Level-Up Insulin

An Intelligent Closed-Loop Insulin Delivery System

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24AIM113 & **24AIM114**

Introduction to NN, CNN and GNN
Analog System Design

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PRESENTATION LAYOUT

- Introduction
- Problem Statement
- Objectives
- Literature Review
- Methodology
- Neural Network Architecture
- Dataset & Pre-Processing
- Prototype Design
- References

INTRODUCTION

“ Diabetes is way more finicky than people realize. You could do everything exactly the same every day and get completely different blood sugar readings. ”

- **Diabetic Danica**

Youtuber documenting her diabetic journey

To deal with “unsteady” glucose levels, we need constant, continuous monitoring, but, should it cost us needle pricks and discomfort?

PROBLEM STATEMENT

Current insulin delivery systems often depend on **manual monitoring** and **administration**, causing challenges in achieving optimal blood glucose control for individuals with diabetes.

How can we make insulin injection **automated** as soon as glucose levels rise??

PROJECT GOALS

1. To provide an enhanced and smart **non-invasive Continuous Glucose Monitoring** (CGM) system and an automated insulin pump.

2. To develop an algorithm to **calibrate insulin dosage** based on live glucose monitoring.

3. To use better CGM sensor and enhancing its accuracy using **deep learning** techniques.

4. To incorporate RF transmitter and receiver for connecting CGM and insulin pump to provide **compactness and portability**.

5. To introduce a **safety system** (buzzer/haptic) for alerting in case of extreme hypoglycemia or hyperglycemia

LITERATURE REVIEW

1

Patent analysis of digital sensors for continuous glucose monitoring

- This research paper brief talks about the historical pathway of CGM system by providing an analysis on different types of methods used for CGM and the number of patents taken on those methods.
- It briefly incorporates almost all the different CGM systems patented and FDA approved.

2

A Review of Skin-Wearable Sensors for Non-Invasive Health Monitoring Applications

- This research paper provides the information about flexible and stretchable non-invasive skin-wearable electronics and classifies them according to their input energy form, i.e., neural, electrical and thermoelectrical
- The materials used by the wearable devices are also explained along with numerical values when and where required.

3

Real-Time Improvement of Continuous Glucose Monitoring Accuracy: The smart sensor concept

- The research paper talks about the methodology involved enhancing a Dexcom SEVEN Plus with three real-time software modules for denoising, enhancement, and prediction of glucose levels.
- The predicted algorithm used here is the simple first-order autoregressive model.

4

Advances in Continuous Glucose Monitoring and Integrated Devices for Management of Diabetes: Improvement in Glycemic Control

- Its introduction emphasizes on the need of AI-based glucose monitoring and insulin pumping system.
- It gives a brief comparison of different CGM systems used such as MedTronics, Abbott, Dexcom etc., on the basis of different parameters, along with future scopes of such systems.

5

Efficacy Continuous Glucose Monitor, Insulin Pump, and Automated Insulin Delivery Therapies for Type Diabetes

- Discusses using Multiple Daily Injections (MDI) with a mix of long and short-acting insulin, or insulin pumps for continuous delivery
- Intensive insulin therapy, including insulin pumps, helps maintain blood glucose levels within a target range, reducing the risk of both hyperglycemia and hypoglycemia.

