# CHANAKYA UG REPORT

SUBMITTED BY:

| | |
|---|---|
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| GARVITA BHATEJA | UG21 |
| SUTIRTHA ROY | UG20 |

UNDER THE MENTORSHIP OF
DR. SAHAJ SAXENA

THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY, PATIALA

1. **About Team**
   - **Teammate details**

     ♦ **Geetanshi Gulati:** She is a 3rd year undergraduate student pursuing her studies at Thapar University, in the field of Electronics (Instrumentation & Control) engineering. She is currently pursuing research projects in areas of Biomedical Devices. Apart from academics, she likes engaging in photography and tennis.

     ♦ **Garvita Bhateja:** She is a 3rd year undergraduate student pursuing her studies at Thapar University, in the field of Electronics(Instrumentation & Control) engineering. She is actively involved in research in the area of Biomedical Devices. Her other areas of interest involve cognitive neuroscience. In her free time, she is usually engaged in reading or jogging. She is an upcoming summer research intern at IISc Bengaluru.

     ♦ **Sutirtha Roy**: He is a 3rd year undergraduate student pursuing his studies, at Thapar University, in the field of Electronics (Instrumentation & Control) engineering. He is actively involved in research in domains of Drone Technology, Biomedical Devices and Electric Vehicles. In his free time, he is usually involved in table tennis and music. He is also an upcoming Mitacs Globalink Research Intern at Saint Mary's University for the year 2022.

   - **Duration (starting to end)**

The total duration of our fellowship, awarded for this project, was 10 months, beginning from 1st August 2021 till 31st May 2022.

2. **About Topic**
   - **Why chosen**

     ♦ In a healthy human body, the pancreas is responsible for production of two hormones, insulin and glucagon. Insulin is produced by beta cells and is responsible for blood glucose regulation whereas glucagon, secreted by alpha cells, is responsible for increasing blood glucose concentrations. The inability of the pancreas to produce or use insulin results in elevated blood sugar(glucose) levels. Continued high blood glucose levels lead to development of a chronic disease known as Diabetes Mellitus. Broadly, diabetes is classified as either T1D (type 1 diabetes) or T2D (type 2 diabetes). T1D is an auto-immune condition wherein the beta cells, responsible for insulin production, get damaged. Hence, individuals afflicted with T1D need daily insulin injections to survive. In T2D, the body makes enough insulin but is unable to utilize it effectively. Adults above the age of forty years are usually detected with T2D.

     ♦ To tackle the problem of diabetes, researchers have developed various mathematical models of glucose-insulin dynamics, glucose level monitoring sensors as well as automatic insulin infusion pumps. The Artificial pancreas (AP) (refer fig 1) is a man-made clinical technology that replicates the functionality of the human pancreas for T1D patients. The aim of this AP system is to ensure euglycemic levels in the human body, while limiting occurrences of both hypoglycemia and hyperglycemia. Automatic maintenance of a balanced glucose level is thus ensured upon adopting this closed-loop smart healthcare device. The AP system consists of three main devices—a continuous glucose monitoring system (CGM), an insulin delivery pump, and a computer-controlled algorithm to allow real-time communication between two devices. Here, the patient acts as a system to be controlled and the decision-making loop are ICT enabled devices, thereby making an automatic system for glucose control regulation.

