Portable IoT Pill Dispenser with Insulin Cooling and Blood Sugar Monitoring

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Abstract: This study presents a compact, IoT-based medication dispenser that integrates insulin cooling and real-time blood sugar monitoring. The system achieved 100% accuracy, recall, precision, and F1-score in detecting and sorting Metformin, Gliclazide, and Dapagliflozin using the YOLOv8 model. Detection occurred within 6–7 seconds, with Gliclazide sorted fastest. Dispensing trials (10 per drug) confirmed a 100% PASS rate with no misdispenses. Although the dispensing time was near-instantaneous, scheduled dispensing showed delays of 13–30 seconds, yielding a 42.86% on-time rate, still acceptable for clinical use. The cooling system reliably reduced internal temperatures from 25 °C to 2 °C within 30 minutes, reactivating automatically above 8 °C. The device, enclosed in a 40 cm × 11 cm × 28 cm acrylic case, supports user access and monitoring via a smartwatch and web portal. These results validate the system's accuracy, responsiveness, and suitability for automated medication management in both home and healthcare environments.

Keywords: *Insulin Cooling System, IoT-based Medication Dispenser, Object Detection, Real-Time Monitoring*

1. Introduction

Diabetes is increasingly affecting adults in their 30s due to sedentary lifestyles, poor diets, stress, and genetic predisposition. Although the elderly remain highly vulnerable, younger adults are now similarly at risk, often struggling with consistent disease management. One of the major challenges in treatment is poor medication adherence, which contributes to serious complications. To address this, innovative solutions—such as smart medication dispensers originally developed for older adults—are now being adapted for broader use. These devices offer features like reminders, dosage control, and remote monitoring to support improved adherence.

Globally, the impact of diabetes is growing. In 2014, 8.5% of adults aged 18 and above had diabetes. By 2019, it accounted for 1.5 million deaths, with nearly half occurring before age 70. Additionally, 460,000 deaths from kidney disease were linked to diabetes, and the mortality rate increased by 13% in lower-middle-income countries between 2000 and 2019 [1]. By 2045, an estimated 783 million adults—approximately 1 in 8—are expected to be affected, reflecting a 46% increase from current figures [2]. In the Philippines, a 2012 DiabCare study found that 78.5% of Type 2 diabetic patients were using oral antidiabetic drugs, and 42% were taking insulin [3]. The COVID-19 pandemic further complicated diabetes management, highlighting the urgent need for accessible, contactless, and real-time healthcare solutions [4].

2. Motivation and Objective

Technological advancements such as smart pills and IoT-integrated dispensers are transforming diabetes care by enabling remote monitoring, tailored regimens, and active caregiver involvement [5]. Existing studies have introduced smart pillboxes equipped with alarms, blood oxygen sensors, automated dispensing, and compatibility with various tablet types [6]. However, gaps remain in system integration, cost-effectiveness, personalization, and user experience.

This study proposes the development of an IoT-based portable medication dispenser with an insulin cooling system and real-time blood sugar monitoring. It aims to improve diabetes management and medication adherence across all age groups, with special attention to the needs of the elderly and their caregivers. Specifically, the system is designed to: (1) classify and sort medications using YOLOv8 object detection; (2) dispense medication based on prescribed dosage and schedule; (3) provide a compact, hand-carry-sized design; and (4) integrate with a website for glucose and medication tracking, accessible to both patients and healthcare providers.

3. Statement of Contribution

The device addresses key challenges in diabetes care, including inadequate insulin storage, lack of caregiver oversight, and poor adherence. It supports real-time monitoring via a dedicated website and applies machine learning for efficient data analysis, assisting healthcare providers in timely decision-making. Targeted at Type 2 diabetic patients, the device is optimized for single-patient home use, ensuring personalized treatment and data security. It emphasizes ease of use, especially for individuals aged 45 and above, and offers caregivers real-time access to health data. Currently, the system is limited to detecting and sorting commonly prescribed diabetic medications—insulin, metformin (Diamet), gliclazide (Diamir), and dapagliflozin (Forxiga)—with a storage capacity of 15 pills per type. Although the device specializes for diabetes care, its object detection function is not yet configured for broader medical applications.