COMPARISON TO EXISTING MODELS

Insulin Pumps

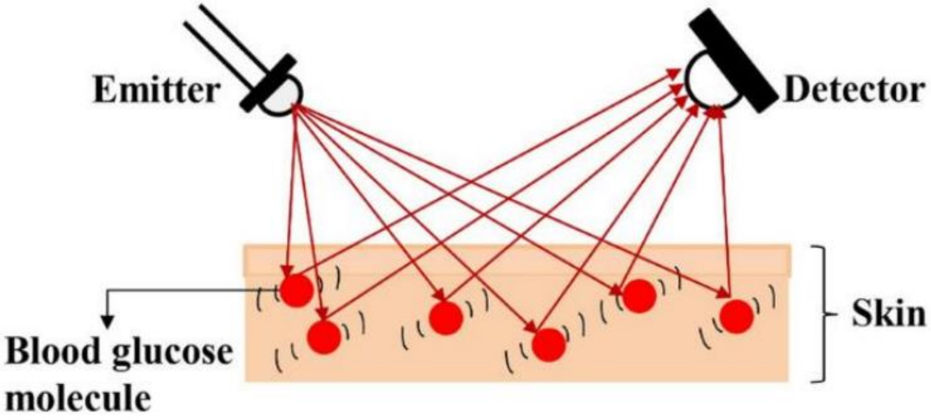
Model	Bolus and Basal Dosage	Motor/Pump	Activity
Tandem Mobi Control IQ	Bolus – 0.05 Basal – 0.01	Peristaltic Pump	Targets 140 to 160 mg/dl of BGL.
Tandem T-Slim Control IQ	Bolus – 0.05 Basal – 0.01	Peristaltic Pump	Targets 140 to 160 mg/dl of BGL.
Beta Bionics Ilet	Auto-determined	Piston Driven (Not publicly detailed.)	No specific target.
OmniPod 5	Bolus – 0.05 Basal – 0.05	Piston Driven	Targets around 150 mg/dl of BGL.
Animas Vibe	Bolus – 0.05 Basal – 0.025	Diaphragm Pump	150 mg/dl of BGL.

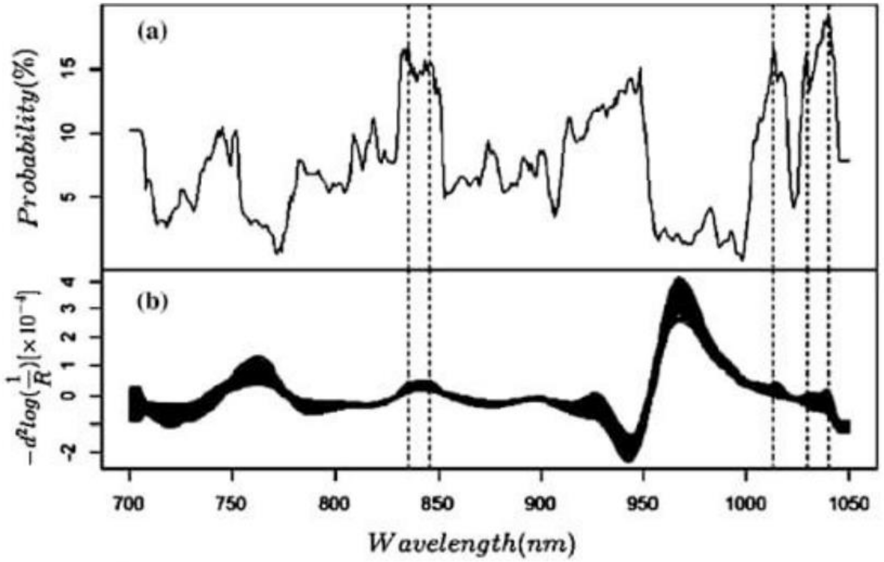
CGMs

Model	Alert System	Sensor Name	Sensor Type
Tandem Mobi Control IQ	Yes- high, low and rapid change alert.	Dexcom G7	Invasive microneedle.
Tandem T-Slim Control IQ	Yes- high, low and battery alerts.	Freestyle Libre 2 Plus	Invasive microneedle
OmniPod 5	Yes- high and low.	Dexcom G6	Invasive microneedle
Bluetooth Low Energy (BLE) (Prototype)	None built-in.	BLE Received Signal Strength Indicator (RSSI)	Non-invasive Electromagnetic
Split Ring Resonator (Prototype)	None built-in.	1.4 GHz Microwave Split Ring Resonator	Non-invasive Electromagnetic

METHODOLOGY

Non-invasive glucose monitoring employs an optical technology called **N**ear **I**nfra**R**ed Spectroscopy or **NIR** spectroscopy.



