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Low-Cost Smart Insulin Box: A Portable and Interactive System for Enhanced Diabetes Management

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ABSTRACT

Diabetes is one of the most common life-threatening diseases in the world. The accurate amount, and on-time injection will directly affect the patient's health. The current standard of care for insulin-dependent diabetes management is paper based, so the patients provided with self-management support through health coaches which consumes time and effort. Smart insulin box as proposed meets the needs of the market by integrating electronic technology and IoT network functionality. The interactive box comprises a particular device with embedded sensors in each compartment. Two Infrared and one DHT11 sensors are used. IR sensors are used for detecting the absence or availability of the insulin pen inside the box. While, DHT11 sensor is used for measuring the internal temperature and humidity of the package. The interactive box not only transmits patient status messages to the cloud but also receives a reminder message to patient mobile phone presented by LCD screen. The system manages the insulin injection process and provides a remote monitoring system for doctors using two individual applications. Doctor application provides remote monitoring and controlling for insulin amount and injection time while patient application used to notify patients about injection time, status, and insulin stock status. The system is laboratory tested and evaluated by the authors. The low cost at 84 USD shows promising results. It has a potential impact on patient health outcomes as a smart, low cost, and interactive management system for the insulin injection process which can be integrated with the existing healthcare systems.

1. INTRODUCTION

The medical advices that are followed well by a patient is referred to a medication adherence which is crucial for the treatment to be effective. This is important for long-term illnesses. Good adherence could give indication of following the healthy habits and eventually reducing the chances of death [1]. A patient who is non-adherent has a persistent problem that undermines treatment benefits and increases healthcare costs [2-4]. In 2003 WHO (World Health Organization) reported on medication adherence ,and it is stated that approximately50% of patients with chronic illnesses do not take medications as prescribed [3]. Real-time and accurate execution of a doctor's advice relates to the patient's health problems .If one goes wrong ,it will result in the failure of the patient's recovery and may even lead to medical accidents [5].
As a result ,the researcher helps the patient follow doctors' instructions and provides direct doctor monitoring for the patient .Some researchers have developed a health monitoring service for monitoring the health condition of a patient [6-8].
Workneh et al. work on Cloud Based Health Care Services using the cloud which offers more powerful enhancement to healthcare [9]. Karageorgos et al. shows the Promise of Mobile Technologies for the Healthcare System. It allows continuous monitoring at any place [10]. Anna Tee, proposed an integrated solution for managing health remotely ,using mobile devices [11]. IoT systems enter this field where Monteiro et al. developed an e-Health System based on IoT, Fog, and Cloud Computing [12, 13]. Diabetic patients require exceptional care when they need to take insulin during their life. Lutz has made a literature review of available smart insulin pens to evaluate their clinical benefits [14]. Tejaswi and his colleague have discussed digital transformation and a connected diabetes care ecosystem [15]. Bai and Kuo proposed a design of a medication reminder machine [16]. An expert system has been created by Prajoona and his coworker to treat diabetes patients remotely [17]. In addition ,O . Alfandi ,proposed a wireless ,non-invasive solution using NIR technology to monitor blood glucose levels in diabetic patients .It uses Machine Learning Algorithms to forecast future critical circumstances ,send SMS notifications ,and provide geospatial without the use of any cloud services such as data storage or database management [18]. An intelligent algorithm was used in the suggested architecture to find threshold exceedance in various parameters .The design detects blood glucose levels and body temperature on the go . Since a portable gadget was developed with a safe wireless connection to cell phones [19].

Based on what was mentioned before ,this paper proposes an IoT-based system for diabetic patients. The proposed IoT system can improve medication adherence among diabetic patients through the smart notification system for the patient and the doctor who is responsible for following this patient. The system connects the patient and doctor to the cloud and allows the doctor to monitor and control the therapy plan. On the other hand, the patient is provided with a notification system to remind about injection time, insulin stock, and insulin temperature. Compatibility, availability, sustainability, affordability, and reusability are the main challenges for the proposed system which are missing in most papers in the previous work.

The system notifies patients about injection time, status, and insulin stock. In addition to the remote monitoring and controlling for insulin amount and injection time by the doctor. The rest of the paper is organized as follows: Section 2 : Explains hardware design. Sectio 3: Discuss the software design, while Sections 4: presents the system architecture design. Ening with Section 5 and 6 which presents the result and conclusions sequentially.