4. Review of Related Literature

A. Diabetes Medication and Patient Challenges

Diabetes management requires precise medication handling, especially with varying insulin types and oral antidiabetic drugs like Metformin and Gliclazide, each with distinct mechanisms and timing requirements [7]. Improper administration or storage of these medications can lead to poor glycemic control and serious health complications. Manual routines are prone to human error, particularly among the elderly and individuals with cognitive limitations, which often results in missed doses or overdoses [8]. In addition, access to proper storage like refrigeration is limited in rural areas, risking the effectiveness of insulin-based treatments [9].

B. Role of IoT in Automated Medication Systems

Innovations on the Internet of Things (IoT) have significantly improved healthcare, especially in medication adherence and remote monitoring [10]. Smart pill dispensers embedded with IoT systems can automate drug schedules and transmit real-time updates to caregivers or medical professionals. These systems improve patient compliance by offering app-based notifications, cloud-stored logs, and SMS alerts, which are essential in supporting aging populations or patients in home-based settings [11].

C. YOLOv8 Detection

Object detection algorithms such as YOLOv8 are being used to automate pill identification and sorting due to their high accuracy and fast inference time. These computer vision systems are ideal for classifying visually similar tablets, ensuring the correct medication is dispensed [12].

D. Insulin Cooling System

For temperature-sensitive drugs like insulin, thermoelectric cooling using the Peltier effect offers a compact and efficient method of maintaining internal temperatures between 2 °C and 8 °C [13]. These combined technologies—smart sorting, real-time monitoring, and active cooling—form an integrated approach to improve safety, reliability, and accessibility in diabetic medication delivery, especially in remote or underserved locations.

E. Synthesis

Managing diabetes requires accurate, timely medication intake, particularly for insulin, which must be properly stored to remain effective. Traditional medication management methods are prone to errors and lack real-time monitoring, leading to poor adherence and increased risk of complications. IoT-based smart dispensers address these challenges by providing remote monitoring, personalized reminders, and automated dispensing. Technologies like YOLOv8 enable accurate medication classification, while thermoelectric cooling systems preserve insulin even without refrigeration access. These innovations are particularly helpful for elderly patients or those with memory impairments. Despite these advancements, key research gaps remain in personalization, integration of lifestyle factors, accessibility, and long-term safety. Future systems must consider individual needs, offer behavioral support, and deliver educational content while remaining affordable and easy to use. With interdisciplinary collaboration, smart medication dispensers can evolve into comprehensive tools that support medication adherence and holistic diabetes management, making quality healthcare more accessible and effective for diverse patient populations.

5. Methodology

A. Conceptual Framework

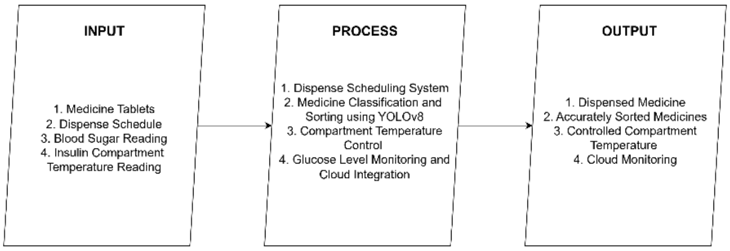

Figure 3.1. Conceptual Framework

The conceptual framework consists of three major components: Input, Process, and Output. Inputs include medication types, prescribed schedules, user authentication, and glucose readings. The process phase utilizes YOLOv8 for pill classification, thermoelectric cooling for insulin, and automated dispensing mechanisms. The output ensures precise medication delivery, remote glucose data tracking, and alerts for adherence.