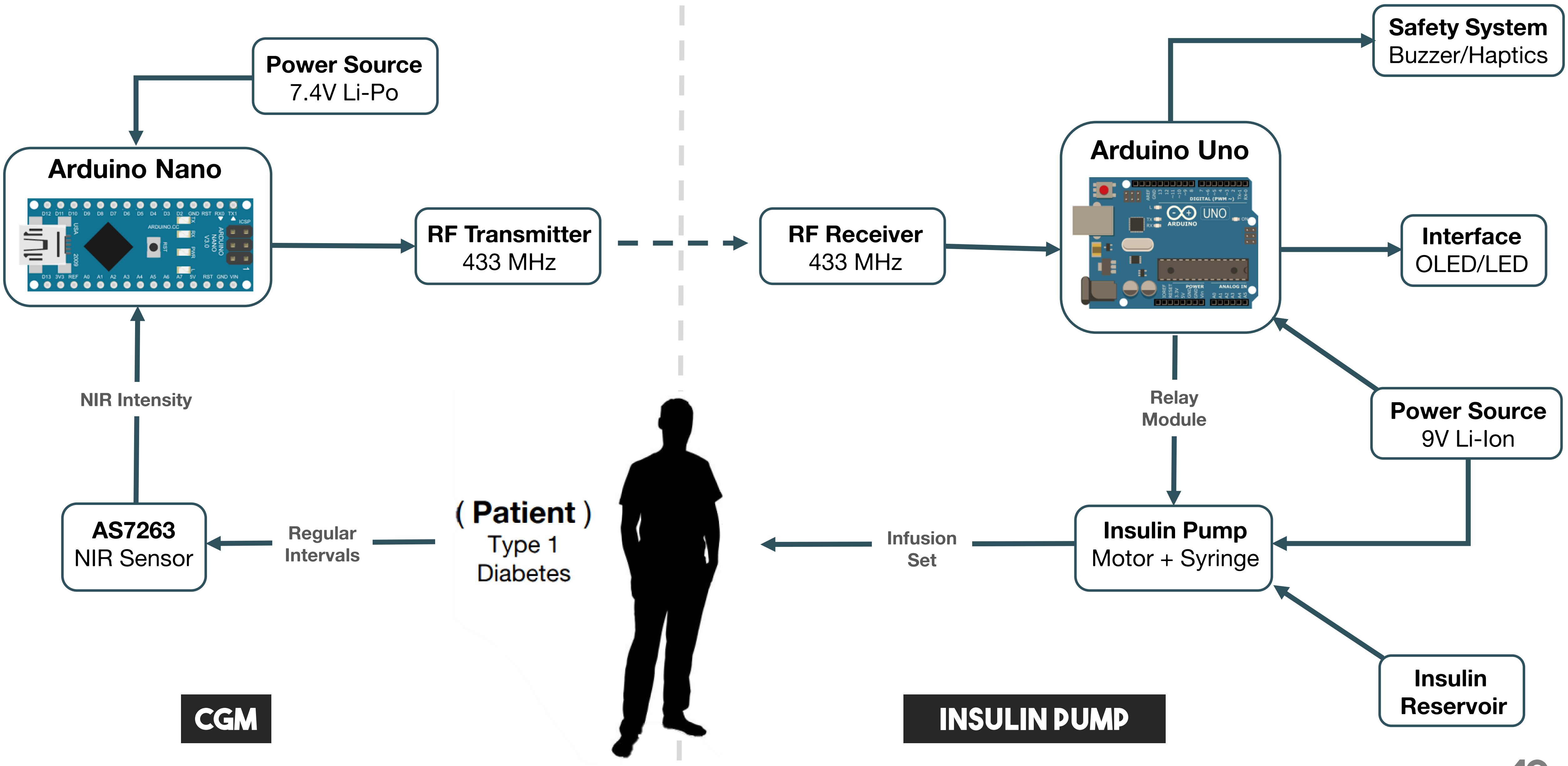


- Glucose molecules absorb and scatters the NIR light that falls on it. While absorption peaks around **950nm**, there are secondary harmonic oscillations at **<850nm** range too.

