Inventory Management System Using IoT

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***Abstract* —** *Inventory management is an important function for organizations that provide services with physical goods, their domains include manufacturing, retail and distribution. The goal of inventory management system is to ensure availability of product, minimize stock outs and improve efficiency. This paper includes deployment of this system for real world scenario using integration of Internet of Things (IoT) technologies with cloud computing and user-friendly interface to provide real-time, automated tracking. This system is designed using, ESP8266 Wi-Fi module, ESP32 Wi-Fi module RFID reader, RFID tags, Firebase and ThingSpeak platform. The system collects the data using RFID tags, processes using ESP8266 and sends this to cloud, which is further optimized for user readability. This ensures accurate control of inventories, minimizing human errors. Compared to older versions this new system also features more reliability using RFID, therefore special goods (medicine, food) can also be managed. Due to the growth in B2B businesses, scientific research has led to the evolution of inventory management systems. Previous researchers have already improved it by using new tools and modules. This paper aims to add thermal reliability, improve accuracy and efficiency, reduce lead times for ordering and restocking. Using this smart inventory management system businesses can improve their profits, time management and decrease waiting times for customers.*

Keywords *— Inventory Management, IoT, ESP8266, RFID tags, Ultrasonic Sensor*

I. INTRODUCTION

Inventory management system is a newer approach to managing inventory that uses already established business resources to improve management and efficiency. This system works by collecting and analyzing data from multiple sensors in the system. This data is processed to provide real-time insights on inventory management. The major benefits of using such system include better time management, cost reductions, reduction in manpower, security enhancement and scalability for business and corporate companies. Time management is a crucial point which leads to the progression of a company.Investing on inventory management system has led to significant revenue growth.

The system consists of multiple sensors and tools, which are used to monitor different parameters such as stock count, stock in and outs and movement of products. The sensors work in conjunction with ESP8266 module, which process the sensor data and send it to a cloud-based ThingSpeak platform. ESP8266 is a powerful development board designed for IoT applications. It is built for the Wi-Fi applications, therefore allowing the device to connect to the internet for wireless connection with other devices. RFID tags are devices based on electronics that store information and communicate with other devices with the help of radio waves. This IoT based inventory management system will help businesses monitor their inventory levels, identify stock outs beforehand and make data-driven decisions to optimize inventory levels, time efficiency and ensure product availability at the right time necessary.

LITERATURE REVIEW

Inventory management is an essential part of supply chain management, and uses IR sensors which can significantly improve inventory management systems. This paper highlights the importance of inventory management in product and time management. The proposed system is capable of real-time computation on inventory levels. This system consists of IoT based sensors, which are used to monitor different parameters. It uses Wi-Fi to communicate between the ESP8266 module and the main server. Network dependence, cost and limitation to specific products are the major disadvantages mentioned in the paper which describes the limitations of the proposed system [1].

Radio frequency identification (RFID) technology has proven to be a better alternative for IR sensors by improving on efficiency, time required and being more organized. This paper emphasizes the importance and significance of Safety Monitoring Process, their study focuses on safety helmets, though not completely related to the proposed methodology but uses a similar detection idea. They have developed a system using tensor flowlite libraries to make the detections effective and lighter on the devices. The proposed system is built an IOT based system where in case of a construction worker not wearing an appropriate helmet, the supervisor will receive a notification. Using methods similar to the proposed system, RFID technology in inventory management systems

to enhance automation. RFID allows for real-time tracking and management of goods, reducing errors and increasing efficiency. This paper proposes the implication of RFID in this system using cloud-based software to store the data collected using RFID tags. The limitations of using RFID technology mentioned in the paper include cost of implementation, privacy issues, data safety, range limitation [2].

Controlling inventory is important for effective retail inventory management. The rise of omnichannel shopping, where customers shift between online and in-store experiences, has added complexity to this task. This paper helps to design an inventory management system using IoT technology to allow store managers to always know what's in stock and where it's located. This ensures the right products are available in the right places at the right times. By using this system retailers can meet customer expectations, optimize operations, and stay ahead in an increasingly competitive market. Major limitations to this system are limited to specific products, calibration and cost [3].