2. HARDWARE DESIGN

The proposed system consists of particle photons, sensors, OLED Display, and electronic components. The existence of particle photons which work as the brain for the system assesses the design with the ability to analyze sensor data in real-time pattern; communicate to servers and perform algorithms on-site. Particle combines a powerful ARM Cortex M3 microcontroller (1MB flash, 128KB RAM) with a Broadcom Wi-Fi chip 802.11b/g/n and 18 Mixed-signal GPIO. Sensors in the system are gathering data to be analyzed later for further enhancements. In addition, Two IR (Infrared) sensors with one DHT11 sensor were used in the system. IR sensors are transceivers which means that each sensor can work as a transmitter or/and a receiver. The IR signal is invisible with wavelength (700nm-1mm) and emitting angle of approx. 20-60 degrees. These sensors would be performed as a detector in the proposed system to detect the state of the pen's absence or availability of the insulin pen in the package. They align side by side together as shown in Figure 1.

While the DHT11 sensor is used to measure the package temperature and humidity. the sensor is specified with a measurement range: 20-90% RH and 0-50℃. Also, Humidity Accuracy ±5％RH, Temperature Accuracy ±2℃ and 8 Bit resolution. It is allocated inside the package. The OLED display (The OLED is a mono color, 0.96-inch display with 128×64 pixels) notifies users about the current state and helps them to learn what to do in each operation. Electronic components like LEDs are used as indicators to simplify the use of the packaging for ordinary people. The proposed design components are arranged in 'up' and 'down' layers to manage the box space. The design for the system up layer is shown in Figure 2(a). Inside the package, particle photon, DHT11, and battery were put together in the down layer as shown in Figure 2(b).

The design protects the internal components by using a two-layer box and a rubber material in the outside corners to protect the box from damaging the components of our prototype. In addition, the box used a lithium battery charged by an external 5 volts DC power supply. The system's power supply has been measured to prove stability during the use with no overheating or fluctuations issues.

The hardware schematic diagram of our proposed system, as shown in Figure 3, shows two IR transmitter and receiver sensors which were connected to particle photons using one digital pin for each sensor to determine the state of the pen. The two LEDs are controlled by two digital pins, while the DHT11 sensor requires one digital pin signal to communicate and synchronize with photons for measurements of temperature and humidity. Finally, an OLED display was connected using two digital pins for SCL and SDA. The system used an external power source to power up the circuit. The display shows instructions to help the patient how to interact with the system and the insulin pen. The hardware connection is shown in Table 1.

The scalability of the proposed design with affordable cost as shown below in Table 2. It makes the system easier to be adopted by healthcare giver and for individual user.

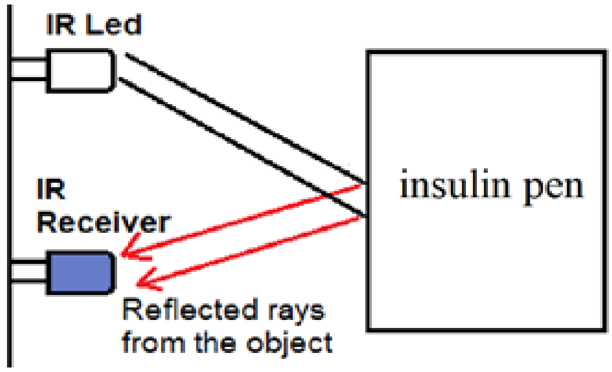


Figure 1. IR transmitter receiver alignment which shows the working principle of infrared sensor as an obstacle sensor

