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RESEARCH ARTICLE

Prototype Innovation of IoT-Based Tissue Box Using Microcontroller ESP8266 and Infrared Sensor

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Abstract: This study presents the development of a smart automatic tissue dispenser prototype utilizing the ESP8266 microcontroller to enable IoT-based real-time monitoring. The ESP8266 was selected for its integrated Wi-Fi, low power consumption, and flexibility in embedded applications. The prototype integrates key components, including a proximity sensor, servo motors, an LCD, and a custom-built casing to facilitate contactless tissue dispensing and stock tracking. The design process involved flowchart modeling, wiring schematics, user interface development, and physical assembly. Functional testing was carried out through five experimental scenarios: motion detection, data synchronization, startup stability, response to various inputs, and low-stock condition alerts. The system achieved 95% motion detection accuracy and 100% synchronization between the hardware and the remote monitoring application. These results demonstrate the effectiveness of the system in providing hygienic, responsive, and efficient tissue dispensing, with the potential for further improvements in sensor reliability and long-term performance in real-world environments.

Keywords: control, monitoring, sensing, tissue, toilet

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1 Introduction

Maintaining personal hygiene, including cleaning private areas, is essential for overall health. Public facilities, indoor and outdoor, often provide tissues in public restrooms or spaces as a gesture of care for the hygiene of users [1]. Previous studies have indicated that bacteria can spread on restroom surfaces, including exposed tissue paper, within 20 minutes after use [2]. This raises concerns about the hygiene level of tissue used in sensitive areas, which can potentially cause skin conditions or other health problems [3] [4].

In addition to hygiene issues, users of public restrooms frequently encounter the problem of tissue shortages, even shortly after restocking. This may be due to excessive tissue consumption, which is often unchecked. On the other hand, janitorial staff or Cleaning Service (OBs) must frequently inspect restrooms to monitor tissue supplies, an inefficient and time-consuming process. From this background, three primary issues can be identified: the relatively low hygiene level of toilet tissue, excessive tissue usage, and inefficient tissue restocking processes. Most tissue dispensers in public restrooms allow unrestricted access, enabling users to take as much tissue as they like, which often leads to waste. This overconsumption contributes to deforestation, as tissue production relies on wood pulp sourced from trees in forests [5]. Although some tissue dispensers use touch-free mechanisms, dispensing tissue automatically upon detection of motion, they still do not address issues of excessive consumption or the need for manual stock monitoring by OBs.

Although some existing studies have proposed touchless or automatic dispensers, most focus solely on hygiene through motion detection, without addressing overuse or enabling real-time inventory monitoring. Moreover, many of these systems are based on expensive or complex hardware, which may not be feasible for wide-scale deployment in developing countries or facilities limited in resources.

This study aims to develop an Internet of Things (IoT)-based tissue dispenser prototype that minimizes waste, optimizes resource use, and improves efficiency in tissue monitoring and usage [6–8]. IoT technology enables communication and data sharing between objects equipped with sensors and software through an internet network [9, 10]. Using IoT, this prototype facilitates OBs in monitoring tissue stocks, ensuring timely refills, and preventing shortages [11].

This study addresses these limitations by introducing a new smart tissue dispenser based on the Internet of Things (IoT) that is affordable and multifunctional. The system is built using an infrared sensor and the ESP8266 microcontroller, whose components were chosen for their low cost, wide availability, and sufficient accuracy in detecting motion and transmitting data wirelessly. Although there are more precise sensors, the trade-off in terms of cost and complexity makes the chosen hardware optimal for public restroom environments where large-scale deployment is a goal.

The contributions of this study are threefold:

1. It introduces a cost-effective IoT tissue dispenser that uses motion sensing and timed delays to minimize tissue overuse.
2. It integrates a real-time monitoring system to alert maintenance staff when tissue levels are low, reducing unnecessary manual inspections.
3. It promotes a hygienic, sustainable, and efficient public restroom experience that is suitable for deployment in high-traffic public facilities such as schools, malls, offices, and transport terminals.

This solution is designed specifically for shared restroom environments in tropical, humid regions where bacterial growth is accelerated and maintenance logistics are often constrained. The prototype also includes a data logging mechanism that enables facility managers to evaluate usage patterns and adjust supply schedules accordingly.