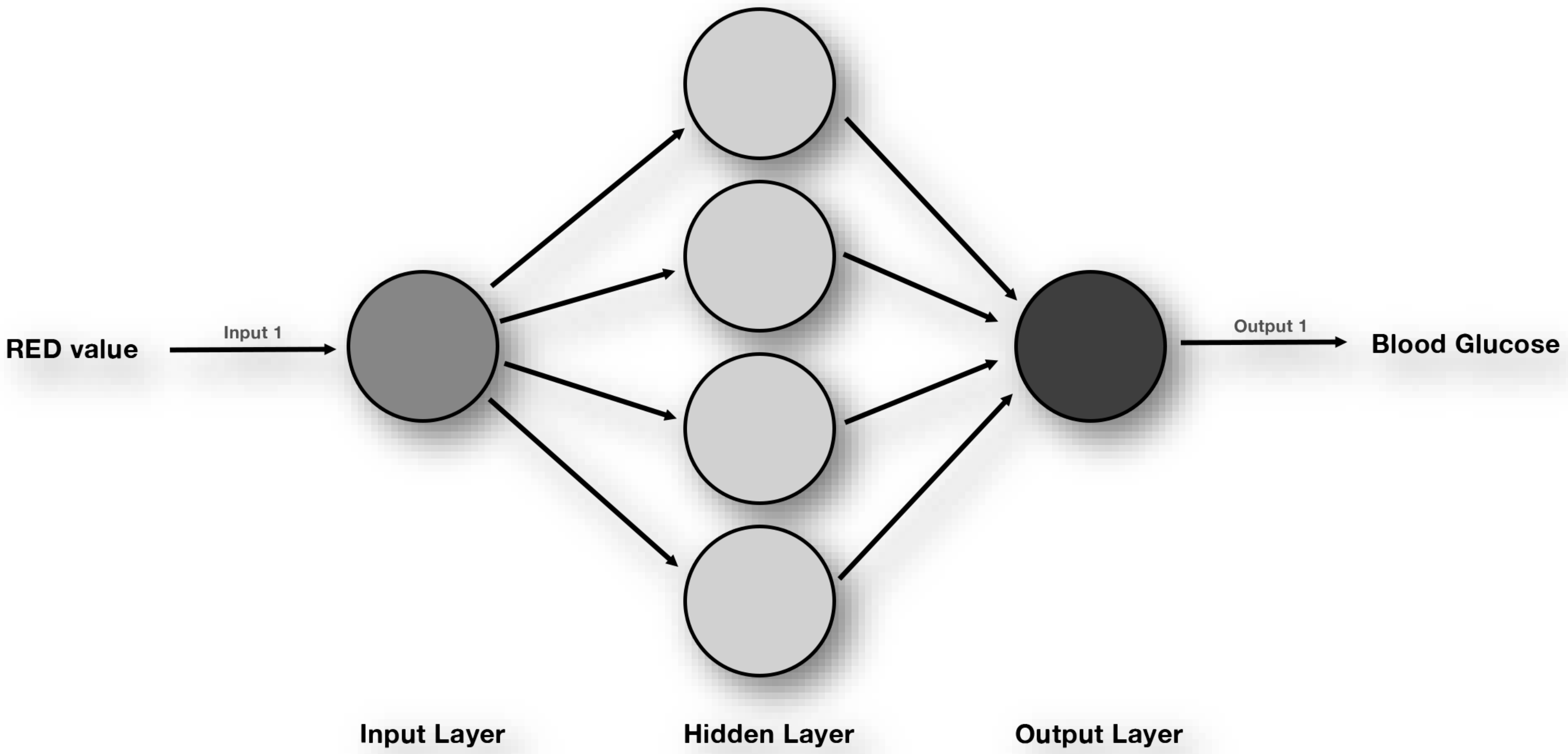
- The **AS7263 NIR sensor** would be fitting for this job. It offers six channels of different wavelengths.

- We will mostly be interested in the **'Red'** channel because it has the **860 ±20 nm wavelength** capability and can capture the glucose molecule's secondary harmonic oscillations.

