Insulin Pump Automation

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InsuLink Medical Solution

INTRODUCTION

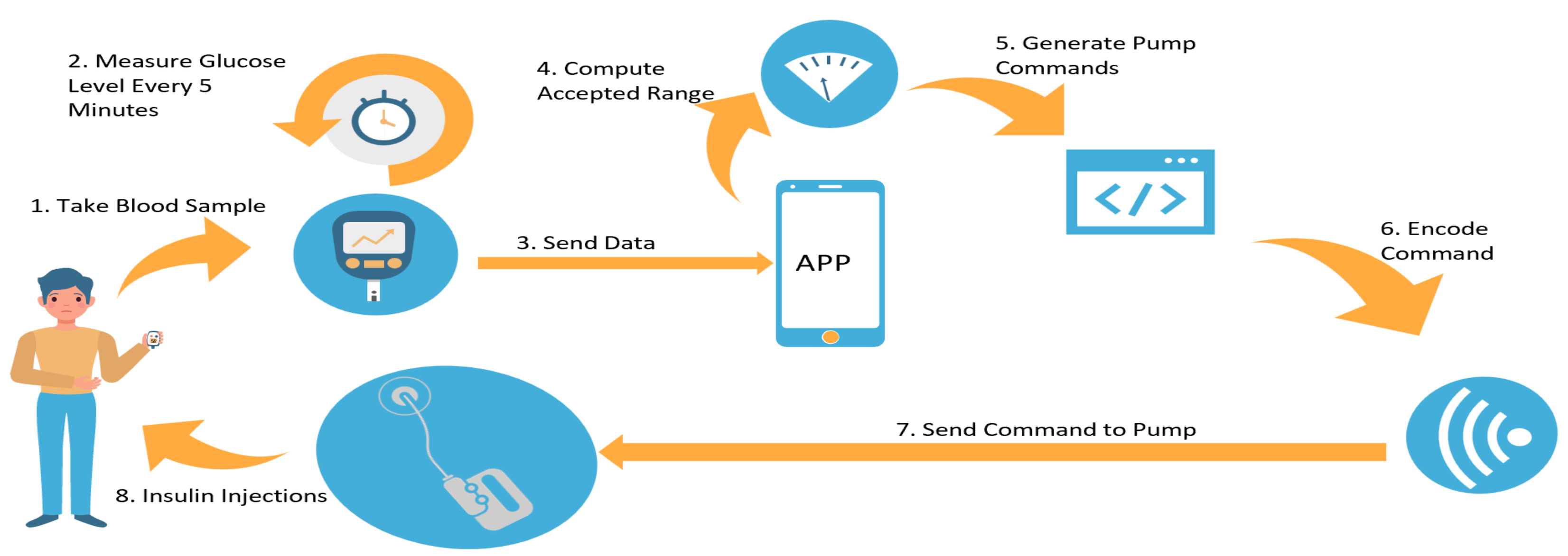
The project aims to automate the process of measuring glucose and adjusting insulin injections for type-one diabetes patients who use a manual insulin pumps and partial CGM (Continuous Glucose Monitoring) sensors. A hardware part will upgrade the glucose reader from its current state into a continuous glucose monitoring (CGM) sensor that sends the glucose reading every five minutes to a mobile application. A mobile application will save the readings and alert the patient when the glucose level goes under or over the required range. This application will be used to communicate with the pump to adjust the insulin injection amounts.

Problem Statement: Create a complete system that enables patients to monitor and inject insulin which uses an application that can send injection requests to the pump and receive readings of the sugar level from the sensor.

Constraints:
Cannot test real insulin injections on humans. Real insulin pumps cost over 10000 SAR (simulation used as an alternative)