Through this IoT-based solution, public restrooms can become more hygienic and resource-efficient, benefiting both users and facility managers. The Internet of Things (IoT) represents a technological revolution that enables devices to connect, communicate, and share data seamlessly over the internet [12]. By embedding sensors and software into physical objects, IoT systems create an interactive environment where devices can collect, transmit, and respond to data in real-time [13]. This connectivity fosters automation and enhances operational efficiencies across various sectors, from healthcare to smart home applications [14]. For instance, integrating IoT technology into resource management systems has proven to optimize operational workflows and improve user experiences [15].

Building on the advantages of IoT, the proposed tissue dispenser prototype provides a practical solution to challenges associated with tissue stock monitoring in public facilities. Utilizing connected sensors, the system continuously tracks inventory levels and sends alerts when refills are necessary [16]. Such real-time monitoring prevents tissue shortages and minimizes manual inspections by maintenance staff [17]. The data-driven insights generated by the IoT-enabled platform enable facility managers to maintain adequate supplies while optimizing service routes and schedules [18].

A unique feature of this prototype is its motion-sensing capability. By detecting the presence of users, the dispenser ensures that tissue is only dispensed when needed, promoting contactless interaction and improving hygiene in public restrooms [19]. Furthermore, the dispenser incorporates a timed delay mechanism between consecutive dispenses, effectively controlling tissue usage and discouraging excessive waste [20]. This design innovation addresses two critical aspects: maintaining high standards of cleanliness and reducing unnecessary resource consumption [21].

The broader impact of this IoT-based solution extends beyond mere convenience. Public restrooms equipped with intelligent dispensers can significantly enhance hygiene standards while fostering more sustainable practices. By optimizing resource allocation, such systems benefit both end users and facility managers alike [22]. The integration of IoT into waste management strategies exemplifies how digital transformation can lead to smarter, greener, and more user-friendly environments [23].

2 Research Method

In general, the prototype implementation is depicted in Figure 1. An application is involved as a medium to provide information about tissue stock availability and the prototype's location to the cleaning staff (OB). The prototypes are placed in each room or public restroom and are integrated with the application via an internet connection. Information about the prototype, including tissue stock, location, and usage time, is stored in Firebase, a cloud-based database provided by Google to facilitate application development without backend involvement [24, 25].

Figure 1 illustrates the system architecture of an Internet of Things (IoT)-based tissue box prototype designed to monitor tissue availability in multiple public restrooms in real-

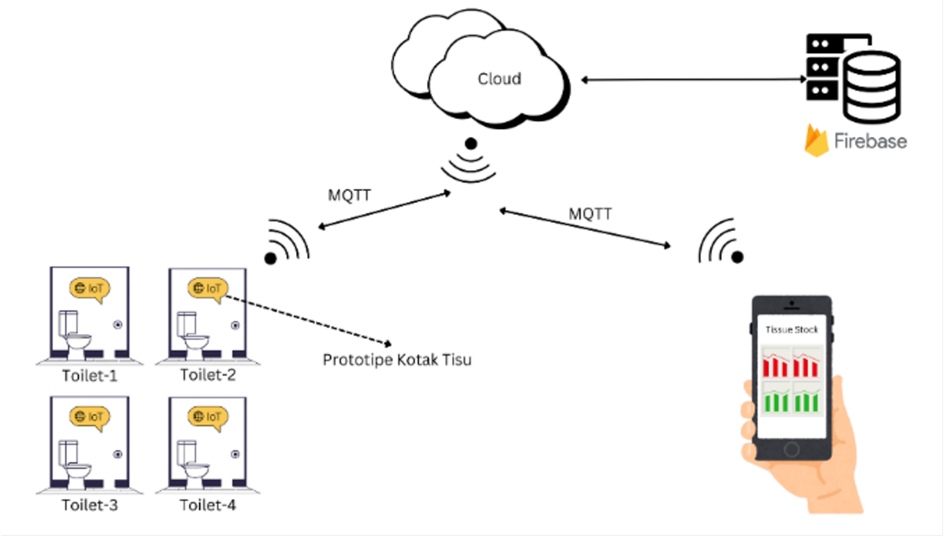


Figure 1: Communication flow concept of the tissue box prototype.

time. The system connects several key components, ranging from the hardware installed in each toilet to a cloud-based monitoring application that can be accessed via mobile devices.