CONCEPT BLOCK DIAGRAM

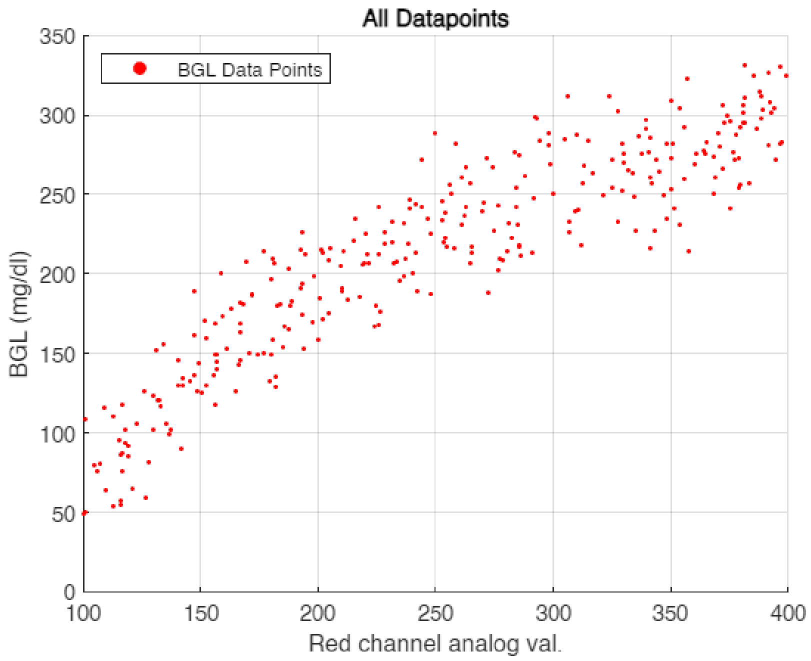


NEURAL NETWORK ARCHITECTURE



The input provided is the **AS7263**'s red channel output, which is then passed through **four** hidden layers, to provide the output. The **Sigmoid** activation function is used.

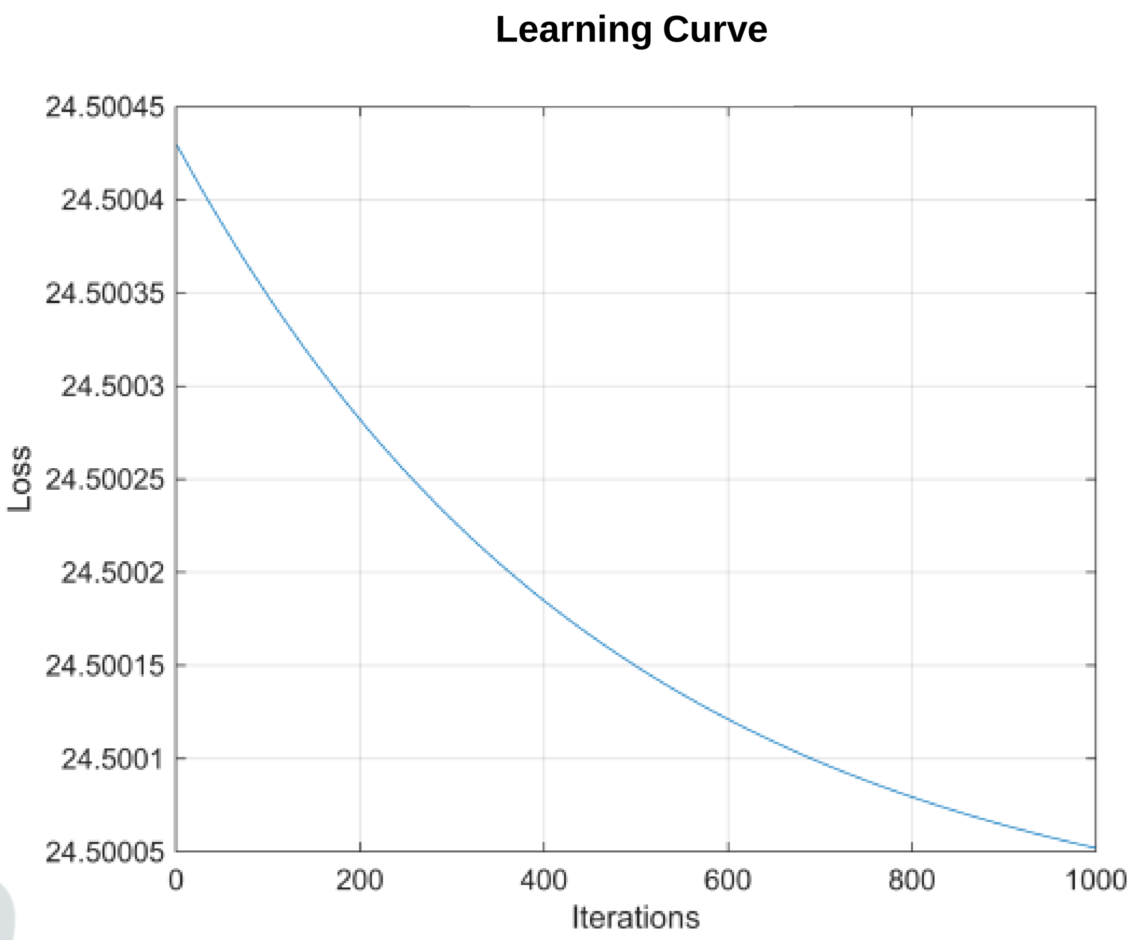
DATASET & PRE-PROCESSING



The dataset required is to be generated manually. Synthetic dataset is used to mimic the data preprocessing.