A smart inventory management system capable of helping companies to manage and track inventory levels and deliveries. This paper proposes the deployment of a system in real world with features like improved accuracy and efficiency in inventory tracking to decrease the time for restocking. This paper specifically elaborates the implementation of this system in real world. Manual processes such as tracking stocks, counting, and managing database can be automated based on the proposed system. major limitations of this system include network dependence, cost, and product limitation [4].

The paper is based on RFID technology. These tags help this system to collect non-stationary activities data from the object. RFID tags can work at a gap and do not require physical connection between tag and scanner. The main reasoning for using RFID proposed by the paper is to avoid limitations of barcode system. This review paper discusses the reasons for using RFID compared to other sensors [5].

NodeMCU and ESP8266 are beneficial for multiple tasks. This paper gives a detailed review of the benefits of using NodeMCU over other firmware available for use. Inventory management system can be enhanced using NodeMCU, it can be used to monitor and control machinery, equipment and packages therefore making it crucial part of such system [6].

This paper presents an effective system for managing inventory dealing with solid or liquid stock. This system is based on Raspberry Pi, to measure the inventory levels and send notifications to user to make order placement efficient. This paper gives a detailed explanation on how to implement Raspberry Pi in inventory management system. The major limitations of this system are delays in the entire system due to notification issues, one sensor dependent system [7].

This paper explains the workflow and use of RFID in inventory tracking system. In this research RFID has been interfaced with ARM Processor to provide secure access. The proposed system uses RFID technology to enhance the readability and improve efficiency. The major use of ZigBee, as it is designed to be low-cost wireless sensor with capability to control networks. ZigBee can connect machines and control through one connection while consuming less power [8].

The paper consists of a method that is capable of indoor location tracking of humans as well as products by utilizing RFID technology. This system uses RFID and ZigBee technology. The proposed system can reduce the number of errors, time management, increase efficiency and effectiveness of tracking system. This system can be integrated into a commercial environment as well to improve upon already existing systems [9].

This paper presents a general RFID based module that can determine the positions of objects in a localized environment with accuracy. The paper proposes a methodology which by varying the power levels of RFID readers is adjusted against the tags. The proposed experiments can identify objects to an accuracy of under 15 cm, and is found to be comparably favorable with previously developed modules [10].

II. METHODOLOGY/EXPERIMENTAL

A. Components

1. ESP8266 Wi-Fi Module
2. Ultrasonic Sensor (HC-SR04)
3. RFID Reader (MFRC522)
4. RFID tags
5. Status led
6. Firebase console
7. ThingSpeak platform
8. ESP32 Wi-Fi module
9. Telegram chatbot

Component description:

1. ESP8266 Wi-Fi Module: An ESP8266 Wi-Fi module is a System-On-Chip microchip used for the development of endpoint IoT applications. It can provide microcontroller access to any Wi-Fi network. Its major upsides include low-cost installation, enable internet connection, and power efficient performance. In the proposed system it Acts as the central controller and communication interface, providing the capability to exchange data with other components in the proposed system. Another reason to use ESP8266 is that it helps to connect with internet to send and receive data via the Firebase console.

2. Ultrasonic Sensor (HC-SR04): It is a module that is made up of two ultrasonic transducers. One works as a transmitter that can convert the electrical signal into sound pulses. The other transducer works as a receiver to capture the transmitted pulses. When the transducer

receives pulses, it gives an output pulse which has a width that is proportional to the distance of the object placed in front of the module. In the proposed system it measures the stock level inside the container by calculating the distance between sensor's location and the stock location. Due to its efficiency and accuracy, it provides outputs of the stock level in real-time, which is displayed on the Firebase console dashboard.

3.RFID Reader (MFRC522): This reader is a radio-frequency module with an antenna that can generate a high-frequency electromagnetic field. It can store and preserve information. In the proposed system this reader reads unique identifiers from RFID cards or tags, each tag is associated with a specific action (e.g., adding or removing inventory). It then Sends the tag data to the Firebase console for logging and notification. This helps organize the inventory and keep track of every product going in and out of system.

4.RFID tags: It works by transmission and receiving information through an antenna. When RFID tag is scanned by reader, the reader then transmits energy to tag which gives the tag enough power to make the chip and antenna relay information back to the reader. In the proposed system this is paired with reader to complete the task of inventory tracking.