As illustrated, there are four toilets, each equipped with a smart tissue box prototype. Each prototype is integrated with an infrared sensor to detect user presence and tissue consumption, as well as an ESP8266 microcontroller module responsible for processing the data and transmitting it wirelessly to the cloud. The device automatically records tissue usage and determines whether the supply is sufficient, running low, or depleted.

The data collected by each prototype is transmitted to the cloud server using the lightweight MQTT (Message Queuing Telemetry Transport) communication protocol. MQTT is chosen for its efficiency and suitability for IoT devices with limited power and bandwidth. Once the data reaches the cloud, it is stored and managed using Firebase, a cloud-based database platform that supports real-time data updates.

Firebase acts as the central hub for storing and managing tissue stock data from all toilets. This information can then be accessed by janitorial staff or facility managers through a mobile application, as shown at the bottom right of the figure. The application displays the status of the tissue stock of each toilet using a visual indicator with three color codes: green for sufficient stock, yellow for low stock, and red for depleted stock. This allows staff to refill tissue boxes quickly and efficiently without having to manually inspect each toilet.

2.1 Flowchart Diagram

This section presents the prototype workflow from tissue usage to stock information. In Algorithm 1, T represents the time value obtained from the difference between the current time and the tissue usage time. If T is greater than or equal to 2 minutes (as an example), a check on the tissue stock (S) is performed. If S is greater than or equal to 20 sheets of paper (as an example), the motion sensor will activate (ON). If movement is detected, the tissue box will dispense 2 sheets of paper (as an example), and the tissue stock will automatically decrease by 2 sheets. The tissue box will not dispense tissue if no movement is detected, and T is less than 2 minutes. In addition, the prototype display will show relevant information.

Algorithm 1 Process flow diagram for tissue box prototype

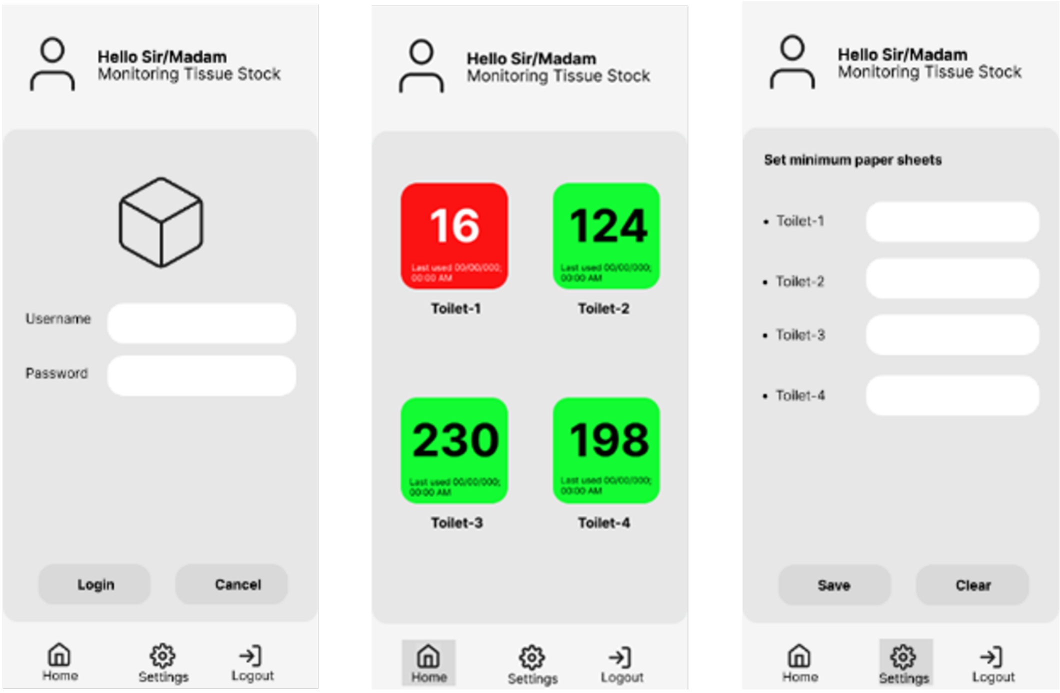
```
procedure TISSUE BOX PROTOTYPE(Input: motion_sensor, Output: information)
    Declaration:
        LU, CT, $T$: data/time
        SM: boolean
        S: ShortInt
    Implementation:
        LU ← Time                                              ▷ Last Used of tissue (LU)
        T ← CT − LU                                            ▷ Current Time (CT)
    if $T \geq 2$ minutes then                                 ▷ Tissue Stock (S)
        if $S \geq 20$ and motion_sensor is ON then
            Information ("Idle")
            if motion_sensor == detected then
                Box tissue gives 2 sheets
                $S \leftarrow S - 2$
                LU ← CT                                        ▷ Current Time
                Information ("please pull tissues")
            else
                Information ("Please shake your hand in front of the sensor")
            end if
        else
            motion_sensor ← OFF
            [Application and Prototype] ⇒ Warning ("It's time to refill")
        end if
    else
        Information ("Save the earth")
    end if
end procedure
```