- The method that will be used for pre processing is – **Normalization.**
- Principal Component's normalization is based on the premise that the salient information in a given set of features lies in those features that have the largest variance.
- This means that for a given set of data, the features that exhibit the most variance are the most descriptive for determining differences between sets of data.

LEARNING CURVE



Architecture of taken NN:

- Input layer (1 node)
- 1 Hidden layer (4 nodes)
- Output layer (1 node)

Activation function:

$$f(x) = \frac{1}{1+e^{-(x)}}$$

Sigmoid Function

Learning Rate / Step Size: 0.1 per iteration

SENSOR COMPONENTS

1. **Continuous Glucose Monitor (CGM)**:
   - The **AS7263** NIR sensor will be used to perform IR spectroscopy on glucose molecules.

2. **Wireless Transmitter**:
   - A **433 MHz** Radio Frequency Transmitter will be used to transmit AS7263's Red Channel outputs to the Insulin pump's microcontroller.

3. **Microcontroller**:
   - Due to it's compactness, we went with the **Arduino Nano**. This will handle the continuous interfacing between CGM and RF transmitter.

Power solution: 7.4V 2S Lithium-Polymer Battery Pack ~1000mAh

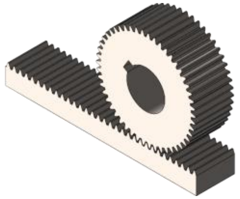
PUMP COMPONENTS

Arduino UNO

This would handle all communications, predictions and the insulin delivery algorithm.

5 RPM DC Motor

A low RPM, high-torque motor is required for precise control over insulin delivery.



Gear Rack

This mechanism is needed to translate the motor's rotational to linear actuation.

Interface

OLED or LED screen to display critical information directly on the device.

Safety Mechanism

Haptics/Buzzer for alerts in case of system failure or abnormal glucose levels.

RF Receiver

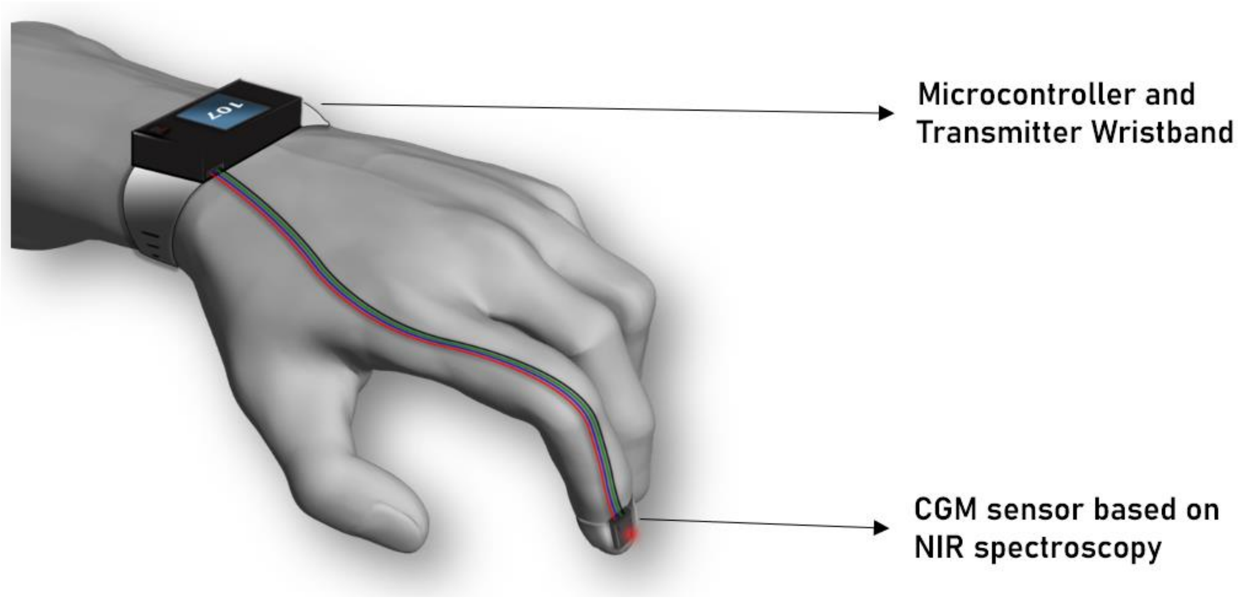
A 433 MHz Radio Receiver in order to receive data from CGM sensor module.