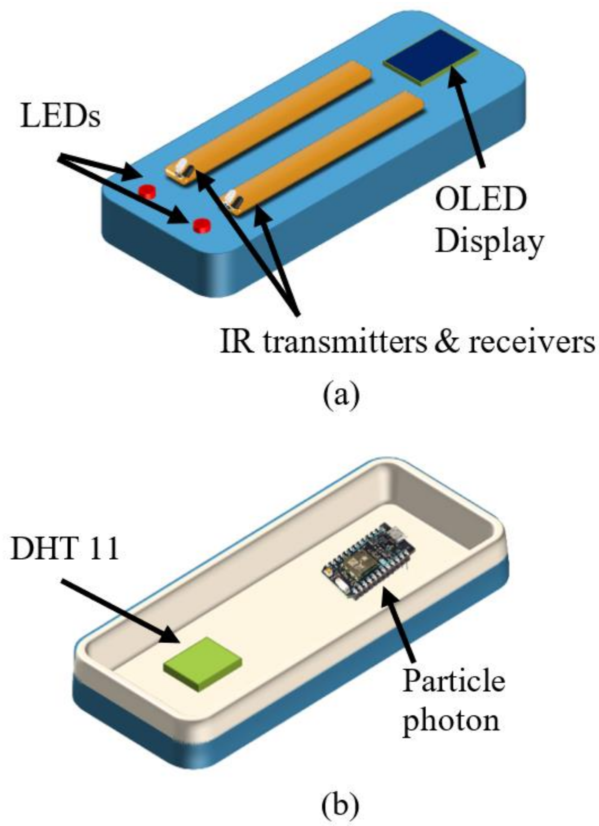


Figure 2. Proposed system design (a) Upper layer; (b) Lower layer

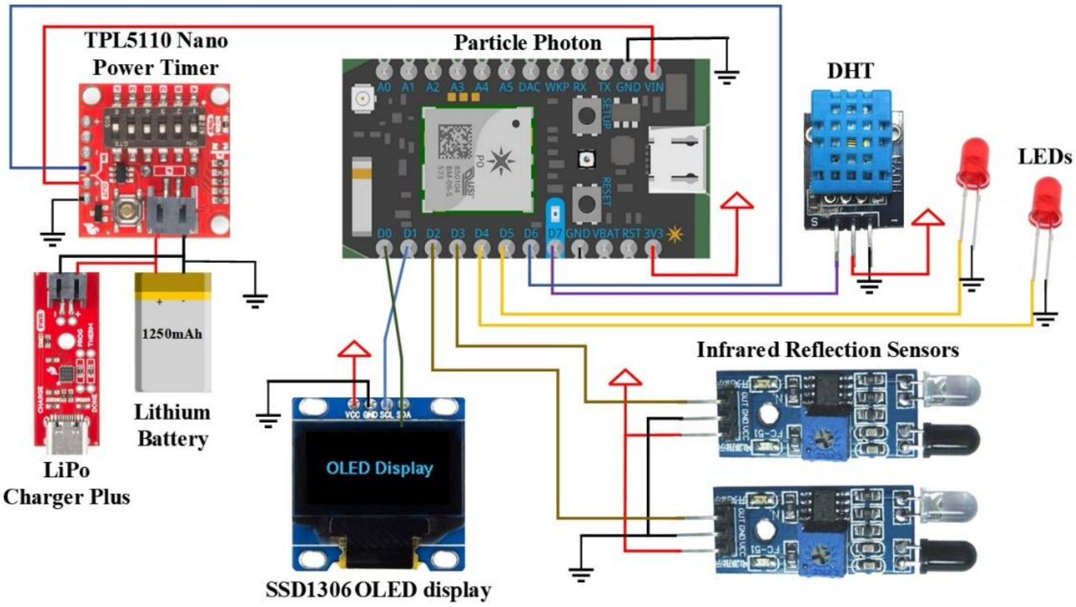


Figure 3. Hardware schematic diagram that shows the components' names and connections

Table 1. Hardware connection

Component Names	From Pin	To Pin
	S	Supply
DHT11	-	GND
	Data	D7-Photon
	S	Supply
Infrared Reflection Sensors	GND	GND
	OUT	D2, D3-Photon
LEDs	-	GND
	+	D4, D5-photon
	VCC	Supply
SSD1306 OLED display	GND	GND
	SCL	D1-photon
	SDA	D0-photon
	+	VIN-photon
TPL5110 Nano	-	GND
	ON	D6