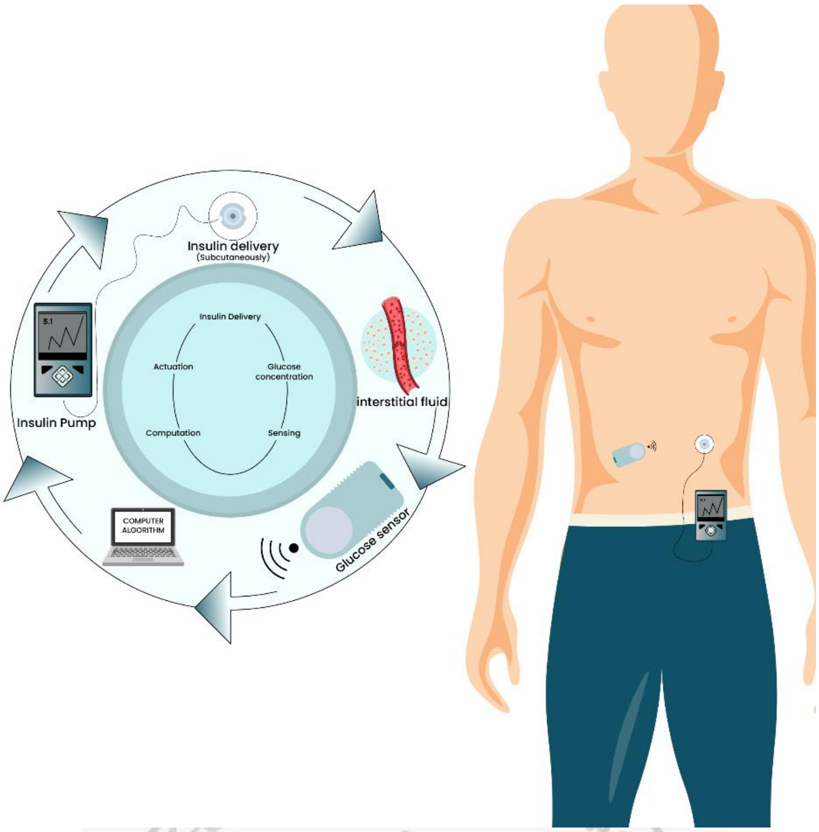


**Fig. 1 Artificial pancreas system**

- **Need of project**
  - As per the International Diabetes Federation, it is estimated that by 2040 about 642 million people within the age group of 20 to 79 years, will suffer from Diabetes. Diabetes contributes to 5% of the total deaths in the world. This number is expected to rise to 50% in the next ten years. Hence, Diabetes remains a challenging healthcare problem. Since, Type 1 diabetes does not have any known cure currently, insulin infusion into the body is suggested via the AP system.
  - Since the AP is a safety -critical medical CPS, hence it's design must be made robust and resilient. This is to ensure that the device performs well under cyberattacks, in case of data breaching and adulteration of signals. A robust design ensures prevention of unauthorized data alteration, detection of various security threat incidents and events, as well as maintenance of smooth functionality in adverse situations of cyber-attacks, by restricting logical access to the device network and its activities and restoring the device after an attack. There is also a need for development of mitigation strategies based on data-driven algorithms (inspired by machine learning) to make the system resilient
  - Since the AP system is a safety-critical system, it is necessary for it to be a robust and resilient healthcare device.
  - Lastly, there is a need to develop a low-cost hardware prototype solution for AP system as it is currently unavailable.

3. **Month wise work details**
   - **Starting till end.**

| S. No. | Progress in the month of September | Progress in the month of October | Progress in the month of November |
|---|---|---|---|
| 1. | Research and development. | Trial 1: Implemented the first insulin delivery model which was inefficient (lack of precision), started working on trial 2. | Trial 2: Implemented the second insulin delivery model this time using electronic components and aspects of IoT. |
| 2. | Market analysis of Artificial Pancreas industry. | GUI development process started. | Mathematical modelling work started for improving the precision of the expected model. |
| 3. | Data collection of 15 patients via PADOVA software (Virginia TECH). | The Padova Software. | GUI development under progress |

| S. No. | Progress in the month of December | Progress in the month of January | Progress in the month of February |
|---|---|---|---|
| 1 | Gained insights on Mathematical Modelling of Diabetes | Sessions taken to improve understanding of Padova software. | Design and development of 3rd hardware setup |
| 2 | Exploration of FDA Approved Padova Software | Contextualized the code files extracted from Padova software | Ran simulations of glucose regulations using data from patients of 3 different age groups |
| 3 | Understanding various data driven techniques for insulin prediction. | Exploration of IoT modules. | Developed understanding of IoT Hardware Interfacing techniques. |

| S. No. | Action Plan for the month of March | Action Plan in the month of April | Action Plan in the month of May |
|---|---|---|---|
| 1 | Extraction of dataset from padova of 11 adolescents | Development of ML model | Analysis of results obtained from ML model |
| 2 | 3D printing of individual components of hardware model | Assembly and testing of hardware | Initiated writing a research paper on collected results. |
| 3 | Started working on ML model for insulin prediction | Exploring 4th hardware design | Making alterations and 3D printing of updated design of 3rd setup |