5. Status led: It is a led in the system set to glow at a threshold value that is specified by the user. It is used to visually alert the user when stock levels are critically low (below a predefined threshold).

6. Firebase console: Firebase console provides a pre-built UI and application through which IoT related tasks and operations can be managed by providing set of instructions and data. In the proposed system this platform is used to display logs of RFID scans on a user-friendly dashboard.

7. ThingsSpeak platform: ThingSpeak platform is an open source IoT based platform to collect, store and link data in the cloud. In the proposed system this is used to store and link the data from MATLAB with a Telegram bot to send notifications of object detection based on the given threshold presets in the proposed system.

8. ESP32 Wi-Fi module: it is a micro-controller with Wi-Fi and Bluetooth connectivity. It is a more powerful dual-core Tensilica Xtensa LX6 processor which operates up to 240 MHz, in the proposed system it is used to program the ultrasonic sensor so as to make it send an alert notification using ThingSpeak platform.

9. Telegram chatbot: It is a software application/ script that is capable of real-time interaction with user. In the proposed system a personalized bot is used to give the user real-time alerts or notifications based on the readings of sensors and processing it using ThingSpeak.

B. Design

• Flow chart:

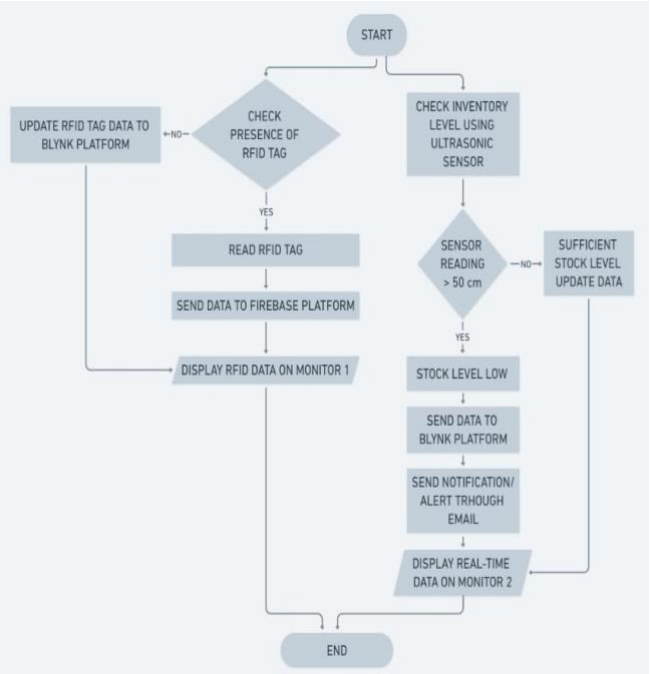

Figure 1. flowchart for working of proposed system

• Proposed system:

This system combines the capabilities of ESP8266 Wi-Fi Module, ESP32 Wi-Fi module, ultrasonic sensor, RFID system, Firebase console IoT platform and ThingSpeak IoT platform to perform stock monitoring and management to keep the supply-line running non-stop and refill the stocks well before exhaustion. This system performs 3 major tasks i) stock level monitoring, ii) logging inventory transactions, iii) visual data presentation to user iv) Wi-Fi connectivity.

1)Stock level monitoring:

The system consists of ultrasonic sensors which is mounted on top of the container for each supply-line of stocks/ products, these sensors emit ultrasonic waves, which reflect from the stock surface. The system calculates this distance based on the time taken for the echo to return and subtracts this from the maximum container height to determine the stock level. If the stock level goes beyond 50 cm, a "Low Stock Level" warning is sent to the ThingSpeak IoT platform. This is also indicative by the LED blinking to visually indicate the low level.

2) Logging inventory transactions:

This part of the system is handled by using RFID system, which consists of RFID reader and tags. Each RFID tag is assigned to a specific inventory action (e.g., "Add Item," "Remove Item"). When a tag is scanned, the RFID reader reads the tag's unique identifier. The system logs the tag ID and sends it to the Firebase console. A notification is triggered via Firebase console to log events, alerting the user of the transaction, thereby helping the user keep track of all the

inventory items/ products location to prevent misplacement and disharmony of supply-line.