B. System Process Flowchart

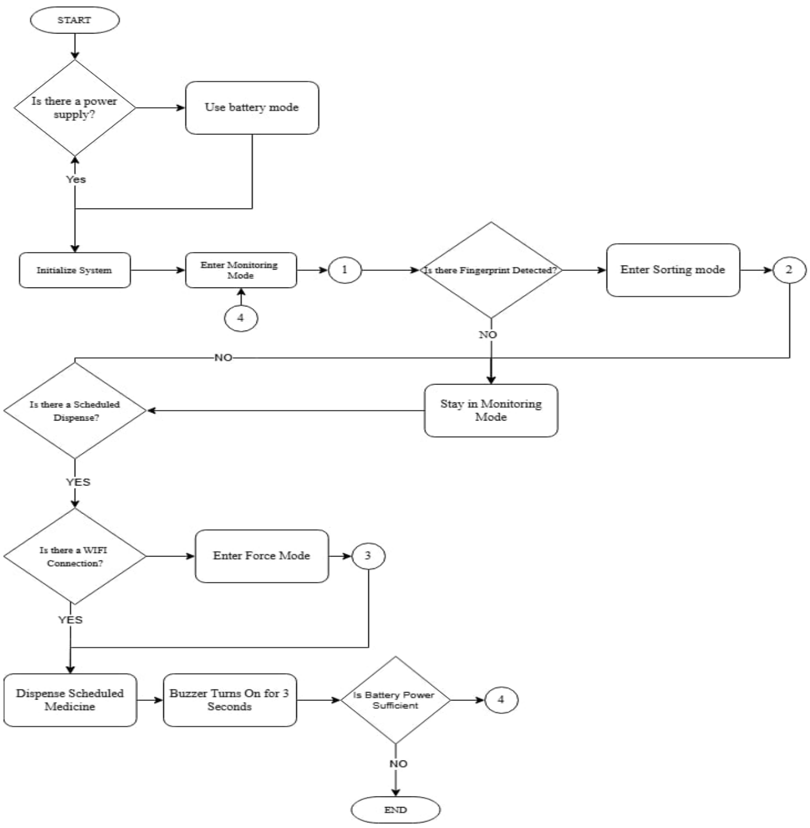

Figure 3.2. Whole System Process Flow Chart

System begins by verifying power availability, defaulting to battery mode, if necessary, then enters a monitoring phase. Upon detecting a fingerprint, it transitions to sorting mode, where medications are identified and categorized using YOLOv8 object detection. Without fingerprint input, the system continues monitoring for scheduled dispensing. If dispensing is due and Wi-Fi is available, it proceeds with the operation and activates an alert buzzer; otherwise, it enters Force Mode for manual control. Monitoring Mode manages blood glucose tracking, data syncing, and schedule updates. Sorting Mode handles pill classification, while Force Mode enables manual overrides. A web portal supports scheduling, and a Peltier cooling system maintains insulin at 2–8°C by toggling power based on temperature. All sub-processes return to the main loop, ensuring seamless automation, real-time adaptability, and continuous, efficient medication management.

C. System Design

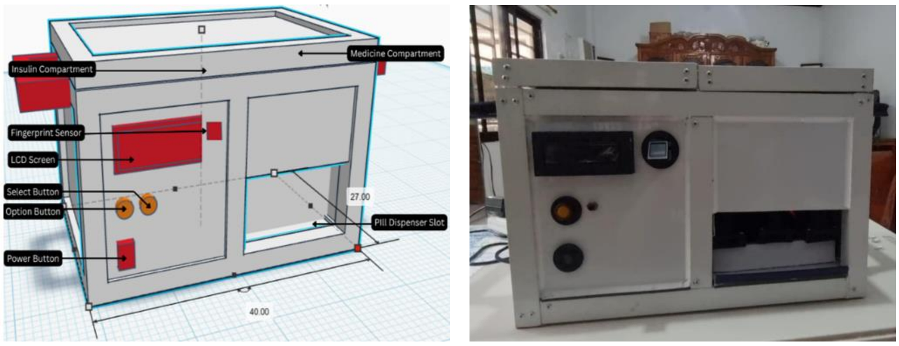

Figure 3.5. 3D Model vs Actual Model

Figure 3.3. shows the design and actual prototype of an automated pill-dispensing machine. The left image presents a 3D model with labeled components while the right image displays the fully assembled prototype, which accurately reflects the digital design. All key features are present, confirming a successful translation from concept to working device used for testing and evaluation.