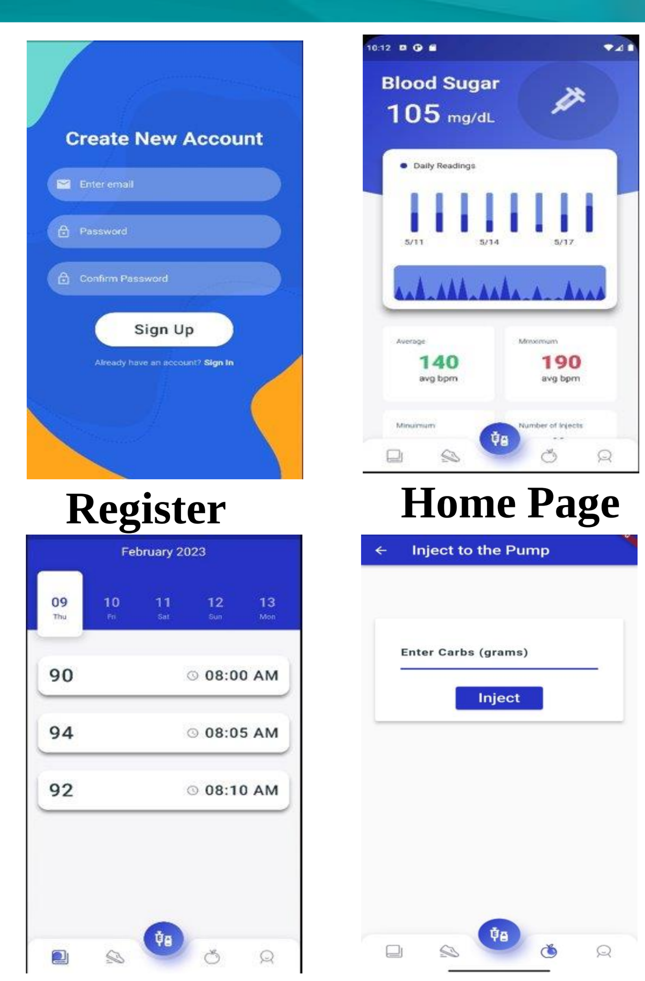
Motivation:
It was reported in 2017 that there are around 35000 type 1 diabetes patients in Saudi Arabia, making it the 8th country worldwide with highest number of type 1 diabetic patients