- **With the contribution of each teammate working.**

| Member Name | Contribution in the month of September | Contribution in the month of October | Contribution in the month of November |
|---|---|---|---|
| Geetanshi Gulati | Research & Development of hardware models | Hardware ideation and implementation (trial phase 1) | Hardware ideation and implementation by incorporating IoT (trial phase 2) |
| Sutirtha Roy | Research & Development of hardware models. | Hardware ideation and implementation (trial phase 1) | Hardware ideation and implementation by incorporating IoT (trial phase 2) |
| Garvita Bhateja | Research & Development of mathematical model and Market analysis. | Mathematical model verification | Development of simulator of blood glucose regulation in type 1 diabetic patients* |

| Member Name | Contribution in the month of December | Contribution in the month of January | Contribution in the month of February |
|---|---|---|---|
| Geetanshi Gulati | Design and simulation of hardware design | Started using Padova software | Code analysis of Padova |
| Sutirtha Roy | Ideation of insulin pump design | Literature review of various types of blood glucose measuring sensors | Explored different data driven techniques |
| Garvita Bhateja | Explored and studied mathematical model (Bergman Minimal Model) | Explored and studied mathematical model (Hovorka model) | Explored and studied mathematical model (Dallaman model) |

| Member Name | Contribution in the month of March | Contribution in the month of April | Contribution in the month of May |
|---|---|---|---|
| Geetanshi Gulati | Extraction of dataset from padova of 11 adolescents | Assembly and testing of hardware | Making alterations and 3D printing of updated design of 3rd setup<br><br>Initiated writing a research paper on collected results. |
| Sutirtha Roy | Started working on ML model for insulin prediction | Development of ML model | Exploring 4th hardware design<br><br>Initiated writing a research paper on collected results. |
| Garvita Bhateja | 3D printing of individual components of hardware model | Analysis of results obtained from ML model | Exploring 4th hardware design<br><br>Initiated writing a research paper on collected results. |

## 4. About prototype

- **Images & Video Description**

**1st Iteration: Hardware Design (Using Stepper Motor and Screw Gauge)**

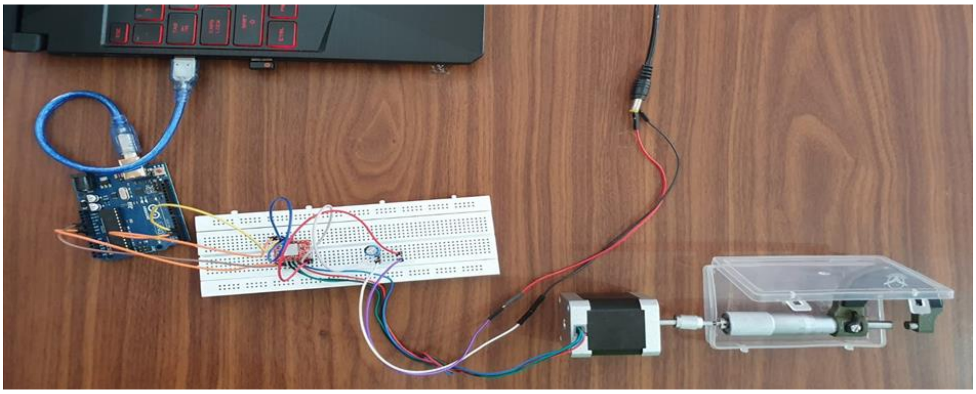

Fig. 2 first iteration

Aim : To dispense insulin in the body (screw gauge was used to get precision)
Problem: the system was bulky because of the use of a stepper motor and screw gauge. It was erroneous because of its incapability to move.

**2nd Iteration: Hardware Design (using electronic components and IoT)**

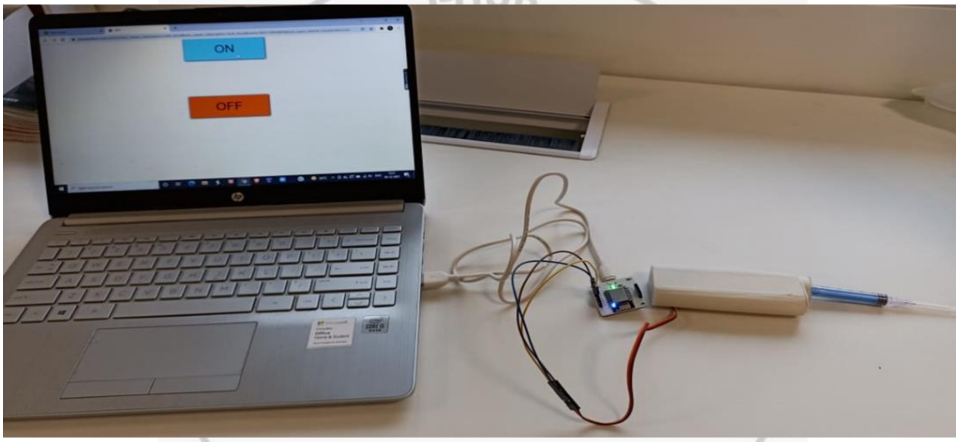


Fig. 3 second iteration

Aim: To inject insulin in the body using IoT capabilities(incorporating bolt Iot module and cloud)
To overcome limitations of bulkiness of the system by replacing stepper with servo motor.
Problem: inability to find as well as design perfect lead screw to fit on top of servo cap and hollow cavity of plunger. Furthermore, faced issues in setting up Bolt IoT modules(microcontroller and cloud) for delivery.