D. Experimental Set-Up

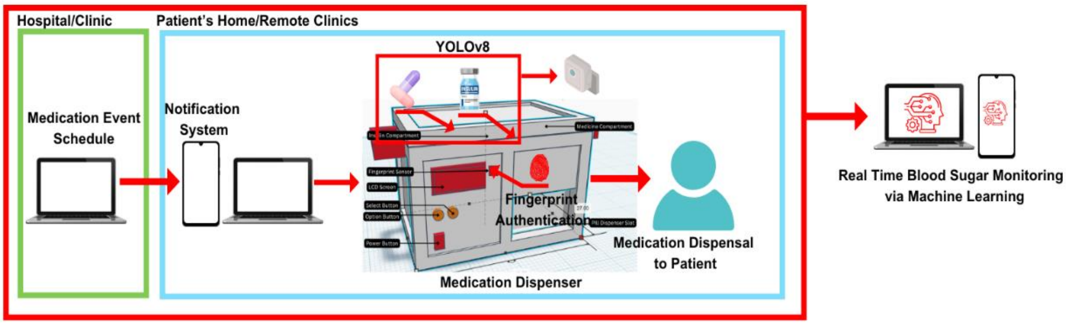

Figure 3.4. Overall Set-Up

The figure shows the workflow of an automated medication dispensing and monitoring system for diabetic patients. Healthcare providers create a medication schedule via a secure web platform, which notifies users of upcoming doses. At home or in remote clinics, authorized personnel access the dispenser using fingerprint authentication. YOLOv8 identifies and verifies medications before automatic dispensing. The system then performs real-time blood sugar monitoring using connected devices. All data is accessible through the web platform, enabling both users and healthcare providers to track medication adherence and health status, offering a secure and efficient solution for diabetes management.

E. Graphical User Interface (GUI)

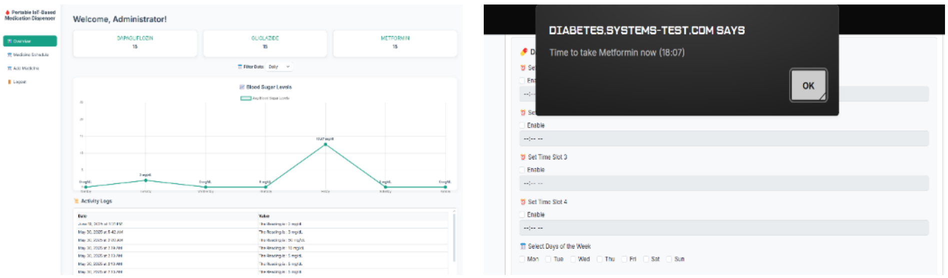

Figure 3.5. Website GUI

Figure shows the system's user interface, which features key sections such as Overview, Medicine Schedule, Add Medicine, and Logout, accessible via a sidebar. The Overview provides a summary of stored medications, blood sugar trends (daily, weekly, or monthly), and activity logs of glucose tests for easy monitoring. The Medicine Schedule tab enables configuration of up to four daily time slots per medication, specifying active days and recording the scheduling caregiver's name and remarks. Once a pill is sorted into its cartridge, the system automatically updates the inventory on the website, either adding or removing the corresponding medicine. The activity log tracks all scheduled and dispensed events. Additionally, a notification bar alerts users two minutes before each dispensing event to ensure readiness and compliance. This centralized interface supports both monitoring and management, promoting efficient medication adherence and real-time tracking for diabetic care.