3) Visual data presentation to user:

The ESP8266 continuously transmits Stock levels to Virtual Pin V1, RFID tag data to Virtual Pin V2. Ultrasonic sensor continuously monitors the supply-line and sends the data in real-time. RFID tags collect and send data of each inventory item through reader. Therefore, all the data needs to be monitored by a human to verify the process. This is possible by integrating this system with Firebase console and ThingSpeak IoT platform so that users can view data on their devices in real-time using the monitors/ display. Firebase console is used in this system to provide user valuable information to act before the stock level is 0. Similarly, ThingSpeak IoT platform is used to send alert notifications based on the readings given by ultrasonic sensor. This ensures a steady flow of stocks/ products in the supply- line (if the user acts).

4) Wi-Fi connectivity:

The system periodically checks Wi-Fi status. If disconnected, it attempts to reconnect automatically, ensuring continuous data transmission, as this system relies on internet connection to provide data for management of inventory levels. This reliance on the internet is necessary to provide real-time data to the user.

- Working of the proposed system:

The prototype for this system works by first running the provided program to check for RFID tags. If the RFID tag is identified by the reader it is programmed to take the input data provided by RFID tag. This is data is to be further transferred to the Firebase console platform to give the user meaningful data to make decisions if required. Based on the data it is programmed to send notifications using ThingSpeak IoT platform.

After checking the data from RFID tag, the ThingSpeak IoT platform is used to program the ultrasonic data with the help of ESP32. ThingSpeak platform then uses this data provided by ultrasonic sensor to check the stock levels/ inventory levels left in the supply chain. This is calculated by setting a threshold level in this case 50 cm to decide whether the inventory is low or enough. If ultrasonic sensor measures less than 50 cm in the given scenario, it is programmed to send update data/ no alerts to the ThingSpeak platform using ESP32 Wi-Fi module. Conversely if ultrasonic sensor measures more than 50 cm, it is programmed to send alerts data for low inventory level.

Fundamental functioning behind this setup:

Ultrasonic sensor is placed in front of the supply line facing the products on a particular supply line/ conveyor belt. Threshold distance value is set such that it will only measure up to 2nd last/ 3rd last product (depending on the user). Therefore, making sure that if the inventory is about to stock out, ultrasonic sensor won't be able to measure a product beyond $(n-1)^{th}$ product (here n is the last product/stock) left in the supply chain. Due to this condition, it will trigger an alert/ notification response in the ThingSpeak IoT platform as per the corresponding program and conditions and turn on the LED placed in the system for visual on the spot indication of low stock levels. Simultaneously, a RFID reader is placed adjacent to the supply line/ conveyor belt to read the RFID tags attached to the products/ stocks. RFID tags are programmed using ESP8266 to define the in and out function of a stock in the inventory, therefore determining the state of every stock in the inventory management system. This data is made easily available to users by using Firebase platform to give easy to read visual data. It will make sure each stock is scanned from the supply line and determine its property whether it is being transferred in the system or out of system. All the data from ultrasonic sensor and RFID tags is processed and converted to meaningful data for user. It is programmed to send alerts for specific conditions if found true and give all the information of stocks in the system.

Other orientations possible include top-down approach. In this alternative system ultrasonic is placed at the top of the supply chain system specifically at the top of $(n-1)^{th}$ product where n is the last product/ stock in the given scenario. Therefore, in this system threshold distance for ultrasonic sensor is programmed such that it will measure the distance between sensor module and top of the product kept on the supply line. As the products move serially on the conveyor belt it will reach to a point where no product is left on the conveyor belt. This will trigger the threshold of ultrasonic sensor since it is programmed to send alert/ notification to the user through ThingSpeak IoT platform only when ultrasonic sensor won't detect a product. For example, box height is 5 cm, and distance between ultrasonic sensor module and conveyor belt's surface is 10 cm. Therefore, in this scenario threshold value for distance will be 8 cm/9cm/10cm. If product is present ultrasonic will read 5 cm, therefore no threshold would be hit in this case. In case 2, no product is detected by ultrasonic sensor, in this case sensor will read distance of 10 cm (conveyor belt's surface). Due to this it will send an alert/ notification as programmed through ThingSpeak IoT platform to alert the user for low inventory levels.

