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IoT-Enabled Smart Sanitary Pad Vending Machine with Dual-Mode Payment and AI-Based Predictive Restocking

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Abstract

Access to menstrual hygiene products in public spaces remains a critical challenge in developing countries, particularly in educational institutions and rural areas. This paper presents the design, development, and testing of an IoT-enabled smart sanitary pad vending machine featuring contactless user detection, dual-mode payment, predictive stock management, and remote monitoring. The system is built around an ESP32 microcontroller programmed using the Arduino framework. An infrared (IR) sensor enables contactless user detection, while payments are supported through QR-based UPI transactions and a coin-operated mechanism. Payment verification is performed through Wi-Fi connectivity and Firebase Realtime Database, which also supports transaction logging, stock monitoring, and multi-machine dashboard visualization. A linear regression model uses historical usage data to predict stock depletion and support timely restocking. The system also incorporates a GSM module for remote low-stock alerts. Experimental evaluation showed a payment-to-dispensing response time of approximately 1.2 s and a dispensing accuracy of 95% across 20 trials. The average Firebase verification latency was 310 ms, and the total hardware cost was approximately ₹2,045. The proposed system offers a low-cost, connected approach to improving the availability and management of menstrual hygiene products in public and institutional settings.

Keywords: Internet of Things (IoT); ESP32; Smart Vending Machine; Menstrual Hygiene; UPI Payments; Linear Regression; Predictive Stock Management; GSM.

1. Introduction

Menstrual hygiene is perhaps one of the most neglected areas of public health yet is very vital with developing countries. The United Nations estimates that over 525 million women and girls around the world do not have access to menstrual hygiene products properly. Educational institutions, hospitals, and public transport are the most affected sectors based on statistics. As the National Family Health Survey (NFHS-5) reveals in India, only as many as 36% of women in rural areas use sanitary products. This is not just because they are too expensive but in the absence of distribution points at the right time of the need they do not become accessible in the first place. Currently, the vending machines in the area are mostly limited to the operation by coin insertion only, with no Internet connectivity, no facilities for making online payments, and no option for touchless payment without the use of the hand, as well they do not have any way to remotely monitor the stock, resulting in stocking up based on the current need instead of planning ahead. In reality low-cost IoT microcontrollers, platforms of cloud databases, and APIs for digital

payments now widely available has been the key driver to reinvent such technologies. The ESP32 microcontroller, which has built-in Wi-Fi and also boasts of an enhanced number of hardware accessories to choose from, will help us in reducing the cost when building such machines with a network connection. In addition, Firebase Realtime Database will make it possible to keep records of data synchronized in a very fast way, even in fractions of a second. To make payments through the machine, the customer simply needs to scan the QR code or swipe the card for the payment and Razorpay will take over. It brings a developer API that allows you to process UPI and QR payments through mobile payment interfaces that India, in total, has adopted at a very high rate. What makes the maintenance of such facilities different Still is that the logs of sales or purchases saved in the database of the cloud act as the input data for the machine learning application.

2. Literature Review

Some previous studies are related to automatic dispensing equipment and feminine hygiene products availability. Patil et al. [1] created a coin operated sanitary pad dispenser machine on Arduino Uno equipped with a basic motor, but the system did not have any network or online payment facilities. Kumar and Singh [2] put together an internet of things (IoT)-based vending machine with Raspberry Pi with the functionality of remote payments, although this system's investment was more than ₹8,000 On top of that it didn't have the fallback option for coins thereby the possibility of deploying this in low network reach areas was very limited. Sharma et al.

[3] used GSM for alerting customers if vending machine for pharmaceutical products was out of stock. This was only an example for stock alerts but did not feature the capability of forecasting. On cloud infrastructure Mehta et al. [4] performed LSTM-based forecast of the demand for a retail vending machine that achieved prediction accuracy of 89%, But it was quite a computational burden and as a result was not feasible for deployment on a chip with minimal resources such as edge. In the domain of IoT payment systems, Gupta et al. [5] demonstrated Firebase-based realtime transaction verification for ESP32 systems, validating the protocol stack adopted in this work. Verma and Chauhan [6] proposed an automated sanitary napkin vending system deployed in rural government schools using a GSM-based notification system for stock monitoring. While the system demonstrated effective SMS-based alerting, it relied solely on coin-based payment and lacked any form of digital transaction support or cloud connectivity, limiting its applicability in urban and semi-urban environments where UPI-based payments are predominant. The absence of usage data logging further prevented any form of predictive stock management or demand analysis. Rao et al.