F. Validation

Table 3.1. Universal Validation Criteria for System Performance

Outcome	**Definition**
True Positive (TP)	The system correctly identifies and accepts a valid input (e.g., authorized fingerprint, correct medication, or valid classification).
True Negative (TN)	The system correctly identifies and rejects an invalid input (e.g., unauthorized user, wrong medication, or incorrect classification).
False Positive (FP)	The system incorrectly accepts an invalid input (e.g., unauthorized user granted access, or wrong medication accepted as correct).
False Negative (FN)	The system incorrectly rejects a valid input (e.g., authorized user denied access, or correct medication rejected as incorrect).

To ensure consistency across all components of the automated medication dispensing system—including fingerprint authentication, pill sorting, dispensing, and medicine identification—a universal validation framework was established. Table 3.1 outlines the standard definitions of true positive (TP), true negative (TN), false positive (FP), and false negative (FN), which are used to evaluate system performance. This unified approach simplifies analysis, enhances comparability across subsystems, and supports reliable calculation of metrics such as accuracy, precision, and recall.

The following equations are used to evaluate the system's

performance in identifying, sorting, and dispensing medications:

$$\text{Percent Error} = \left| \frac{V_a - V_e}{V_e} \right| \quad \text{(Eq. 1)}$$

$$A = \frac{TP+TN}{TP+TN+FP+FN} \times 100\% \quad \text{(Eq. 2)}$$

$$R = \frac{TP}{TP+FN} \quad \text{(Eq. 3)}$$

$$P = \frac{TP}{TP+FP}$$

(Eq. 4)

$$HN = \frac{P \times R}{P+R}$$

(Eq.5)

$$Rate\ (\%) = \left(\frac{Count\ of\ Events\ Matching\ Condition}{Total\ Doses}\right) \times 100$$

(Eq. 6)

6. Results and Discussion

A. YOLOv8 Model Evaluation

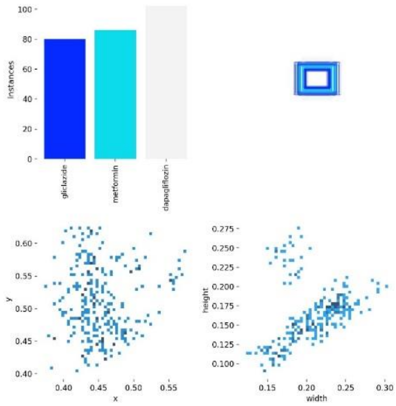

Figure 4.1. Validation Dataset Label Distribution

The figure illustrates the label distribution and spatial characteristics of the validation dataset. The bar chart shows a balanced number of instances per class: approximately 80 for gliclazide, 86 for metformin, and 102 for dapagliflozin. Bounding box plots indicate consistently sized and centered objects across classes. A scatter plot of bounding box centers reveals clustering near the image center, confirming centralized object placement. Another scatter plot shows most objects have similar dimensions, with widths around 0.2 and heights near 0.15. Overall, the dataset is well-structured, with balanced class representation, consistent object size, and stable positioning.

Table 4.1. Model Performance Results Summary

Class	Images	Instances	Box(P)	R	mAP50	mAP50-95
all	268	268	0.999	1.0	0.995	0.919
gliclazide	80	80	0.999	1.0	0.995	0.905
metformin	86	86	0.999	1.0	0.995	0.936
dapagliflozin	102	102	1.0	1.0	0.995	0.916

The table summarizes the validation results of the object detection model across three drug classes: gliclazide, metformin, and dapagliflozin, as well as the overall performance. A total of 268 images containing 268 object instances were evaluated. The model achieved a precision (Box(P)) of **99.9% to 100%** across all classes, indicating that almost all positive predictions were correct, with minimal false positives. The recall (R) was also 100% for all classes, meaning the model successfully detected every object instance. In terms of accuracy, the mAP50 score — which measures detection accuracy at a 50% IoU threshold — was consistently high at **99.5%** for all classes. The stricter mAP50-95 score, which evaluates performance across multiple IoU thresholds, ranged from 90.5% to 93.6%, depending on the class. These results demonstrate that the model performs with extremely high precision (99.9%–100%) and high accuracy (mAP50 of 99.5%, mAP50-95 between 90.5% and 93.6%), confirming its strong ability to correctly detect and localize objects on the validation dataset.