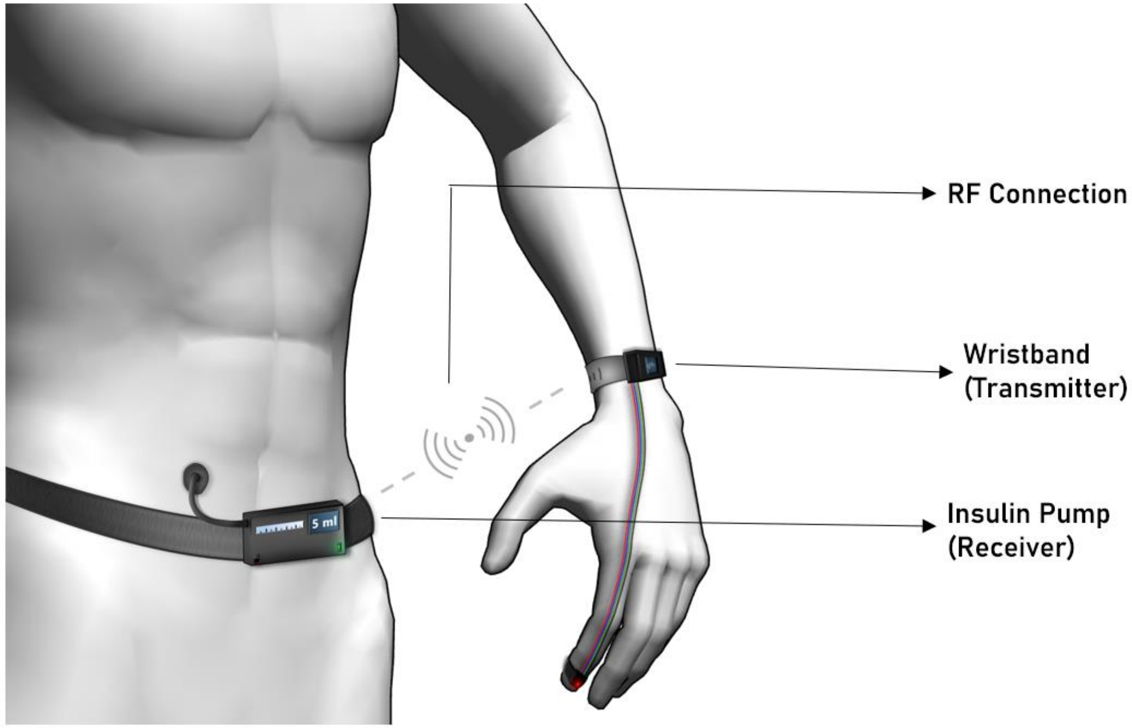
Power Solution

A 9V Lithium-Ion battery ~1200mAh (Rechargeable).