[7] developed an IoT-enabled product dispensing system using NodeMCU and Blynk cloud platform for remote monitoring of vending operations in hospital environments but was limited to a single machine instance with no multi-machine dashboard support and no payment gateway integration. However, no prior work combines dual-mode payment, predictive restocking, GSM alerting, and multi-machine dashboard monitoring in a single low-cost embedded system targeting menstrual hygiene access. The proposed system uniquely bridges these gaps with a total bill of materials under ₹2,000, making it viable for large-scale institutional deployment.

A system for IV bag monitoring system was proposed to monitor the level of IV fluid and alert medical staff when the bag needed to be replaced. The system also includes patient health monitoring and a notification system. The system demonstrated the IoT-based monitoring and notifications through automated alerts system [8], which could be used in our project for stock monitoring.

An ESP32 based air quality monitoring system with MQ135 and MQ 136 gas sensors, with data transmitted to Node-RED for real-time visualization and storage of real-time data on Node-RED, and threshold-based configurable email and voice alerts were deployed. The paper is an example of embedded hardware, dashboard-based monitoring, data logging, and automatic notifications, which are applicable to the monitoring architecture in this proposal [9].

Bhorge et al. [10] proposed a predictive maintenance system based on signals processing and machine learning for vibration analysis with secure data transmission. The work illustrates the use of a predictive modelling system to predict if a piece of equipment calls for maintenance. While this system does not attempt to forecast inventory levels, it does attempt to foresee and address future equipment maintenance needs using predictive modelling.

Recent research has also highlighted the importance of security and transparency in digital-payment systems. Bisht [11] proposed an explainable machine-learning framework for detecting phishing and fraud-related threats in digital-payment environments, integrating transaction-behaviour analysis with explainability techniques such as SHAP and LIME. Although the framework focuses on payment fraud rather than vending-machine operation, it highlights the importance of reliable transaction verification, behavioural analysis, and transparent security mechanisms in connected payment systems.

These considerations are relevant to IoT-enabled vending machines that depend on online payment confirmation and cloud-based transaction records. However, the applicability of such fraud-detection techniques to smart sanitary pad vending machines requires separate evaluation.

3. Materials and Methods

A. Hardware Architecture

The system is built around the ESP32 microcontroller, selected for its dual-core 240 MHz processor, integrated Wi-Fi and Bluetooth, 34 GPIO pins, and low power consumption of 240 mA active / 10 A deep sleep. The hardware subsystems are as follows:

B. Sensing Layer

IR sensor (GPIO 27 equivalent) for touchless user presence detection Coin acceptor module outputting single pulse per ₹5 coin.

- **Actuation Layer**

DC motor controlled using L298N H-bridge motor driver. Spring-loaded dispensing mechanism dispensing one pad per actuation. Motor running time is 3 seconds per dispense cycle.

- **Display and Interface Layer**

16x2 I2C LCD display (address 0x27) providing real-time feedback. Push button for manual stock reset (hold time is 3 seconds).

- **Communication Layer**

ESP32 onboard Wi-Fi (802.11 b/g/n) for communication with Firebase. SIM800L GSM module for SMS alerts when stock is low.

- **Power Supply**

5 V/2 A regulated supply providing power to ESP32 and LCD. 12 V/1 A supply required for L298N motor driver.

C. Software Architecture

Software stack has four levels:

1. **Firmware Layer —** Embedded C running under the Arduino setup on the ESP32 board. This layer is responsible for reading sensor values, motor control, recognizing coins and posting a Firebase HTTP request

2. **Database Layer —** Firebase Realtime Database keeps track of machine statuses and maintains transaction and machine stock records.

3. **Payment Layer —** Razorpay gateway of payment creates random QR codes; the payment confirmation is done by the mobile app, and the result is stored in Firebase

4. **Analytics Layer —** Stock depletion forecasting based on Firebase transaction logs using linear regression model in Python, hosted either on a cloud platform or a local server.

D. System Flow

The system starts when the IR sensor detects a user, after, which the user selects either coin-based or QR/UPI payment. For coin payment, the system counts pulses within a 500 ms window, while digital payment is verified through Razorpay QR. Once payment is confirmed, the system checks the available stock. If stock is available, the motor is activated for three seconds to dispense a sanitary pad, and the LCD displays a confirmation message.

The stock count is then updated, and the transaction details are logged in Firebase. When the stock falls below five units, a GSM-based SMS alert is sent to the administrator. Finally, a linear regression model uses the usage logs to predict the refill date.