2.2 User Interface Design

The application design consists of three interfaces: login, home, and settings. Figure 2a shows the login interface for cleaning staff (OB) to access the settings for the minimum stock levels and view the remaining information on the tissue stock for each tissue box prototype. Figure 2b displays the remaining information from the tissue stock. In restrooms where the stock is less than or equal to 20 sheets, the box is highlighted in red, whereas otherwise it is highlighted in green. The tissue used is bamboo tissue with an initial stock of 234 sheets, and the application is preconfigured with this initial stock. Next, Figure 2c shows the interface for adjusting the minimum level of tissue stock to trigger notifications or warnings in the form of color and text information.

The application interface designed for the IoT-based smart tissue box system provides a simple yet effective way for cleaning staff to monitor and manage tissue stock in real-time.

The interface consists of three main views: the login screen, the home screen displaying tissue stock information, and the configuration settings screen.



(a) user login (b) dashboard (c) settings

Figure 2: User interface design.

Upon opening the application, users are greeted by the login interface, which serves as the gateway to the system. Cleaning staff are required to enter a username and password to gain access. This authentication step ensures that only authorized personnel can access sensitive settings and stock data. The layout is clean, with intuitive buttons for logging in or canceling the input, and a navigation menu is available at the bottom of the screen to guide users through the main features of the app.

After logging into the system, users are directed to the home screen, where they can view current tissue stock levels in each toilet. Each smart tissue box is represented by a rectangular display showing the number of sheets remaining. These displays are color-coded to reflect the urgency of restocking. Toilets with stock levels at or below 20 sheets are highlighted in red, indicating that the tissue supply is low and should be refilled soon. In contrast, toilets with sufficient stock are highlighted in green, signaling that no immediate action is required. For instance, Toilet-1 may display 16 sheets and appear in red, while Toilet-2 may show 124 sheets and appear in green. This visual approach enables cleaning staff to quickly assess the status of all toilets without the need to physically check each one, significantly improving efficiency and responsiveness. The settings screen offers customization options for minimum tissue stock levels. Here, users can adjust the threshold that determines when the app should trigger a warning for each toilet. By default, this threshold is set to 20 sheets, but it can be modified based on specific needs or patterns of use. For example, if one toilet tends to have more traffic, the minimum stock level can be increased accordingly. Input fields are provided for each toilet, and users can save the new configurations or remove them if necessary. This flexibility ensures that the system remains adaptable and tailored to real-world conditions.

Throughout the system, the initial stock for each tissue box is set to 234 sheets, using bamboo tissue. This default value ensures uniformity between devices and simplifies monitoring. In general, the design of this application emphasizes clarity, accessibility, and real-time control, empowering cleaning personnel to manage public restroom supplies more effectively and sustainably.

2.3 Wired Diagram of Prototype

The prototype uses electronic components, including an ESP8266 NodeMCU Amica V2, a 16 × 2 LCD, a counter sensor, a proximity (motion) sensor, a roller mechanism, a servo, buttons, an adapter, and a switch. The ESP8266 is a Wi-Fi module that connects directly to Wi-Fi and establishes a TCP/IP connection [26]. All components are integrated into a wired diagram as shown in Figure 3. The figure demonstrates how each component is connected to the ESP8266.