**Individually 3D printed components:**

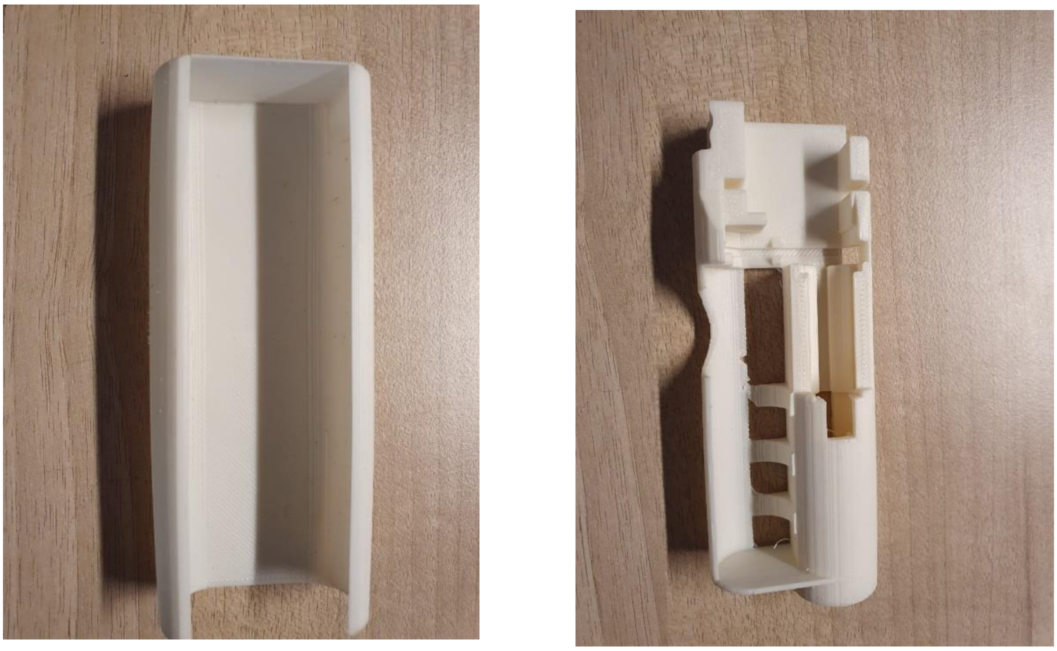

Fig. 4 Outer case to enclose all components

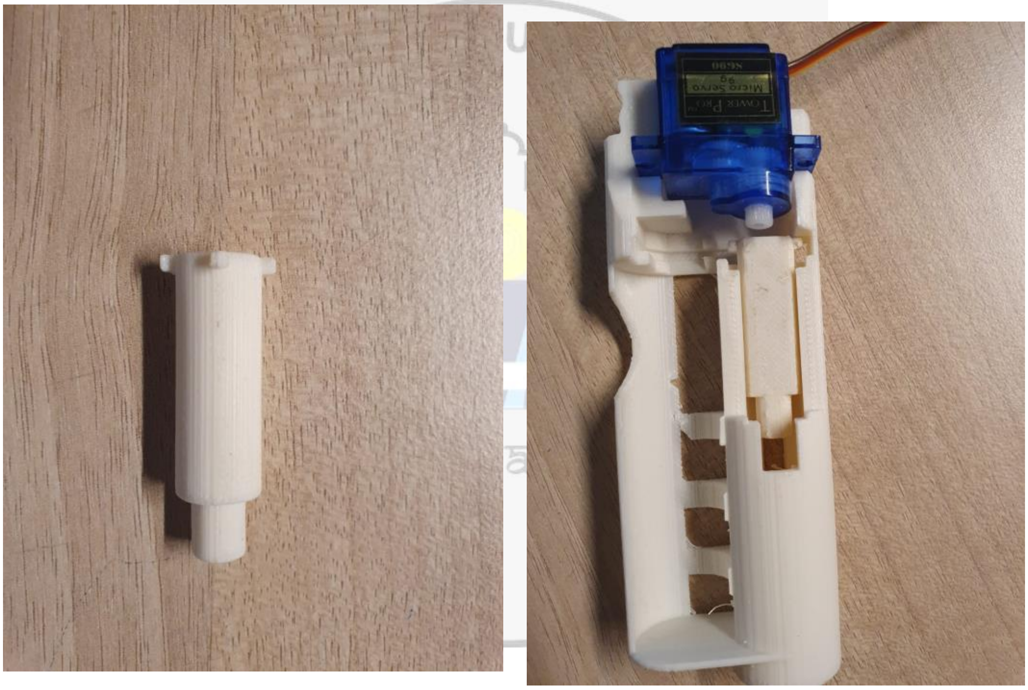

Fig. 5 Plunger to inject insulin

**3rd Iteration: Hardware Design (currently being worked upon)**

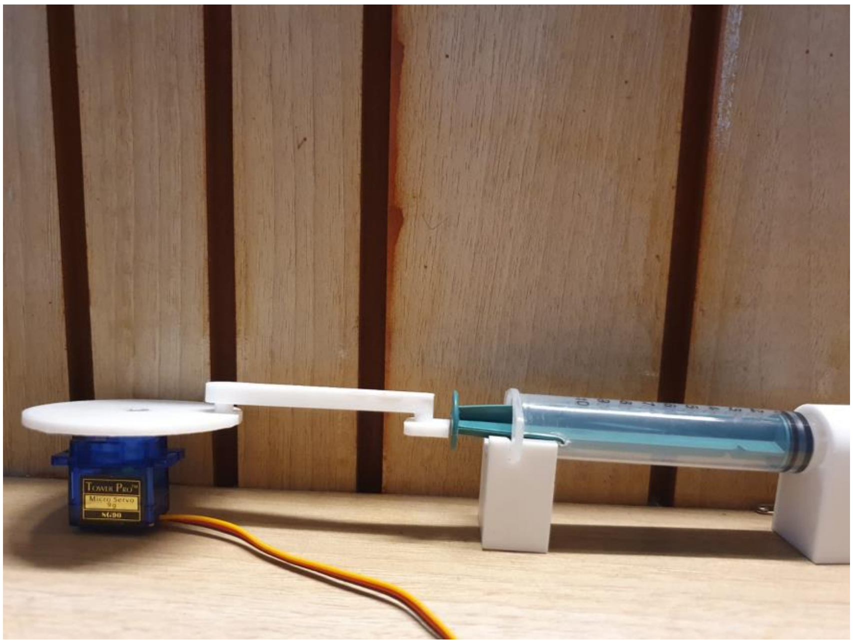

Fig. 6 third iteration

Aim: To inject insulin using self-designed delivery system by deploying simple crank shaft mechanism
Challenges: Modified design of delivery system as per new measurements.