B. System Performance

Table 4.1. Sorting and Dispensing Metrics

Total Sorting Performance	
Accuracy	100.00%
Recall	1
Precision	1
F1-Score	1
Total Dispensing Performance	
Accuracy	100.00%
Recall	1
Precision	1
F1-Score	1

The system's sorting performance was evaluated using three medications: Gliclazide, Metformin, and Dapagliflozin, with each undergoing ten trials. For Gliclazide, the system consistently identified and sorted tablets into the correct bin (BIN A), achieving a *100% true positive (TP) rate*. Detection times ranged from 6.34 to 7.55 seconds, with an average of 6.927 seconds, while sorting times ranged from 1.40 to 2.05 seconds, averaging at 1.725 seconds. Metformin tablets were correctly sorted into BIN B in all trials, also yielding a 100% TP rate. It had the fastest average detection time of 6.578 seconds and the highest average sorting time of 2.676 seconds. For Dapagliflozin, all tablets were correctly directed to BIN C, achieving a perfect TP record. Its detection times ranged from 6.68 to 7.76 seconds (average: 7.104 seconds), and sorting times ranged from 1.85 to 3.12 seconds (average: 2.437 seconds). The slight variations in sorting time among the medications may be attributed to their physical characteristics, such as size, weight, or surface texture.

Overall, the system demonstrated flawless sorting accuracy across all trials, achieving a perfect score in all key performance metrics: 100% accuracy, 1.0 recall, 1.0 precision, and an F1-score of 1.0. This indicates that no tablets were misidentified or misclassified, and all were correctly assigned to their respective bins. Such consistent performance confirms the system's ability to handle automated sorting tasks with high precision and efficiency.

In terms of dispensing performance, the system was tested with the same three medications over ten trials each. In every instance, the correct drug was dispensed, resulting in a 100% true positive rate for all medications. No mismatches or errors occurred during dispensing, validating the system's reliability in delivering the expected output. Although specific time metrics for dispensing were not recorded—due to the rapid and instantaneous nature of the dispensing action, additional unrecorded tests were conducted to verify continued accuracy and consistency. These supplementary tests further reinforced the system's capacity to perform without mis-dispensing any tablets.

Hence, the system accurately identified, sorted, and dispensed all medications without a single error, making it highly suitable for automated applications in clinical or pharmacy settings where accuracy and efficiency are paramount to patient safety and operational effectiveness.

Table 4.2. Automatic Dispensing Performance

Patient	**Medication**	**Scheduled Time**	**Actual Dispense Time**	**Delay (sec)**	**Status**
1	Metformin	8:00:00 AM	8:00:26	26	Delayed
	Dapagliflozin	8:01:00 AM	8:00:21 AM	21	Delayed
	Metformin	7:00:00 PM	7:00:13	13	On Time
2	Gliclazide	7:30:00 AM	7:30:24 AM	24	Delayed
	Metformin	7:31:00 AM	7:31:18	18	On Time
	Metformin	12:00:00 PM	12:00:30 PM	30	Delayed
	Metformin	6:30:00 PM	6:30:14 PM	14	On Time
On Time Rate		42.86%			
Delayed Rate		57.14%			

Out of 7 scheduled doses, 3 were dispensed exactly on time, while 4 experienced minimal delays of just over 20 seconds. This results in a 42.86% on-time dispensing rate. Despite some delays, all medications were delivered within a short window, well under one minute, which remains acceptable for real-time patient use. These slight variations do not compromise therapeutic effectiveness and demonstrate that the prototype is capable of reliable and timely dispensing, with room for minor enhancements to improve precision. However, it also suggests that while the system performs well overall, some optimization may be beneficial to meet stricter real-time dispensing standards.