This section describes the design steps of the automatic tissue dispenser prototype using the NodeMCU ESP8266 microcontroller. The design follows a systematic approach consisting of hardware integration, sensor-actuator coordination, and wireless data processing. The step-by-step design process is as follows:

1. Component Identification
   Selection of key components such as microcontrollers, sensors, actuators (LCD, motor, servo), and power supply based on the requirements of automation, responsiveness, and cost-effectiveness.
2. Circuit Design A schematic was created (see Figure 3) to visualize the interconnection of components, particularly the assignment of GPIO pins from the NodeMCU to input/output devices.
3. Pin Mapping and Wiring
   Each device is mapped to a specific GPIO pin (see Table 1), ensuring non-conflicting communication and logic-level compatibility.
4. Firmware Development
   Custom firmware was developed to handle input signals (from the motion and counter sensors), process logic, and activate actuators (servo motor for cutting, roller motor for movement, and LCD for display).
5. Testing and Evaluation
   The circuit and code were tested to ensure reliable performance in detecting motion, cutting tissue, and counting the dispensing events.

Additional components, such as an adapter and a reset button, are included in Figure 3. The adapter is used to convert electricity from a power source (e.g., household electricity or batteries) into the specific voltage required by the prototype. A 12V-DC adapter is connected to Pin 1. The reset button is used to reset the stock and is connected to Pin 22, along with other components connected to the ESP32 microcontroller (see Table 1).

When a user places their hand near the dispenser, the motion sensor quickly detects the presence and sends a signal to the ESP8266 microcontroller. In response to this signal,

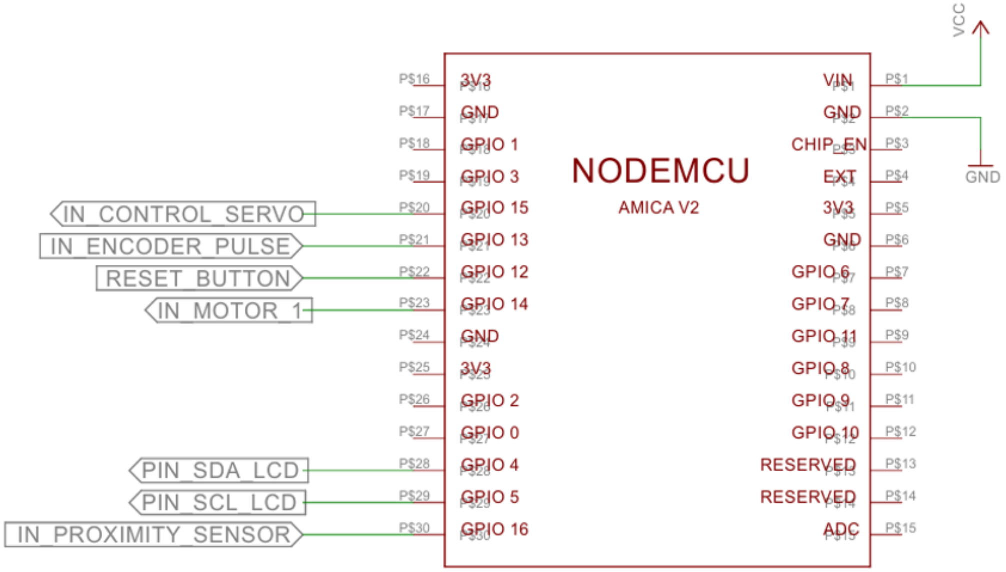


Figure 3: Component wiring diagram.

the microcontroller activates the roller mechanism, which smoothly advances the tissue forward. As the tissue moves, a counter sensor keeps track of how many sheets have been dispensed, continuously updating the count to ensure accuracy. Once the designated length of tissue is reached, the microcontroller triggers the servo cutter to precisely cut the tissue at the right point. Throughout this process, the LCD provides real-time information, showing details such as the current tissue count or remaining stock, and keeping the user informed. Additionally, if the tissue supply is running low or if the system needs to be reset for any reason, the reset button offers a simple way to restart the system. All of these components are powered reliably by a stable 12V DC adapter, ensuring consistent and uninterrupted operation.

2.4 Physical Design

Figure 4 illustrates the physical design used to test the prototype's functionality. All activation buttons are placed at the front for ease of testing. A cover is included to simplify tissue refilling. The components or parts are shown in Figure 4.

