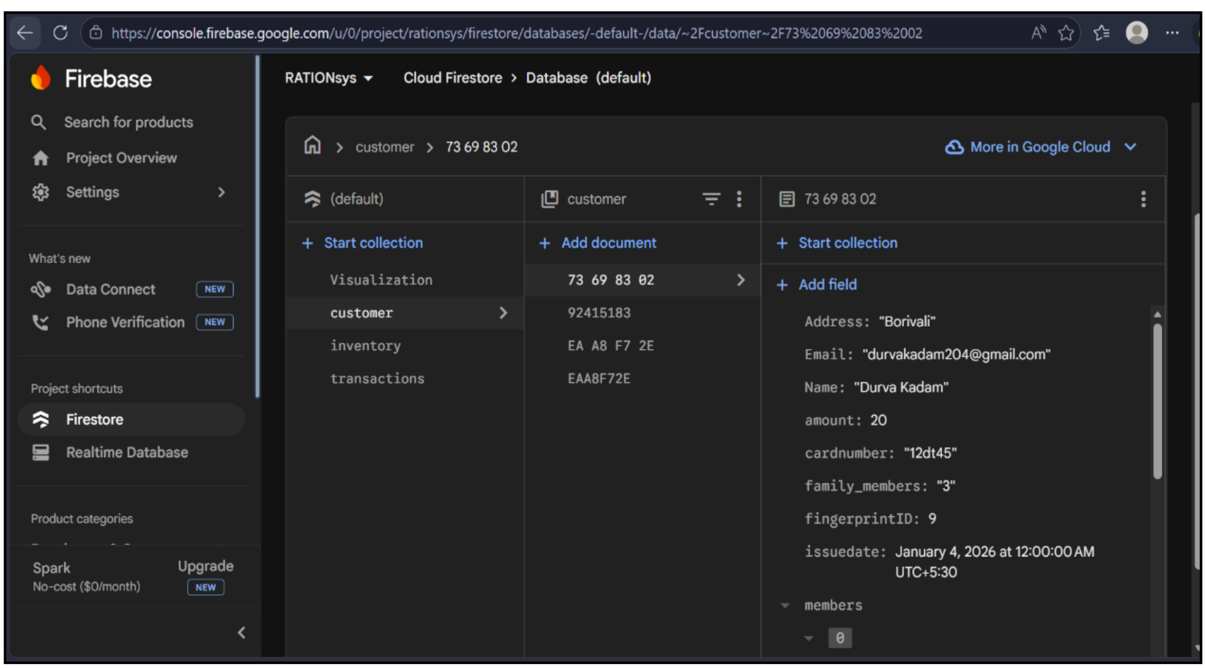

Fig. 17 Firebase database structure

Scope of project: The prototype system proposed in this paper can handle automatic dispensing of rations in small/medium-sized Fair Price Shop environments with precision dispensing of measured quantities of both liquid (water, oil) and dry (rice, wheat, sugar, pulses) consumable items. The system is configured to operate over a Wi-Fi-based communication network by means of an ESP32, which has a communication range of approximately 30-50 meters indoors, and cloud-based monitoring (Firebase and Blynk), with limited offline functionality. The system has a limitation in user management because of fingerprint sensors that can store about 1000 users, and RFID-based authentication, which can be run on 13.56 MHz frequency. Since a 20 kg load cell is used, the grain measurement system is limited to this capacity. Similarly, liquid dispensing is restricted by tank capacity and pump specifications. The ultrasonic sensor (HC-SR04) supports stock monitoring within a range of 2 to 400 cm. A stable power supply is required for the system, with auxiliary battery support for pump operation. The system is fit for moderate load in local shops, as the mean processing time per user is about 2 minutes. The system has support for 6 local languages as listed below: English, Hindi, Marathi, Tamil, Telugu and Kannada, which would provide support all across the country. The created prototype can be operated at Indoors; it is not designed to serve a large-scale centralized distribution network or heavy-duty industrial uses.