**Individually 3D printed components:**

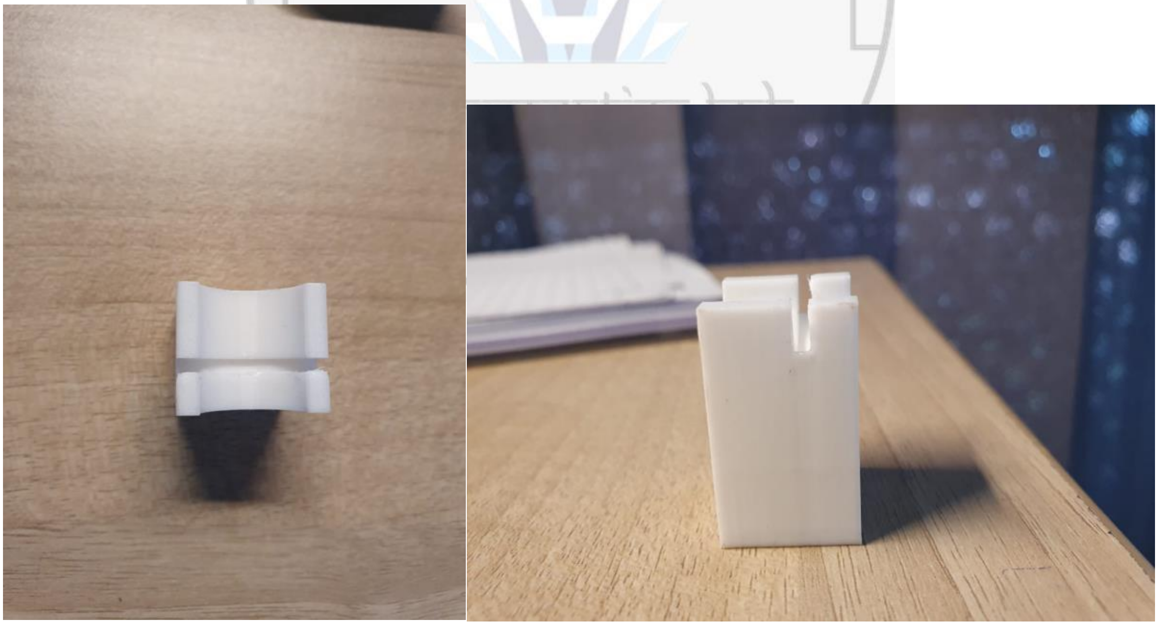

Fig. 7 injection mounting brackets (top view and side view)