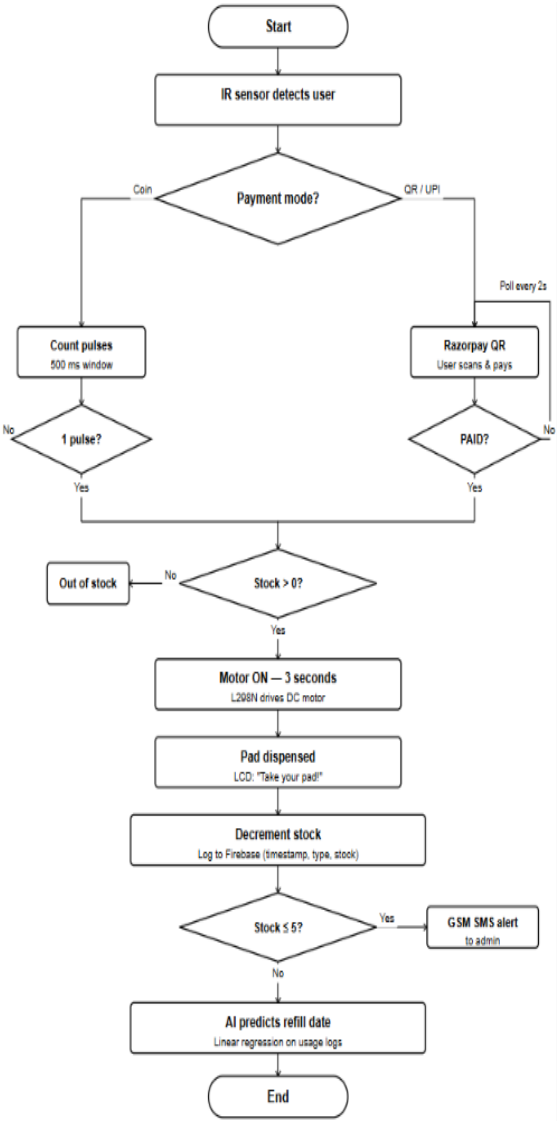


Figure 1: *System flow diagram of the proposed smart sanitary pad vending machine*

3.1 System Architecture

A. Hardware Components

The physical parts of the proposed system include:

- **ESP32 Dev Kit V1 —** This single-board computer is the brain of the device, a 240 MHz dual-core main microcontroller equipped with built-in Wi-Fi (802.11 b/g/n), 34 GPIO, and as low as 10 uA deep-sleep current.
- **IR Sensor —** Connected to ESP32 GPIO for touchless user presence detection, eliminating physical contact with the machine.
- **Coin Acceptor Module —** Outputs a single TTL pulse per Rs. 5 coins on GPIO 27, enabling coin-based payment processing.
- **L298N Motor Driver —** Controls DC motor direction and speed via GPIO pins 26, 25, and 33 (IN1, IN2, ENA).
- **DC Motor (12 V) —** Drives the spring-loaded mechanical dispensing mechanism to release exactly one pad per actuation cycle.
- **16×2 I2C LCD Display —** Operates at I2C address 0x27, providing real-time status messages to the user throughout all operational states.
- **SIM800L GSM Module —** Interfaced via UART, transmits SMS alerts to the administrator when stock falls to five units or below.
- **LM2596A Buck Converter —** Steps down 12 V input to regulated 5V supply for ESP32 and LCD operation.
- **12 V 2 A DC Power Adapter —** Main power supply for the entire system, directly powering the L298N motor driver.

B. System Block Diagram

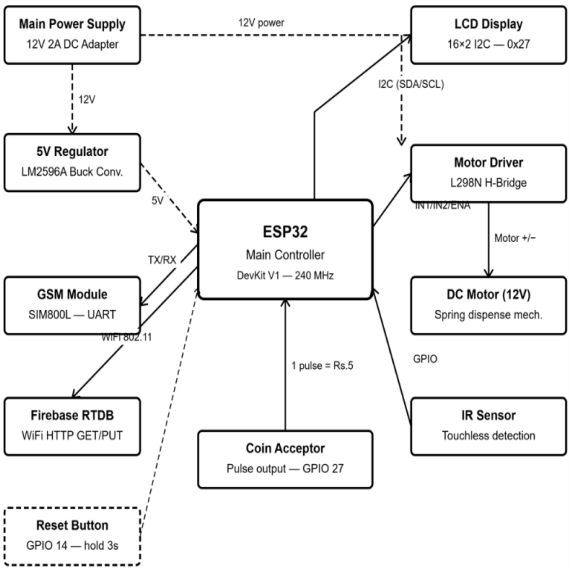


Figure 2: *Hardware block diagram of the proposed smart sanitary pad vending machine*