4.2. Comparison with State-of-the-art

This project has received multiple recognitions as listed below-

1. The project secured first prize at the intercollegiate project technical competition 'Colloquium-IT for Society' held at St. Francis Institute of Technology, Mumbai, during the academic year 2024-25.
2. The project also secured third prize at the regional level science and engineering fair 'Anveshana-Building Bridges to Innovation' organized by the Agastya International Foundation and technically sponsored by Samsung Semiconductor India Research. The regional fair was held in Mumbai on 7th and 8th January 2026. The project got selected for the national finals.
3. The national level final was held in Bangalore on 12th February, where the project was further recognized with an appreciation award. These recognitions indicate the feasibility and relevance of the proposed system when evaluated in competitive academic and innovation platforms.

The project was able to achieve better results than the state-of-the-art implementations because of the following reasons.

1. The team made an initial attempt to understand the present-day ration distribution system in the Mumbai Metropolitan Region (MMR).
2. The team created a survey form and took a survey from the people who actually use the ration distribution system on a monthly basis to understand their pain points. This helped to understand the design requirements.
3. The project was build using low-cost and readily available resources. Incorporation of the 'regional language' module helped it to gain popularity

5. Conclusion and Future Direction

The DISPENZO: Smart Ration Distribution System that is proposed here is an example of how automation with the use of the Internet of Things (IoT) can enhance ration distribution systems in terms of transparency, efficiency and control. Integration of secured authentication features (RFID and fingerprint identification) to automated distribution through the use of sensor-based feedback mechanisms (such as automatic motor control) diminishes the dependency on human operation and errors occurring from measurement uncertainties. The system is also aimed to assist in accurate distribution as well as keep a check on the storage status of food commodities by use of a load cell for grain measurement, ultrasonic sensors for the checking of stock and other sensors for the environment factors. It provides a platform to keep track of transactions online by use of Firebase for cloud data management and use of Blynk platform to allow for remote monitoring from a mobile device. The prototype, which is developed here, confirms that the integration of authentication, automation and remote monitoring into a single system is achievable. The future directions can be-

a) Implement AI/ML algorithms for demand prediction and fraud detection: AI/ML algorithms will be trained on historical transaction data to forecast the demand and accordingly maintain the stock.
b) Integrate the system with the Aadhaar database and the government portals: This integration will lead to real-time identity verification. This prevents duplicate beneficiaries and fake users and thereby maintains transparency among all distributions.
c) Develop a mobile application that will access and manage the system in real-time: With the aid of a mobile application, it will be possible to monitor the system at any time from anywhere. This also helps the system administer to obtain real-time updates, view transaction history and notifications. This increases user accessibility and convenience.
d) Expand the system to domains like healthcare and disaster relief: This system can be generalized to other public welfare areas, such as public healthcare supply chain management and disaster management as well. This ensures the platform's scalability and versatility.
e) Scale the system up to more locations: It will be helpful to distribute the system to more places in order to make the system cover a wider region and have a greater impact. This will enable centralized control over more numbers of FPS. The national scaling of this solution would thereby be possible.
f) Introduce a sealed cartridge-based refill mechanism: A tamper-proof pre-sealed grain cartridge will be

introduced that may be fitted directly into the dispenser unit, which can help to maintain correct stock count, hygiene standards, and eliminate possible errors during the refilling stage.

g) Provide the system with a modular, solar-powered portable architecture: The system would have to be developed to be lightweight, portable and integrate solar energy support so that it may be easily transferred from one location to another and may even be deployed in remote regions without electricity.

h) Enable an offline data synchronization mechanism: A data synchronization protocol will be developed that ensures that, if the network connectivity breaks, the operations may continue, and later automatically synchronize the data with the central server once the connection is restored.

Conflicts of Interest

No conflict of interested

Funding Statement

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