Fig. 8 channel to ensure stabilized injection position during insulin delivery

Fig. 9 Mount for servo motor

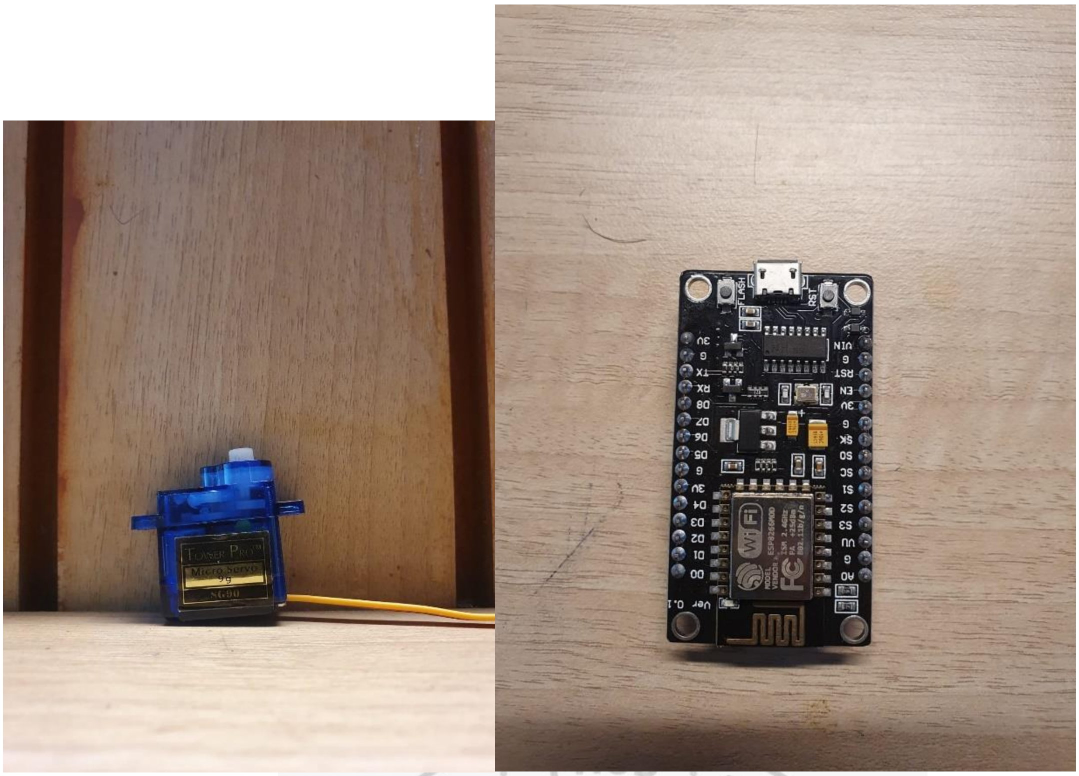

Fig. 10 servo motor and NodeMCU

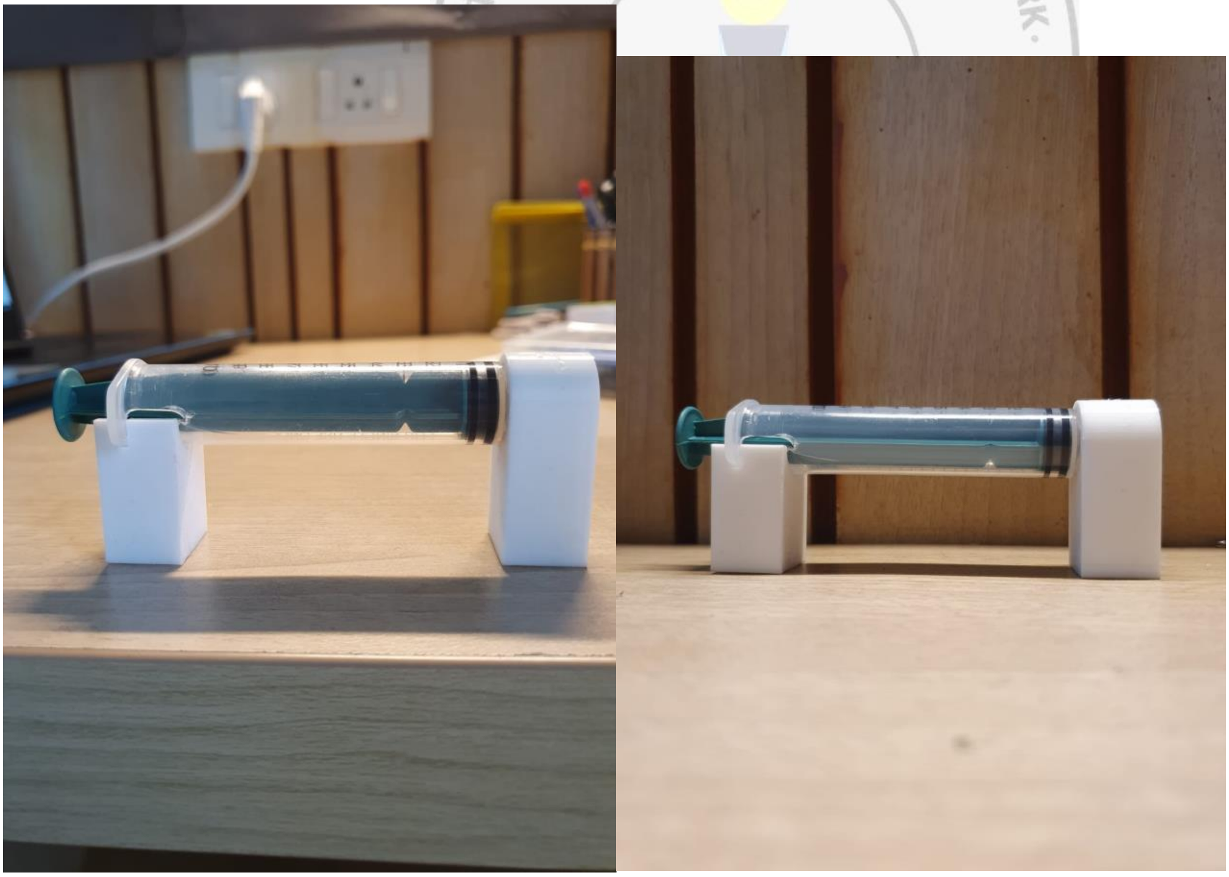

Fig. 11 injection and its  holders

**Simulation and LabTrial Videos:**

https://drive.google.com/drive/folders/1j6-L78575C_J_mpzcf4odgmotnsvuHNL?usp=sharing

- **Software/ Applications/ Product Descriptions**

The closed loop Artificial Pancreas system (refer to fig. 12) consists of a T1D patient (whose glucose levels are to be regulated), a glucose sensor, a computer-controlled algorithm and an insulin delivery system, all of which are interacting in a wireless communication network.
Here, we have replaced the T1D patient by a Virtual Patient. This Virtual Patient is a circuit being developed using the Hovorka Model for glucose-insulin subsystems. This glucose level is being measured in mg/dl using a blood glucose sensor. This BG reading is then fed into a Data Driven Controller i.e., our insulin prediction ML model. The corresponding insulin predicted is being injected into the patient using an IoT based insulin delivery system. The above displayed 3rd hardware iteration is our currently proposed design for insulin pumping.