The system will perform according to the code given below. The code consists of setup for ultrasonic sensor, RFID reader, Firebase console application, functions for scanning RFID tags, function to send ultrasonic sensor data to Firebase console, function to calculate the distance read by ultrasonic sensor, function to check and reconnect to Wi- Fi.

- Block diagram:

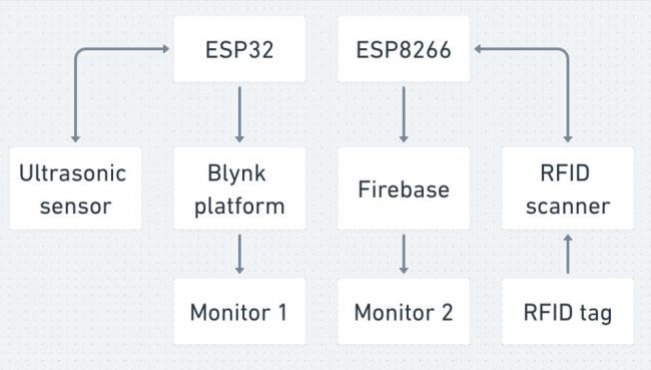

Figure 2. block diagram for all components in proposed system

III. Results and Discussions

After multiple rounds of testing statistical data is collected on the proposed system's output reliability, efficiency, time saving and manpower requirements. The system can prevent stock outs and alert/ giving a notification to user successfully each time the required conditions are met. The statistical data provides a overview on i) reliability of the proposed system, ii) projections for revenue of a company based on cost and time management. The proposed system can easily scan all the stocks/ products using RFID tags and scanners. RFID can scan each tag under 2 seconds. The data uploaded to Firebase, similarly data from ultrasonic sensor is sent to ThingSpeak IoT platform which is then processed to give alerts if given conditions are met. The alert takes approximately 2 seconds to reach to the user. Based on the time saved further calculations can be made to project a certain revenue growth and time saved. Ultrasonic sensor can provide accurate distance measurements therefore ensuring the accuracy of the system in terms of alerts and time management.

The system was tested under enclosed environment like that of warehouse. The major parameters and metrics for this system were calculated based on a testing of ten 10-hour cycles and 20 individual randomly timed samplings. Based on the 10- hour cycle it was concluded to be capable of performing without flaws and glitches nine times out of the ten cycles therefore giving an accuracy of 90% for system performance with one flawed cycle due to misplacement of object. Major metrics calculated were scan rate, latency and alert time. Based on the 20 randomly timed samplings, scan rate at 1 cm or less was 99%. Increasing the distance to 2.5 cm reduces its scan rate to 90% as some samples failed. Increasing further to 3 cm reduces its scan rate exponentially at 55%. Therefore, the most optimal scanning distance recommend is 1 cm if the distance is not feasible 2.5 cm is the maximum distance recommend for this system. Latency rate was found to be 500 milliseconds as it is a passive RFID tag, and the latency rate for display of sensor data was found to be 1.5-3 seconds depending on Wi-Fi connectivity. The alert time for this system which is sent to telegram chatbot is under 5 minutes.

Figure 3. prototype of proposed system. 1) RFID scanner used for outlet of product, 2) RFID scanner used for inlet of product, 3) ultrasonic sensor programmed with ESP32 to set threshold distance for alerts, 4) representation of product attached with RFID tag, 5,6 are same as that of 4.

i) The reliability of this system depends heavily on the placement and position of products on the conveyor belt that has this system integrated. Depending on the product positioning it can detect all the products if they are facing the reader. This is a limitation of this system but can be solved if the user can add tags on all four sides of the product therefore guaranteed scanning can be achieved.

This is proven by the research of Sharif Vakili's comparison of IR and RFID system in a clinical setting. According to their research RFID system has proven to be better than IR sensor in terms of reliability as their research concluded by a 83.7 % success rate for recording events, whereas IR based system successfully recorded 75.4 % of total 252 events.

ii) This data is used to create a statistical revenue projection graph for a company if these systems were to be implemented. The graph defines the difference between revenue growth if RFID based inventory management system were to be implemented compared to IR sensor-based inventory management. This graph gives a generalized impact on revenue as to how it will affect the growth rate of a company in a generalized sense. The major points covered by the graph are what time efficiency translates to revenue growth of a company. What reliability leads to in terms of revenue growth of a company. All these factors combined are key factors in a manufacturing/ product-based companies for their steady increments in revenue growth, timely deliveries and fast services for the end user.