1. Box casing as the prototype container
   The box casing serves as the physical enclosure for the tissue dispenser prototype, typically made from durable plastic or lightweight metal. Sized around 30 cm by 20 cm by 15 cm, it provides sufficient space to accommodate all internal components while remaining portable. This casing offers structural support and protects the delicate electronic and mechanical parts inside. Designed for convenience, the casing panels are assembled using screws or clips, allowing easy access for maintenance,

Table 1: Main components and their specifications

No.	Main Component	Function	Pin	Justification
A	**Microcontroller**			
1	ESP8266	A microcontroller module used for IoT applications, automation, and data processing, with robust wireless connectivity features.	-	Provides wireless connectivity, GPIO flexibility, and integration ease.
B	**Sensors**			
1	Counter sensor	Count the number of events when the prototype dispenses tissue.	P21	Enables monitoring of usage events, critical for automation and logging.
2	Motion Sensor (infrared)	Detects movement within a range of 2–80 cm.	P30	Allows contactless detection to improve hygiene and automatic response.
C	**Activators**			
1	LCD 16×2	Displays information with a maximum of 2 rows and 16 characters per row.	P28 (SDA), P29 (SCL)	Provides user interface feedback and instructions.
2	Roller	Aids tissue movement.	P23	Essential for mechanical dispensing of tissue.
3	Servo cutter	Cuts tissue precisely based on microcontroller instructions.	P20	Ensures the correct length of tissue is cut per cycle.

repairs, or upgrades, while also ensuring a neat, compact, and user-friendly appearance.

2. Prototype controller
   At the heart of the prototype lies the ESP8266 microcontroller, a compact and energy-efficient unit operating at 3.3 volts. It manages inputs from sensors, controls actuators such as motors and servos, and handles communication with the user interface. The built-in Wi-Fi capability makes it suitable for potential remote monitoring or control. The microcontroller is securely mounted inside the casing on a PCB or breadboard and connected to other components through jumper wires or soldered connections, forming the control backbone of the dispenser.
3. 16×2 LCD display The 16×2 LCD provides a straightforward way for users to receive real-time feedback. It shows up to 16 characters on two lines, enabling a clear display of information such as the number of tissues dispensed, stock levels, or device status. Operating typically at 5 volts, this LCD is installed on the front panel behind a transparent window or cutout for easy visibility. It connects to the microcontroller via data pins, allowing contrast and backlight control for better readability under various lighting conditions.
4. Tissue roll

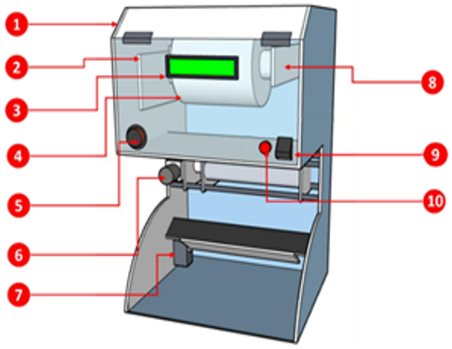


Figure 4: Physical design of the prototype.

The tissue roll used is a standard commercial size with an approximate diameter and width of 10 cm. It is the consumable part of the prototype, placed inside the casing on a spindle or holder that allows it to rotate freely. This setup enables the roller mechanism to pull the tissue smoothly during dispensing. Using a common tissue roll ensures that the dispenser is tested under realistic conditions that simulate everyday use.

5. Motion sensor
   To enable hygienic, touchless operation, an infrared (IR) proximity sensor is installed on the front exterior of the dispenser casing. This sensor detects the presence of a user's hand within an approximate range of 2 to 80 centimeters. Operating at 5V, it sends a trigger signal to activate the dispenser mechanism when motion is detected. This design eliminates the need for physical contact, thereby enhancing user convenience and reducing the risk of cross-contamination. The sensor is strategically positioned near the dispensing slot to ensure accurate and consistent detection during use.
6. Roller mechanism
   The roller mechanism consists of a DC motor coupled with rubber rollers or gears designed to grip and pull the tissue forward smoothly. It is powered at 12 volts, and the motor provides adequate torque to advance the tissue without tearing it. Installed inside the casing aligned with the tissue roll, the roller mechanism is controlled by the microcontroller via a motor driver, ensuring precise and consistent tissue feed during each dispensing cycle.
7. Servo cutter
   A small servo motor with a torque rating of approximately 10kg/cm operates the cutting blade attached to its arm. This servo cutter is mounted near the dispensing outlet, where it can move freely to slice the tissue cleanly once the set length has been dispensed. Operating at 5 volts and controlled by the microcontroller, the servo cutter automates the cutting process, improving user experience by providing a consistent tissue length and minimizing waste.
8. Tissue holder and clip for refilling
   The tissue holder and clip, made from plastic or metal, secure the tissue roll in place inside the casing. This component prevents unwanted roll movement during oper-

ation and simplifies the refilling process. Positioned near the roller mechanism and easily accessible when the casing cover is opened, it enables quick and convenient replacement of empty tissue rolls, supporting uninterrupted dispenser functionality.