System Function



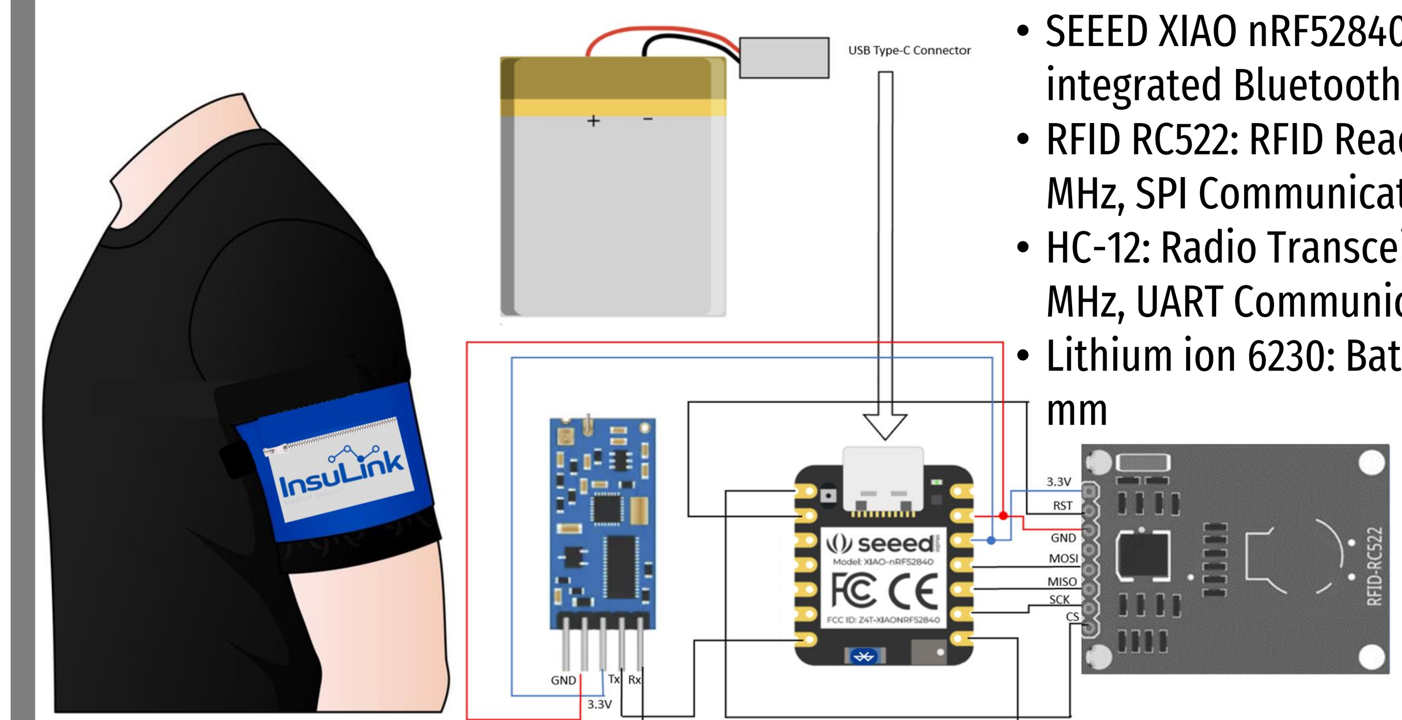
Mobile Application

Type 1 diabetes requires continual monitoring of blood sugar levels and an easy way to inject insulin to maintain optimal levels of sugar levels. Application will be developed using Flutter. Flutter is a mobile app development framework that allows developers to create high-quality, fast, and visually appealing cross-platform mobile apps for both Android and iOS platforms. Application will have three main functionalities which are monitoring patient sugar level, receiving sugar level reading from sensor, and sending injection signals to sensor then to the pump. Application will communicate with the sensor using Bluetooth. By doing so, this communication method will provide a more efficient way of tracking because of eliminating the need for manual monitoring (using NFC) and record-keeping. All the readings for the patent will then be saved into a database. The user then can see all the readings from his account in the application and see all the readings for a specific date. Using FlutterBlue which is a Bluetooth plugin for Flutter, a new app SDK to help developers build modern multi-platform apps.



Register | Home Page | Readings | Inject

Prototype Design



- SEEED XIAO nRF52840: Microcontroller with integrated Bluetooth module 21x17x4 mm
- RFID RC522: RFID Reader Operating on 13.57 MHz, SPI Communication,37,33,4 mm
- HC-12: Radio Transceiver working on 433 MHz, UART Communication 27x13x4 mm
- Lithium ion 6230: Battery 300mAh, 6x21x32 mm

Mathematical Analysis

Glucose-Insulin Response Model

$$\begin{cases} \frac{dG}{dt} = -k_1[G(t) - G_b] - X(t)G(t) + C(t) \\ \frac{dX}{dt} = k_3[I(t) - I_b] - k_2X(t) \end{cases}$$

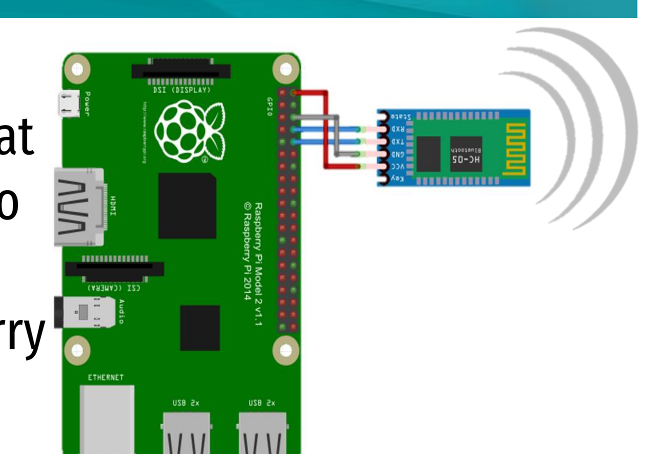
Insulin Calculation

$$BI = \frac{CHO}{ICR} + \frac{Current_{BG} - Target_{BG}}{CF}$$

- CF: Correction Factor
- BI: Bolus Insulin
- G: Glucose
- X: Insulin Concentration in tissue fluid
- I: Insulin Concentration in blood
- C: Glucose intake from Carbohydrates
- BG: Blood Glucose
- ICR: Insulin to Carb Ratio
- Gb: Basal Concentration of Blood Glucose
- Ib: Basal Concentration of Blood Insulin
- Ki: Control Parameters

Insulin Pump Emulation

In order to test that the device sends a command that controls the insulin pump, a Raspberry Pi 4 is used to emulate the behavior of a real insulin pump, operating on the same radio frequency. The Raspberry Pi is also running the Glucose-Insulin model.