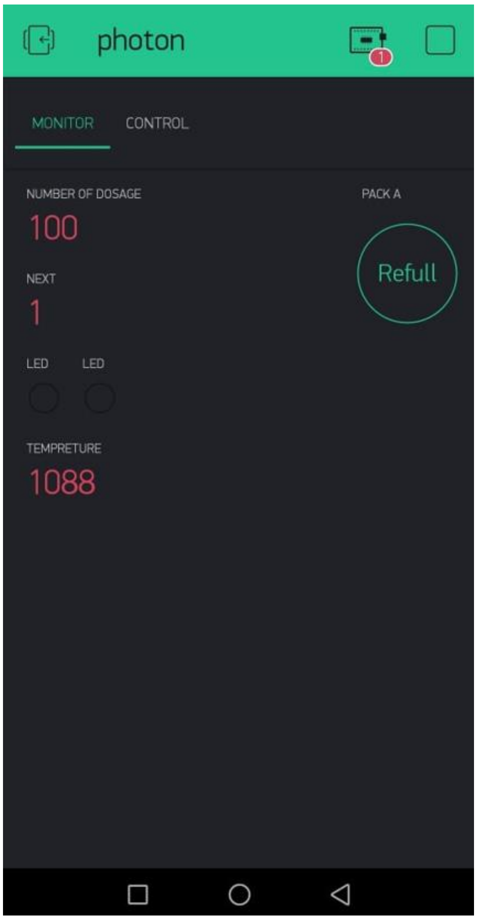
Table 2. Hardware component cost

Designator	Component	Total Cost-Currency	Source of Materials
Photon	Particle photon	19$	https://www.sparkfun.com/
DHT11	Humidity and Temperature Sensor	3.15$	https://www.robotshop.com/
IR	IR Infrared Sensor Obstacle Avoidance	3$	https://www.amazon.com/
LED	light-emitting diode	0.33$	https://www.sparkfun.com/
SSD1306	128X64 OLED Display Module SSD1306	9.99$	https://www.amazon.com/
Battery	Lithium Ion Battery (6Ah)	9.95$	www.sparkfun.com/
Box	Device enclosure	21$	3d printed
Charger	SparkFun LiPo Charger Plus	10.5$	https://www.sparkfun.com/
TPL5110	TPL5110 Nano Power Timer	6.50$	https://www.sparkfun.com/

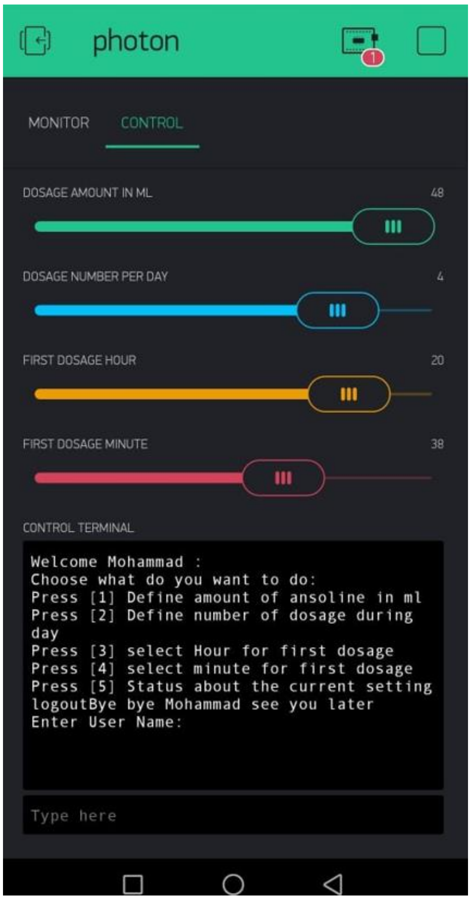
3. SOFTWARE DESIGN

The authors define two applications programmed to assure transparency for the proposed system: Patient Application and Doctor Application. The patient application works as a notifier and monitors the user who uses a basic user interface for diverse levels of technical proficiency. The last contains one button only in addition to monitoring labels related to insulin pen status that shows information about the insulin pen stock, package temperature, insulin dosage, and next injection time. Also, it sends notifications whenever the due time is reached for injection, low insulin stock, and critical temperature range detection. App interface layout contains a bottom to refill stock with insulin, as shown in Figure 4(a).

The doctor's application, as presented in Figure 4(b), has a higher level of administration than the patient's application. It monitors and controls the therapy plan where monitoring shows information about the insulin pen stock, package temperature, insulin dosage, and next injection time. Adding to that, the App. provides controlling slides for dosage amount, number of injections per day, and time of injection. It also provides a terminal for coding commands and retrieving data.



(a)



(b)

Figure 4. (a) Patient's mobile phone application interface; (b) Doctor's mobile phone application interface

4. SYSTEM ARCHITECTURE DESIGN

The architecture diagram of the proposed system, shown in Figure 5, can be split into two sides: Patient Side and Doctor Side. For the doctors' side, the application controls monitor, and communicates with the package through cloud infrastructure. The cloud was used as data storage which has excel sheets for every patient which are updated for every use. Each input has a time and date stamp which is supported by a particle cloud. While the messaging protocol uses a private mode to secure the patient's privacy. While on the patient side, the patient application keeps track of monitoring and works as a notifier.