9. On/off switch
   A toggle or push-button switch rated for the device's voltage (0-250 V DC/AC) is installed for manual power control. Located on the front or side panel for easy user access, this switch enables safe turning on or off of the dispenser. It is wired in series with the power supply, ensuring that the entire device can be completely powered down when not in use, helping to conserve energy and extend component life.
10. Reset button
    The reset button is a momentary push-button switch connected directly to the microcontroller's reset pin. Positioned on the front panel, it allows users or testers to quickly reset the system without unplugging the device. Pressing this button restarts the microcontroller, clearing counters or recovering from errors, which is useful for maintenance, troubleshooting, or initializing the dispenser after refilling.

2.5 Experimental Setup

To evaluate the performance and stability of the automatic tissue dispenser prototype, tests were conducted based on five distinct scenarios that simulate real-world operating conditions. These scenarios are described as follows:

1. Scenario 1 – Motion Detection
   This scenario tested the sensor's ability to detect hand movement within a range of 2 to 80 cm under both normal and brightly lit environments. The goal was to observe how accurately the proximity sensor responded to motion and how external lighting conditions affected its reliability.
2. Scenario 2 – Data Update Accuracy
   This test assessed whether the system correctly updated the tissue stock count each time tissue was dispensed and motion was detected. The updates were monitored on both the LCD screen and the monitoring application to evaluate synchronization between the hardware and software.
3. Scenario 3 – Startup Stability & Reset Functionality
   This scenario evaluated the system's stability upon initial activation and after using the reset button. The test ensured that the system could operate correctly from startup and recover properly even after intentional misuse or disruption.
4. Scenario 4 – Response
   The prototype's behavior was tested against different timing conditions, such as very brief or extended hand movements. This scenario aimed to verify how well the system handled edge-case inputs and whether the motion detection algorithm responded appropriately to variations. This scenario examined the system response when tissue stock fell below a predefined minimum threshold. The objective was to ensure the system could notify users appropriately and maintain stable behavior despite low stock conditions.

3 Results

The prototype design was tested in four distinct scenarios to comprehensively evaluate its overall functionality, responsiveness, and reliability. In Figure 5b, tissue is inserted in the front part of the prototype. In general, the results of the test scenario can be said to have nearly achieved 100% success. In the first scenario, the focus was on the accuracy of motion detection. The prototype demonstrated the ability to detect hand movement in a range of 2 to 80 cm, successfully triggering the dispensing mechanism. However, during testing in brightly lit environments, particularly those with direct sunlight or strong artificial lighting, the proximity sensor occasionally misinterpreted intense light as movement. This highlighted a potential limitation of the sensor in high-luminance conditions, which may need to be addressed through sensor calibration or shielding in future iterations. The motion sensor was tested by placing a hand at 10 cm intervals from 2 cm to 80 cm. For each distance, five tests were conducted to verify whether the sensor accurately triggered tissue dispensing and data transmission to the application. Successful detection was recorded when the motor tissue was administered and the stock count was updated on both the LCD and the application.

The second scenario evaluated the system's ability to update and display the stock count of tissue rolls. Every time motion was detected and tissue was dispensed, the system accurately reduced the stock count, which was then consistently reflected on both the onboard 16×2 LCD and the external monitoring application (see Figure 5a). This consistency ensured that users and administrators could reliably track tissue usage in real-time.

Hallo, Tommy Jones!

Tissue IoT Advanced
Real-time Management

Area 1: 233 Sheet, Last Update 16-34-20|15-01-2025
Area 2: 231 Sheet, Last Update 16-34-33|15-01-2025
Area 3: 0 Sheet, Last Update 00:00:00 00-00-0000
Area 4: 0 Sheet, Last Update 00:00:00 00-00-0000

(a) front view (b) side view (open condition) (c) application display

Figure 5: Physical prototype.