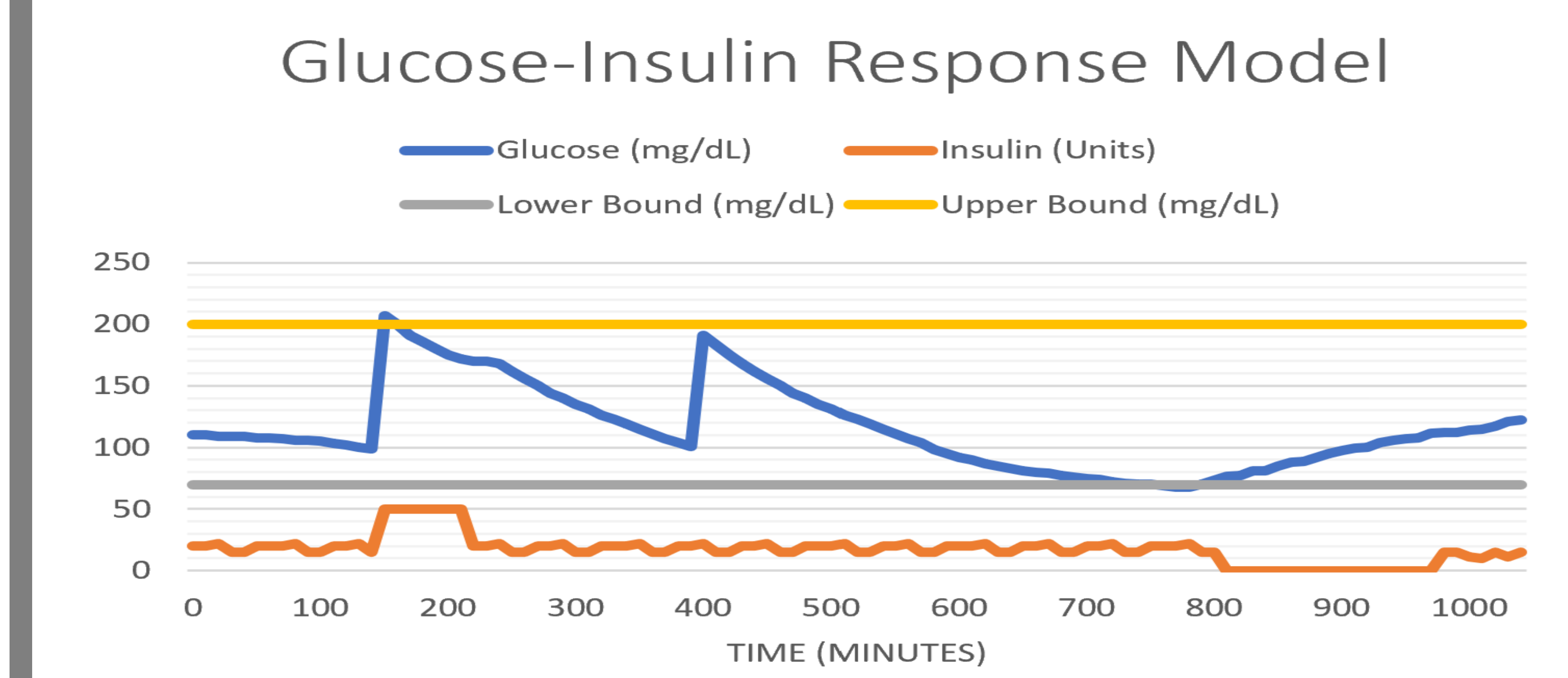


The command packet includes 5 fields in addition to a constant padding at the end. Device Type is unique for the version of the pump, the PIN is number written on the back of a remote that is purchased with the pump, Information is a unique code that tells the pump what command to execute, the counter is incremented to 255 and then goes back to 0 similar to sequence numbers. CRC is cyclic redundancy check of 8 bits output.

80 bits

Device type	Device PIN	Information	counter	CRC	0101
4 bits	36 bits	12 bits	12 bits	12 bits	4 bits

Testing & Simulation



Proof of Specifications

To ensure the effectiveness and reliability of this project, it must meet specific design specifications. Some of the critical design specifications that need to be considered include:

- Battery life
- range of communication
- weight of the device
- Reaction time

Specification	Proof Analysis
Battery life	The total needed current per day is 0.4757mA for the RFID + 0.0086mA for the Transceiver + 0.438mA for the microcontroller, that will be **0.9223mA per day**. The battery that is going to be used in this project is 3.7 voltage with a capacity of 30mAh. This battery will provide the system with power for **32.5 hours**
Range of communication	SEEED XIAO BLE uses Bluetooth Low Energy (BLE), BLE devices can transmit data over short distances, typically up to 100 meters
Weight of the device	The total wight of the parts is approximately equal to 17 grams, and finally the band is within 18 grams hence, the total wight of the product is equal to 35 grams
Reaction time	Total time = microcontroller transmission time + microcontroller processing time + Application transmission time + Application processing time = 0.35s + 1s + 0.60s + 1s = 2.95s

Conclusion

In conclusion, the proposed wearable solution automates the process of measuring glucose readings every five minutes and sending them to mobile applications and adjusting insulin injections. Overall, the system will make insulin management more convenient and efficient giving them greater control over their health and reduce the burden of managing their condition.

References