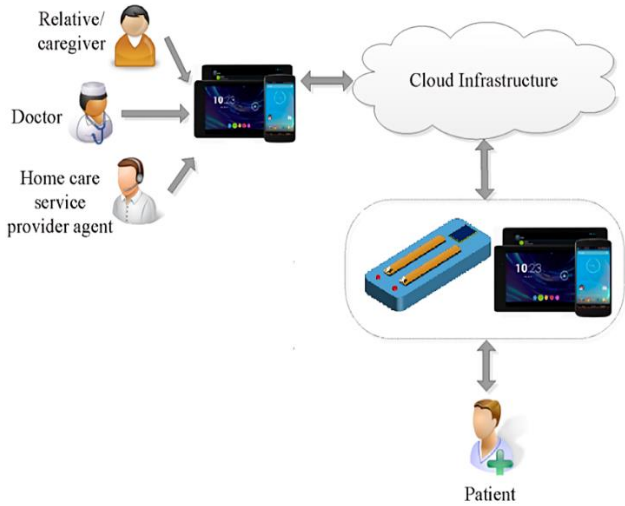


Figure 5. Architecture design of the proposed system

The algorithm starts by initializing the system functions and parameters. The initial configuration is automatically initiated whenever the system boots and ready to work. The system timing should be synchronized with the online time service. Since the Photon uses Wi-Fi services, the system time is synchronized with the online service by server. If the device went offline, an internal clock can be used to ensure synchronization. Then, the system reads all doctor configurations about the time of the first injection, the amount of insulin, and the number of injections per day which are determined by the doctor who is responsible for the correct prescription for every individual patient.

Based on this information, the system calculates specific times of injection per day. The system keeps track of the time of injection for the next injection time. When the time reaches, the system notifies the user to take his/her injection and track the user by monitoring package stats. The system assumes that the user has taken an injection whenever the IR sensor is activated, and the level of insulin reduces, the doctor will be informed about the action.

As a result, the assistant doctor notified whether the user had received his injection in a timely manner or not. In addition, the system calculates the amount of insulin already available, decreasing the old stock by the amount of each injection that has been taken by the patient.

The system monitors stock and informs the user to change an insulin pen if there is one available. Also, send notifications to users to order a new pen. On the other hand, when stock is empty the user should be notified by the algorithm to order a new package, and so on. The most frequent notifications will be on injection time. The last will be determined based on App configuration as shown in Figure 6. It will notify the user whenever the time is due for the next injection.

The system returns to its normal pattern of work after a new insulin pen is added to the package. If injection time reaches and there was no insulin added, then the user must be notified again in addition to the doctor and caregiver.

During the normal pattern of work, the system assures the quality of doses and assesses the right conditions of saving medicine by monitoring package temperature. The temperature monitoring was performed using the DHT11 sensor. For each 10min cycle, a programming function was used to check up the temperature and to submit the value to the cloud in case of exceeding a threshold level. This is a mandatory point to make sure that it is in the right range of saving temp. which is allowed by manufacturers. If the Temp. exceeds the limits of that range, then the user should be notified about the issue. All smart packages, user applications, and doctor applications are connected to gather and exchange information between them. Figure 6 Shows the flowchart diagram of our proposed system.

The communication system may consider using VPN to transfer messages. In addition, a secure IPv6 (IPsec) can be used to assure the integrity of recorded data.