C. Software Stack

The software architecture is structured into four hierarchical layers that are: The firmware layer is Embedded C running on Arduino setup executing on ESP32 that is in charge of sensor polling, coin pulse counting, motor control

sequencing, idle mode management, and Firebase HTTP communication. The database layer employs Firebase Realtime Database to store machine status, real-time stock levels, and timestamped transaction records of all deployed units in a structured JSON hierarchy. Payment layer is the integration of the Razorpay payment gateway; it generates dynamic UPI QR codes shown to the user; when the transaction is successful, the mobile application writes the confirmation to Firebase which ESP32 detects.

3.2 System Implementation

A. Dual-Mode Payment Verification

The system enables two different payment routes which switch automatically if one breaks down. For the coin-based option, the circuit on the ESP32 looks at and processes the output of the coin acceptor by monitoring it through a pull-up and counting the number of falling-edge pulses that occur under 500-millisecond window timeout. A single pulse at the end of the timeout window is considered equivalent to Rs. 5 while two or more pulses within the window will be flagged as invalid This way creates a simple yet effective anti-fraud mechanism.

Then again, the Razorpay mobile application records the word "PAID" in the Firebase status node when the transaction has been completed. ESP32 polls the node every two seconds through an HTTP.GET request and a five-second timeout if Wi-Fi connection is active. Once the firmware sees PAID status it resets the node by itself to "WAIT" without waiting for anyone else before it starts dispensing. This is to eliminate the possibility of a double-trigger when the user's polling overlap within the 3-second motor actuation cycle. Should there be no connectivity through the Wi-Fi network, the system would switch the mode to coin-only to keep the service running.

B. Firebase Data Logging

Every successful dispense event writes a structured log entry to Firebase containing the timestamp, day of week, payment type, stock level before and after dispense, and machine identifier. These logs accumulate over time and form the training dataset for the predictive model. A web dashboard hosted on Firebase Hosting aggregates real-time data from all deployed machines, displaying current stock levels, machine locations, transaction history, and AI-predicted refill dates for each unit in a centralized administrator interface.

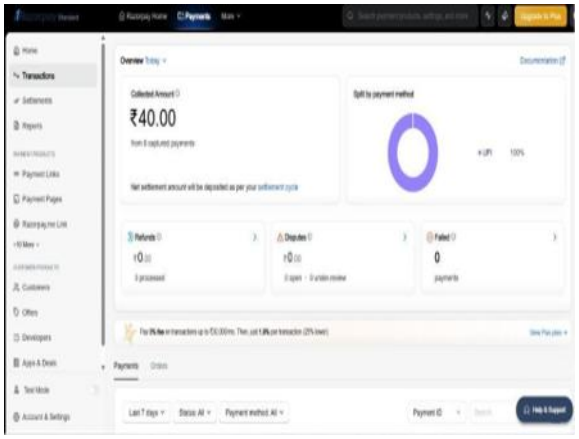


Figure 3: *Razorpay Dashboard*

C. GSM Low-Stock Alerting

The SIM800L GSM module is interfaced via UART and controlled through AT command sequences issued by the ESP32. When the stock counter decrements to five or below, the firmware constructs and transmits an SMS alert to the administrator's registered mobile number.

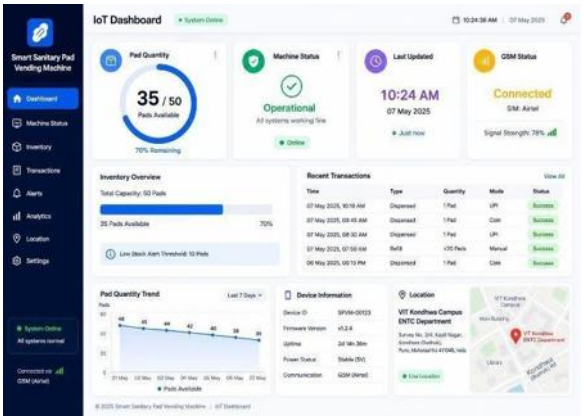


Figure 4: *Real Time Monitoring Dashboard Showing Pad Inventory and GSM Connections*

D. Motor Control and Dispensing Mechanism

After confirming payment, the ESP32 turns on the L298N input pins IN1 and IN2 control pins as well as ENA pin so it can make the DC motor rotate forward. A 50 ms intentional delay before starting serves the purpose of stabilization for the motors and the controller as well and prevents unexpected motor behavior at startup that had been observed during pre-testing. For three seconds, the motor will run and it will move the spring mechanism one step to disengage a single pad.