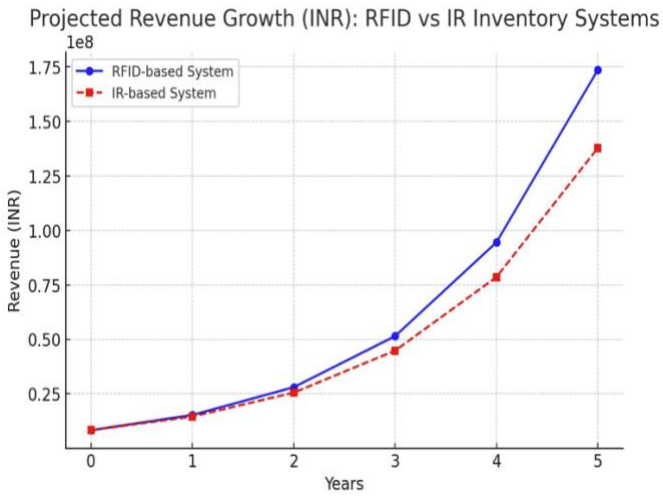

Figure 4. graph of projected revenue growth from using RFID based system vs IR based system.

The graph is based on the assumptions that a company is generating 1,00,000 rupees of base revenue and it grows proportionally to the efficiency percentage (as explained earlier in the research outcomes of Sharif Vakili) over a period of 5 years. Based on these assumptions, the following calculations were made to determine the difference in revenue growth and how it is affected by using a more time efficient system as compared to IR sensor-based inventory management system. Although these systems were already capable of being time efficient and reliable these factors are further optimized/ enhanced using RFID based inventory management system. This graph depicts how the revenue growth of a company will be affected using the proposed system (note: this graph is not meant to completely replicate any company's growth it is only to give generalized benefits of using this system.)

IV. FUTURE SCOPE

The system has its limitations that can be solved by further addition of components. Improvements than can have major effects on the usability of this system are addition of thermal sensors for temperature sensitive products, load sensor to manage bulk orders for stocks/products. Reducing the time needed for alert/ notifications to the user can be significantly reduced by using advanced IoT platforms and concatenations in system for real-life scenarios can be expanded using machine learning to predict the stock outs well before time. Machine learning can also be used to analyze which stocks/ products are selling faster compared to other products to alert the user in advance. Machine learning algorithms can be developed to self-deploy bulk orders of stocks/ products if alerts by the system are ignored for more than a certain amount of time. Machine learning tools such as linear regression can be used to understand patters that can help the system predict timings where stock levels are low and based on these it can also be programmed to send alerts. Other application of machine learning includes self-order placement to make the system capable of placing order based on the predictions made by machine learning tools used. This can be optimized further by creating a prototype to help the machine learning tools to host practice sessions in a real-life scenario to improve its prediction accuracy and further help the system to make correct decisions. Use of better software is also an upgrade that can be with implementation of a dedicated site for the system to show all the outputs, stock levels and stock warnings in a much pleasing manner for the user. Therefore making the system user friendly. Audio alerts can be implemented to make the system accessible to disabled population therefore making it accessible for everyone irrelevant of their abilities and disabilities.

V. CONCLUSION

The proposed system is capable of providing real-time data on stock/ product's status using RFID tags. System is designed to give alerts in the form of notification to the user of this system for certain conditions one of which includes low stock levels in the inventory or entered in the system. This system is programmed to send alerts just before stock outs to prevent delay in stock refiling and ensure the smooth running of the supply line. The system is made as an easy to implement system in pre-established inventory management system. It is designed as an add on to the already existing system. Due to its easy to use and easy to attach abilities it proves to be a reliable and cost effective add on to improve already existing systems. The only major downside of this system is its reliance on Wi-Fi connectivity for its smooth operation and alert management. Main application of this system is in the supply chain industrial companies, relying on B2B business and trade. The system is aimed to improve the time management, efficiency and reduce manpower for such companies. Further improvements in the system is possible using machine learning and algorithmic deployment to predict stock outs and pre-plan orders for the user.

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