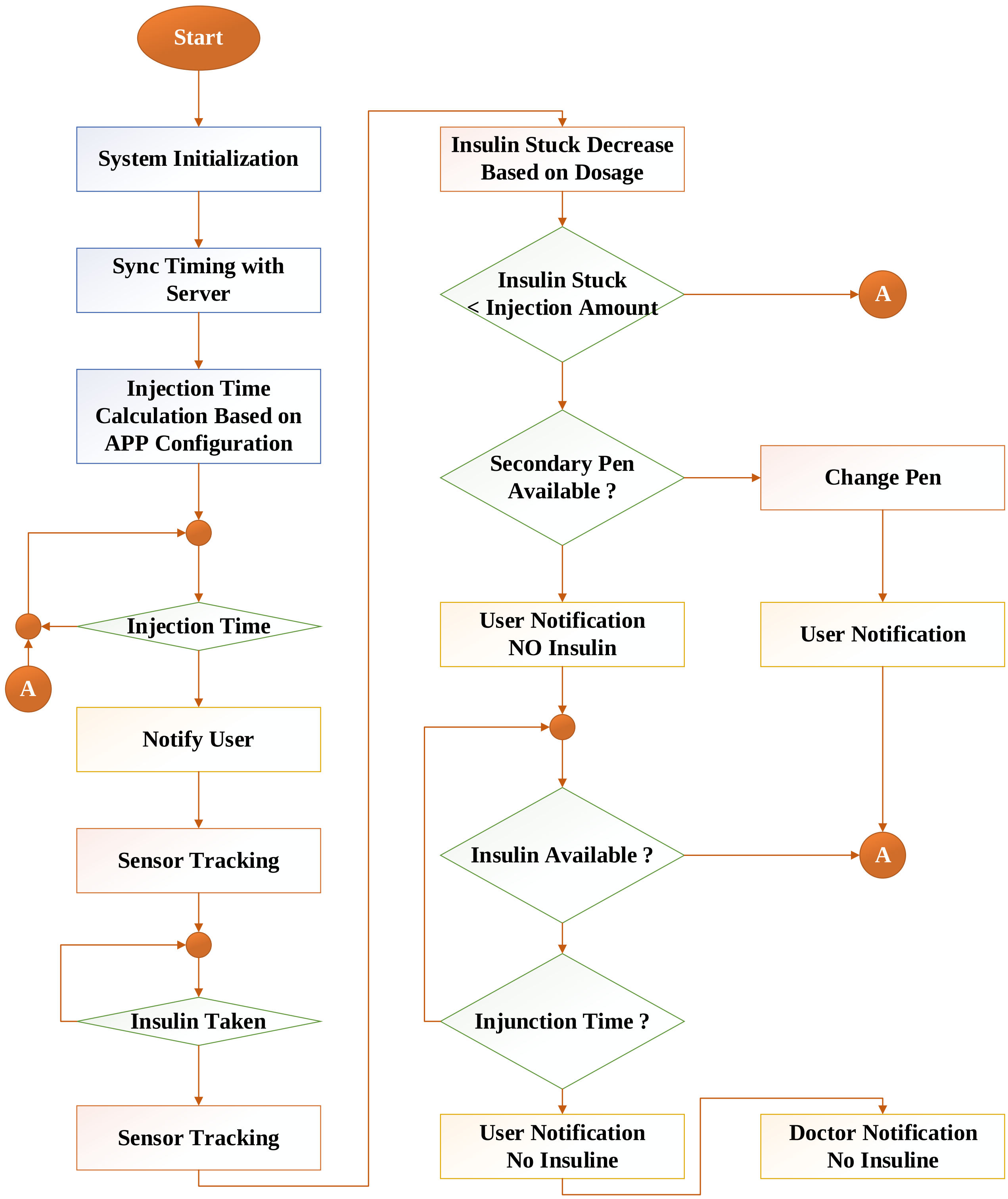


Figure 6. Flowchart diagram of our proposed system algorithm

5. OPERATING RESULTS

The operation sequence of the device was clarified as shown in Figure 6. While the user's actions begin when one of the pens is lifted. Firstly, the user shows a "Pull up" message on the OLED screen. After lifting the pen, the corresponding system feedback is recording the injection time and notifying the user to return the pen by showing a flashing "Return it" message on screen. The last message disappears when the user returns the pen to the right place. Meanwhile, the system records the new level of the insulin stuck.

This section is divided into prototype testing procedures which shows how a regular stakeholder faces during the test process and the recorded results by the system as discussed in subsection 5.2.

5.1 Prototype testing

Laboratory test was performed for the system for the expected condition: during the injection, during the empty insulin stuck, when one of the insulin pens is empty, during heat increase, wrong box used for injection.

The results observed while operating the system device as shown in Figure 7(a), (b), and (c). Initially, when turning the power ON, the device displays a moving picture on the OLED Display. The System syncs with the server online time for celebration and then reads sensor values to detect the insulin pen and temperature of the box. All monitoring information is sent to the patient mobile application and the doctor mobile application or caregiver. Doctor or caregiver enters the first injection time, amount of injection, and number of injections per day. So, the Blynk notification system notifies patients and doctors about the different states.