In the third scenario, the prototype's performance during system startup and under abnormal usage conditions was assessed. The device consistently initialized without error, and the LCD immediately synchronized with the application to show the correct stock count (see Figure 5c). Furthermore, tests involving intentional misuse, such as rapid or repeated activation attempts, did not disrupt the system's functionality. This resilience was attributed to the inclusion of a reset button, which allowed the system to recover quickly from abnormal states and resume normal operation. Finally, the fourth scenario tested the response of the system algorithm to varying inputs and operational limits. The device accurately processed motion inputs regardless of whether the hand was present briefly or for an extended period. In addition, the system responded correctly when the tissue stock reached or fell below a minimum threshold, ensuring that appropriate warnings or operational adjustments were made. These results confirmed that the prototype was capable of handling edge cases and critical conditions while maintaining stable functionality.

To strengthen the evaluation results, several quantitative measurements were performed during testing. In Scenario 1, the proximity sensor demonstrated a motion detection success rate of 95%, with accurate activation in 19 of 20 trials in the range of 2 to 80 cm. The average response time from motion detection to tissue dispensing was measured at approximately 1 second. In Scenario 2, the synchronization between the hardware and the monitoring application was tested on 10 dispensing events, where the stock count update was consistently successful and reflected with a time lag of less than 1.5 seconds. Scenario 3 tested system robustness through 10 deliberate misuse attempts involving rapid repeated inputs. In each case, the system was restored correctly using the reset function, indicating strong stability under abnormal conditions.

In addition, specific tests were performed to assess the performance of the IoT system and sensors. The infrared motion sensor showed a deviation of approximately ±2 cm when compared to manual distance measurements, indicating acceptable precision for its intended range. However, under direct and intense lighting, such as from LED or sunlight, 2 out of 10 trials resulted in false positive motion detections, highlighting the sensor's sensitivity to environmental brightness. Regarding IoT performance, data communication between the hardware and the application achieved a 100% success rate during the 30 dispensing cycles tested. These results confirm that IoT integration and sensor functions are reliable and responsive under typical usage conditions.

4 Discussion

The prototype was comprehensively evaluated in five experimental scenarios, demonstrating its functionality, stability, and responsiveness. Compared to previous studies, such as the touch-free tissue dispenser developed by Zaki et al. [27], which used an Arduino UNO and an infrared sensor to detect the presence of the hand and activate a stepper motor, this study presents a more advanced implementation. Our prototype integrates real-time stock monitoring through the ESP8266 microcontroller, which offers built-in Wi-Fi and low-power operation, along with an LCD interface and automated tissue-cutting mechanism. These features significantly improve usability and system intelligence, allowing both users and administrators to monitor and manage usage remotely.

Similarly, the Intelligent Tissue Dispenser System (ITDS) introduced by Man et al. [28] aimed to improve user sustainability through IoT and big data integration. However, their system focused primarily on software-based solutions and did not address physical mechanical functions such as automated cutting or resilience to operational anomalies. In contrast, our prototype not only dispenses tissue in response to detected motion but also successfully handles edge-case scenarios, such as inconsistent hand movements and low-stock alerts, while maintaining system integrity. This robustness supports real-world deployment in high-traffic environments where reliability is crucial.

A recurring limitation observed in earlier works [27], [28] is the reliance on infrared-based sensors, which are known to be vulnerable to interference under intense ambient lighting. Our findings reaffirm this issue, as false motion detections were recorded in brightly lit conditions. This limitation highlights the need for future system enhancements through the adoption of more reliable sensing technologies, such as ultrasonic or Time-of-Flight (ToF) sensors, which are less susceptible to light-induced inaccuracies.

The novelty of our design lies in its holistic approach, integrating real-time IoT monitoring, an intuitive user interface, and a high-torque (10 kg·cm) servo motor for precise cutting. In addition, the system includes a reset button that ensures recovery from operational errors or misuse, features not commonly addressed in similar dispenser systems. These advances contribute to a more efficient, hygienic, and maintainable solution to the public hygiene infrastructure. Future work should focus on evaluating the performance of the system in long-term field applications and exploring improvements in energy efficiency and sensor adaptability.

5 Conclusion

This prototype is intended for indoor use. Based on the results of functional testing, almost all scenarios were successfully implemented with a motion detection precision of 95%, while IoT performance and data communication between hardware and applications reached 100%. However, further trials are needed with radar-based motion sensors, similar to those used in vehicles, for more accurate movement detection. The use of infrared motion sensors is prone to external light interference, such as sunlight or strong artificial light, which leads to detection errors and reduced accuracy. Future trials could use ultrasonic sensors for higher accuracy and outdoor applications.

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