Table 4.3. Cooling System

Test No.	Time	Final Temperature	Cooling Status Change	Remarks
1	0	25	OFF-ON	Cooling activates above 8°C
2	10	15	ON	Midway to Target
3	15	8	ON	Desired minimum cold temperature reached
4	20	4.5	ON	Still cooling
5	25	2.1	ON	Borderline Temperature
6	30	2	ON-OFF	Cooling stops at 2°C
7	80	8.1	OFF-ON	Cooling reactivates

The cooling system activates at 25 °C, above the 8 °C threshold, and cools steadily to reach 8 °C by 15 minutes. Cooling continues to 2 °C by 30 minutes, triggering automatic deactivation. As the temperature rises, the system reactivates at 8.1 °C by 80 minutes. This confirms the system reliably activates above 8 °C, cools to 2 °C within 25–30 minutes, and cycles OFF and ON based on set temperature thresholds.\

Table 4.4. Battery System

Test No.	Power Status	Cooling	Elapsed Time (min)	Result
1	OFF	OFF	30	Still running
2	OFF	OFF	114	Shut down
3	OFF	ON	30	Still running
4	OFF	ON	63	Shut down
5	OFF	ON-OFF	30 (20 ON + 10 OFF)	Mixed Usage Running
6	OFF	OFF-ON	86 (53 OFF + 33 ON)	Shutdown
7	OFF	ANY	ANY	Battery not Used

Battery performance was tested under various conditions. Without cooling, the system runs for up to 2 hours, shutting down at 120 minutes. With cooling on, it lasts 63 minutes, aligning with the expected 1-hour limit under load. In mixed use (e.g., 20 minutes cooling + 10 minutes off), the system remains operational at 30 minutes, showing partial cooling conserves power. However, in a longer mixed scenario (53 minutes off + 33 minutes cooling), shutdown occurs at 86 minutes, indicating cumulative energy use exceeds capacity. When main power is available, the battery remains idle, confirming correct power source prioritization.

Table 4.5. MOS Table for User-Experience

Category	Average Rating (MOS)	Interpretation
Pillbox User-Friendliness	4.4	Good
Mobile App User-Friendliness	4.4	Good
Pillbox Overall Design	4.5	Excellent
Medicine Recognition Responsiveness	4.3	Good
Medication Dispensing Convenience	4.5	Excellent
Usefulness of Key Features	4.3	Good
Overall Satisfaction (Pillbox & Site)	4.6	Excellent

A user satisfaction survey involving 10 participants evaluated the prototype's usability across various aspects, including the pillbox, website portal, and core features. Ratings were collected on a 1–5 scale and analyzed using the Mean Opinion Score (MOS). Results showed consistently high satisfaction, with MOS values ranging from 4.3 to 4.6. The highest rating (4.6, "Excellent") was for overall satisfaction with the pillbox and website, while design and dispensing convenience followed closely at 4.5. User-friendliness, responsiveness, and feature usefulness scored between 4.3 and 4.4, all classified as "Good." Additionally, 90% of respondents found the system useful beyond diabetes care. Overall, the survey confirmed the prototype's strong usability, responsiveness, and potential applicability to broader health management.

7. Conclusion

This study demonstrates the potential of an IoT-based portable medication dispenser with insulin cooling and real-time glucose monitoring as a practical solution for diabetes management. By integrating object detection, automated dispensing, temperature control, and health tracking, the system improves medication adherence and supports remote care, particularly for elderly or mobility-limited users.

To enhance its functionality, future work should focus on expanding the object detection model to recognize a wider range of medications, improving the dispensing mechanism for simultaneous delivery, and increasing the cooling chamber's capacity. Extending battery life and integrating OCR for label verification are also recommended to improve safety and portability. Incorporating multiple dispensing slots would further support patients with complex treatment plans, allowing the system to adapt to broader healthcare applications beyond diabetes.

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