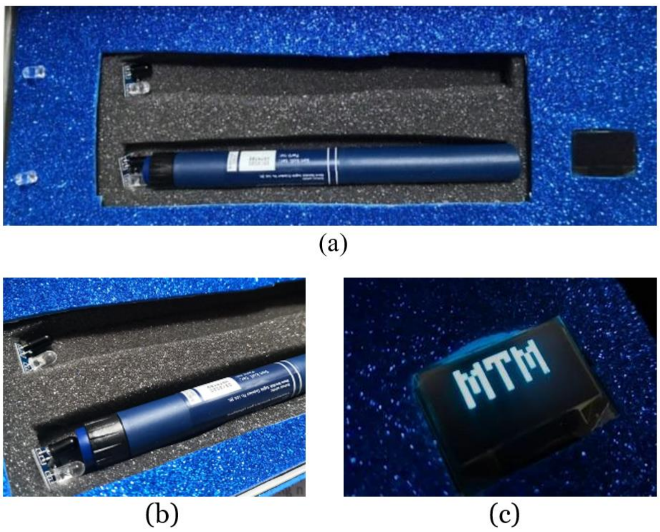


Figure 7. (a) System prototype (top view); (b) Pen detecting mechanism; (c) OLED display patient initials

The instructions are general for everyone except the injection protocol which can be customized by the doctor for each patient as shown in Figure 4.

When injection time reaches, our system directs the patient to what he needs to do by displaying instructions on the OLED display. Starting with "Pickup" on OLED to pull up the pen, and LED flashing to notify the user to turn it back. After that, the system returns to its normal state as shown in Figure 8. When the main pen stock is empty, the patient will be notified in addition to displaying information displayed on OLED. If stock B is available, the system asks a user to change the pen. If not, then the system displays "empty stock," and you need to buy insulin.

IFTTT server is used to collect data about patient insulin injection time and number. Whenever the user takes an injection particle, the photon publishes data. IFTTT server monitors the registered publication and checks if the last has satisfied conditions, it will add an entry on the patient Excel sheet as shown in Table 3. The Blynk notification system can be presented as a pop-up message which appears on the user Mobile Phone screen. While the OLED supports the instruction for the patient during the injection.

IFTTT handles the system notification. A username and password must be used to protect patient data during transmission and storage.

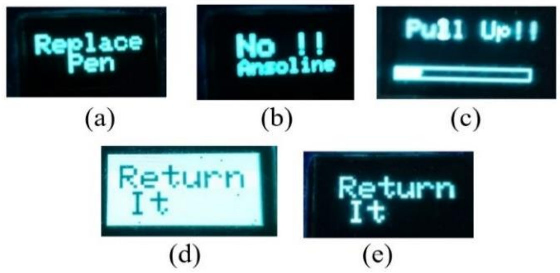


Figure 8. Pen insulin states (a) Replace pen alert, (b) No insulin alert, (c) Pull up!! alert, (d) Return it alert, (e) Flashing return it alert

Table 3. Sample for patient injection history

No.	Type	State	C	Time
1	Medicine	Taken	MTIots	April 23, 2022, at 06:05PM
2	Medicine	Taken	MTIots	April 24, 2022, at 06:02PM
3	Medicine	Taken	MTIots	April 25, 2022, at 06:07PM
4	Medicine	Taken	MTIots	April 26, 2022, at 05:55PM
5	Medicine	Taken	MTIots	April 27, 2022, at 06:09PM
6	Medicine	Taken	MTIots	April 28, 2022, at 05:58PM
7	Medicine	Taken	MTIots	April 29, 2022, at 06:01PM
8	Medicine	Taken	MTIots	April 30, 2022, at 06:02PM

The hardware was designed and tested as a prototype design which shows successful experiment results. For the long-term use: we are planning to test long-term use by doing further research to discover any failure during the process.

5.2 Prototype results

The results as in Table 3 show the type and the state of the medical supply with timely bases. So, the doctor can easily assess the right time of injection test by the patients and follow up with 24/7 real time monitoring assurance.

The overall cost of $84 is promising to make the final product compared with other products in the markets, hoping to decrease when producing a large number of the packages.

By comparing our proposed system to other works which have been presented by other researchers, we can notice that the proposed product is compatible with a wide range of insulin, supplying flexibility and convenience to users. Because of its affordable cost, patients may simply use this technology and customize their insulin dosages in exact increments. The largest dose capability ensures that it caters to varying needs.