PROTOTYPE DESIGN

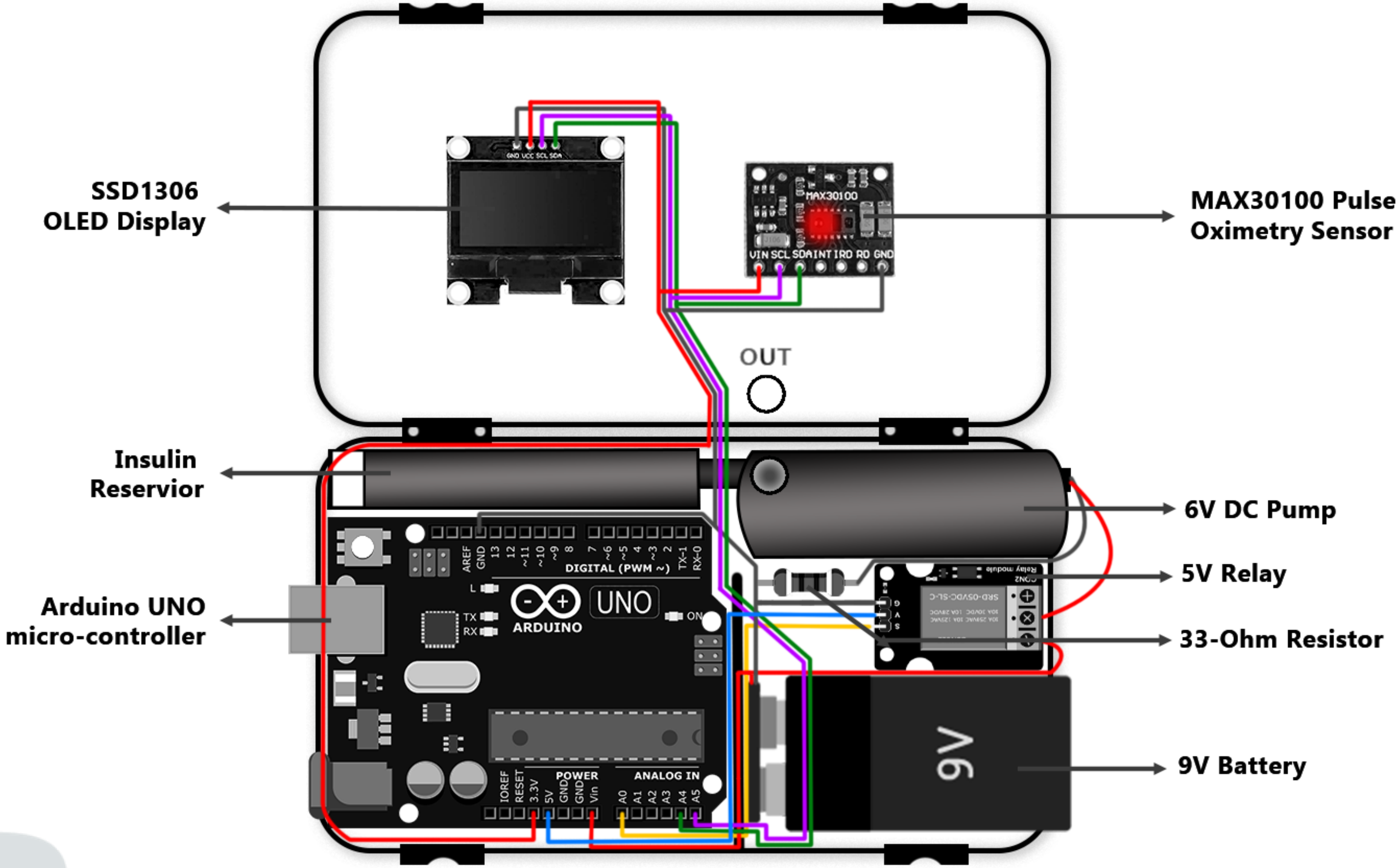
CGM	Insulin Pump





The **CGM** and **Insulin Pump** would be two separate devices integrated seamlessly through radio technology, as opposed to our previous design.

PREVIOUS PROTOTYPE DESIGN



Enhancements and additions

- Replace Pulse Oximetry Sensor with a Raw NIR Spectroscopy sensor.
- Replace Arduino UNO with a smaller microcontroller, e.g. Arduino Nano.
- Replace the high-speed pump with a syringe driven by a low-speed/high-torque pump.
- Power the system via a rechargeable battery pack as to avoid frequent needs of battery swaps.

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1. Litvinova, Olena, et al. "Patent analysis of digital sensors for continuous glucose monitoring." *Frontiers in Public Health* 11 (2023): 1205903. – [Link]

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3. Facchinetti, Andrea, et al. "Real-time improvement of continuous glucose monitoring accuracy: the smart sensor concept." Diabetes care 36.4 (2013): 793-800.– [Link]

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5. Pauley, Meghan E., et al. "Continuous glucose monitor, insulin pump, and automated insulin delivery therapies for type 1 diabetes: an update on potential for cardiovascular benefits." Current cardiology reports 24.12 (2022): 2043-2056.– [Link]

PROPOSED TIMELINE

Jan 3rd week

Research on implementations, component selection and literature.

Feb 1st week

First Review

Feb 3rd week

Dataset building and development of DL model.

March 1st week

Tentative 2nd Review

March 4th week

Completion of DL model; algorithm implementation with embedded programming

April 1st week

Prototype completion, final testing and implementation.

April 2nd week

Tentative final review

Thank You