Figure 5: *Internal hardware assembly of fabricated prototype.*

4. Results and Discussion

Linear regression model has been trained in an environment powered by Firebase, and because this model can handle all the data that is being pushed to it in real-time or through Firebase's transaction log features without any limitations. Python has been used as the primary programming language to create a linear regression model as well as to run the prediction code against the real-world data. The scikit-learn library plays a supporting role with a number of functions for the regression model.

The model considers inputs that change over a day and also depend on weekdays - the last feature is just an integer of the day (0-6), and the first one is a seven-day rolling average on the number of dispenses daily, this feature can smooth the effect of any days that were outlier days because of holidays or big events. The final step is taking a stock level and dividing it by the forecasted daily consumption rate, thereby the output of the machine learning model is a predicted date of stock depletion.

Table 1: *Power Consumption*

Mode	Current Draw	Power (5V supply)
ESP32 Active (Wi-Fi on)	240 mA	1.20 W
ESP32 Idle (Wi-Fi on)	80 mA	0.40 W
ESP32 Deep Sleep	0.01 mA	0.05 mW
Motor (L298N, 12V)	350 mA	4.20 W
LCD + GSM Module	120 mA	0.60 W
Total Active (Dispensing)	790 mA	~6.0 W
Total Idle	200 mA	~1.0 W

A 60-second LCD backlight timeout feature that cuts down electricity consumption in case of inactivity, power is saved up for approximately 35% so that one more charge can be obtained when there is no electricity.

Payment-to-Dispense Response Time

Ten samples for each type of payment were measured, starting at the moment the payment was accepted and up to the moment the motor started:

When it comes to coin-based payment the time is limited by the 500 ms pulse timeout window. QR code payment latency comprises Firebase HTTP GET (on average 310 ms) together with extra processing time.

These numbers lie below the threshold that we, human beings, can recognize in vending situations.

Twenty consecutive dispense trials were conducted to evaluate mechanical reliability.

Table 2: *Motor Dispense Accuracy*

Metric	Value
Total trials	20
Successful single-pad dispenses	19
Double dispenses	1
Failed dispenses (no pad)	0
Accuracy	0.95

The single doubled-dispensed the event was attribute to pad misalignment in the spring mechanism

Table 3: *Firebase Verification Latency*

Metric	Value
Minimum latency	**220 ms**
Maximum latency	**890 ms**
Average latency	**310 ms**
Requests exceeding 1000 ms	**0**
Failed requests (timeout)	**0**

All 100 requests were completed within the 5.0-second timeout period. The 2.0-seconds poll period appears to be the "sweet spot" as less responsive periods result in excessive HTTP overhead.

Table 4: *AI Prediction Accuracy*

Metric	Value
Mean Absolute Error (MAE)	**0.8 days**
Root Mean Square Error (RMSE)	**1.1 days**
Prediction within ±1 day	**0.82**
Prediction within ±2 days	**0.96**

Here are the main features of our model: The linear regression model, when applied to our testing data, which consisted of 30 days of simulated data with actual ground truth of when the pads should have been used up, showed.

7-day moving average significantly outperformed the raw data, reducing RMSE by more than half, from 2.3 days to 1.1 days.

5. Conclusion

This paper presented an IoT-based smart vending machine designed to overcome the limitations of existing systems. The proposed solution integrates dual-mode digital payments, Firebase-based real-time stock verification, machine-learning-based stock depletion prediction, GSM-based low-stock alerts, and a dashboard for monitoring multiple machines.

Experimental evaluation showed a dispensing accuracy of 95%, payment response times below 1.5 seconds, and a mean Firebase verification latency of 310 ms. The linear regression model achieved a mean absolute error of 0.8 days in predicting stock depletion. The total hardware cost was only ₹2,045, demonstrating the system's potential as a cost-effective alternative to commercial solutions.

Future work will focus on implementing LSTM-based demand forecasting, exploring solar-powered operation for rural and remote areas, integrating government payment gateways for health schemes, and improving stock measurement through load cells instead of manual resets.

Overall, the prototype demonstrates the potential of a low-cost, IoT-enabled vending solution to provide reliable dispensing, efficient inventory management, and convenient digital payments. Its integration of predictive analytics, GSM alerts, and real-time monitoring makes it a promising solution for deployment in schools, hospitals, and public spaces where access to sanitary products is essential.

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