Table 4. Products comparison

	NovoPen6 [20]	InPen [21]	GoCap [22]	Insulcheck Connect [23]	Proposed System
Type	Pen	Pen	Cap	Cap	Pack
Company/ Country	Novo Nordisk	Companion, Medtronic	US	Ireland	Iraq
Compatible Insulins	Novorapid, Fiasp, Levemir, Tresiba	Humalog, Novorapid, Fiasp	SoloStar, FlexPen, KwikPen	FlexPen, KwikPen, SoloStar, NovoPen 3/4/5/Echo, Luxura HD, Savvio, ClikSTA	All Insulin Pens
Price*	$69 Pen $26/Cartridge	$35 pen $31/ Cartridges	$25/month	35/month	≈60$Pack Pen starts from $1
Dose Increments	1 UI	0.5 UI	Pen Type	Pen Type	Pen Type
Max. Dose	60 UI	30 UI	Pen Type	Pen Type	Pen Type
Shows the last dose Units	Yes	Yes	N/A	N/A	Yes
Connect to Apps or Mobile	Yes	Yes	Yes	Yes	Yes
Active insulin Dose	Not	Yes	N/A	N/A	Yes
Temperature Monitor	N/A	N/A	Yes	Yes	Yes
Insulin Injection Reminder	N/A	N/A	Yes	Not	Yes
Connectivity	NFC	Bluetooth	Bluetooth	Bluetooth	Wi-Fi
Battery Life	5 years	1 year	1 year	Replace	Replace

(*) Prices affected by marketing, date, and taxes in the store region.

Table 5. Major features and performance of the proposed system

System Software	C code under online Particle Ide
System Hardware	Particle photon, DHT11, IR, LED, SSD1306, Battery, Box, Charger, and TPL5110.
Networking Issues	Network Types: Wi-Fi Networks Standards: IEEE 802.11g Networks Data Rate: 22Mbps.
Powered	Battery powered
Estimated Cost (June 2023)	84$ but decrease up to 50% in mass production

Additionally, the product displays the last dose units, allowing for easy reference. Customers may easily check their active insulin dosage and track their insulin intake thanks to its seamless connectivity with applications or mobile devices. The temperature sensor function guarantees the safety and effectiveness of insulin. The product also has a reminder for insulin injections, encouraging patients to follow their treatment schedules. Data sharing with healthcare specialists is made possible through connectivity possibilities for remote monitoring. Our product has a long life and replaceable battery life enabling uninterrupted use and giving patients convenience. It is worth mentioning that the long-term expectations for device use will be beneficial for the user's awareness. Any patient can observe the insight information by reading his long-term medical history records; Therefore, we can expect to see a more aware and knowledgeable society of their health challenges around the globe. Product Comparisons are shown in Table 4, and the main features and performance of the proposed system are shown in Table 5.

6. CONCLUSIONS

This paper proposes a smart insulin box. This design is relatively simple to use for a user who requires a reminder insulin injection, insulin stock management, and doctor remote observation. Two applications for patient and doctor supply cloud monitoring and control. IFTTT supplies medication history for the patient. The cost is promising compared with other products in the market since some reports from the World Bank and WHO, there are more than half of the world population who cannot obtain essential healthcare insurance. Adding to that, there are a vast number of people who are driven to poverty because of the payments from their own pockets.

The system delivers an interactive OLED screen to improve the patient's compliance. In addition, the proposed box ensures affordability for low-income patients who cannot afford expensive pens. More than that, it assures scalability since the patients can use any smart pen from different manufacturers. The system has been tested and shows a reliable and applicable reaction for several weeks within more than 60 tests. The experiments showed promising results inside the testing environment which encouraged the author to do further research for long-term use. The last enables the system to provide a valued dataset not only for patients themselves but even for healthcare providers, and insurance companies. This could be implemented by aggregating and analyzing the data to highlight the insight information from the row of data that was gathered by sensors. Thus, further optimization could be suggested like changing the schedule, reducing the dose…etc. to assure the affordability, sustainability, and quality of service. Even Though the current design cannot differentiate between handling and actual injection, we may add some extra sensor in the top of the insulin pen to detect for instance the oxygen level under the skin of that patient. The second limitation is there are many traveling stakeholders who keep the box inside a suitcase under harsh environment circumstances; therefore, the author may need to test the solidity and the functionality of the box under these conditions.

In the future, the next design will add sensors not only to sense any picking up action on the part of an individual, but also to ensure that users have indeed taken the injection and other functions. Furthermore, the authors may ask a third-party institute to provide a medical certification to regulate the box as a certified medical product which can be used in homes, institutes and everywhere.

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