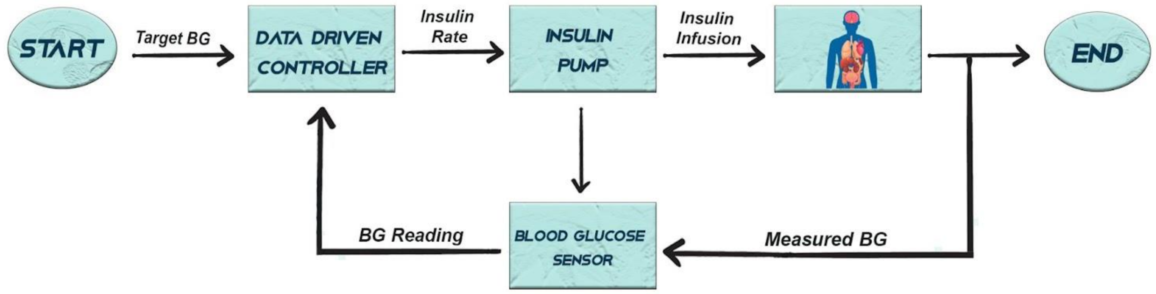


Fig. 12 Closed loop Blood Glucose regulation in an Artificial Pancreas System

- **Working Method**

**Virtual Patient:**
The process starts from the Virtual Patient. The input to this virtual patient is meal intake as well as insulin. The output of the patient is glucose.

**Blood Glucose Meter:**
This glucose level is being measured in mg/dl using a blood glucose sensor. This value is then fed into our ML Model.

**ML based Insulin Prediction System**
Machine Learning techniques were used in our experiments in order to predict deliverable Insulin level for the patient, using the Padova Dataset. ML easily identifies trends and patterns and we can handle multi-dimensional data very easily. For the predictions, tree-based models have been used namely Random Forest and Decision Tree mainly because tree-based models are powerful and mostly accurate in a wide range of cases. The pipeline using which predictions have been made have been is described below

I. **Data Pre-processing**: In order to convert raw dataset into an understandable format. In case of any missing data, the tuple is dropped off the dataset. After this process, possible outliers are removed since it makes a stronger correlation. Normalization is then applied where the dataset is transformed to be on a similar scale. This improves the performance and training stability of the machine learning model.

II. **Model Training Phase**: This step involves the development of DTree and RF models. Based on the performance the hyperparameters are tuned appropriately to give optimized performance while training. DTree builds a regression model in the form of a tree structure. On the other hand RF is an ensemble of multiple DTrees and gives better performance.

III. **Testing**: We use the Train, Validation and Test approach for the model pipeline. The test data is a separate set from the Padova Dataset used to test the model after its training is completed. Based on the test data predictions, the final performance of the models is evaluated.

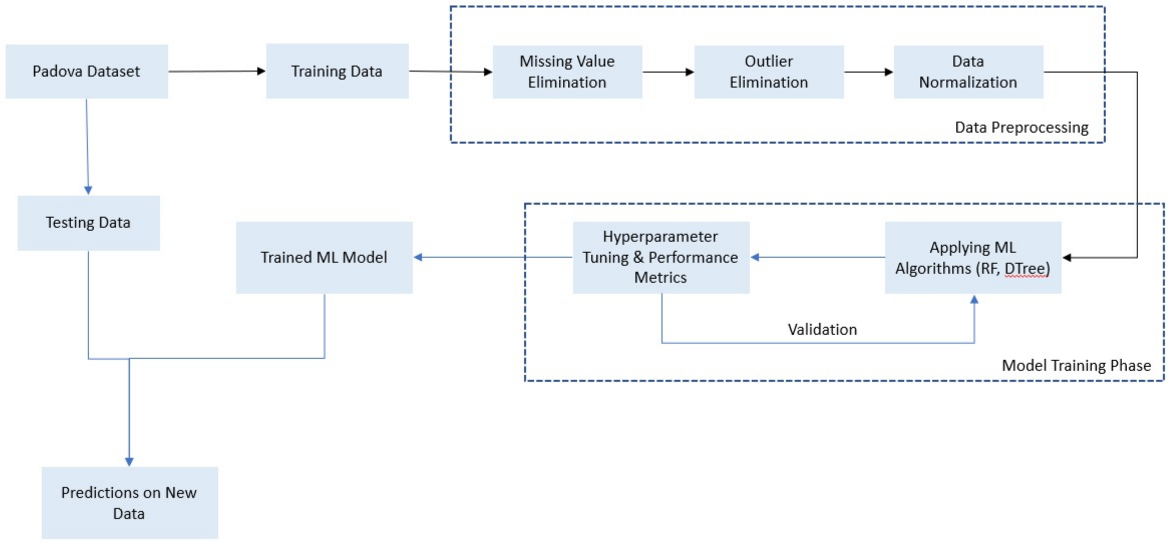


Fig. 13 flowchart of ML based insulin prediction model

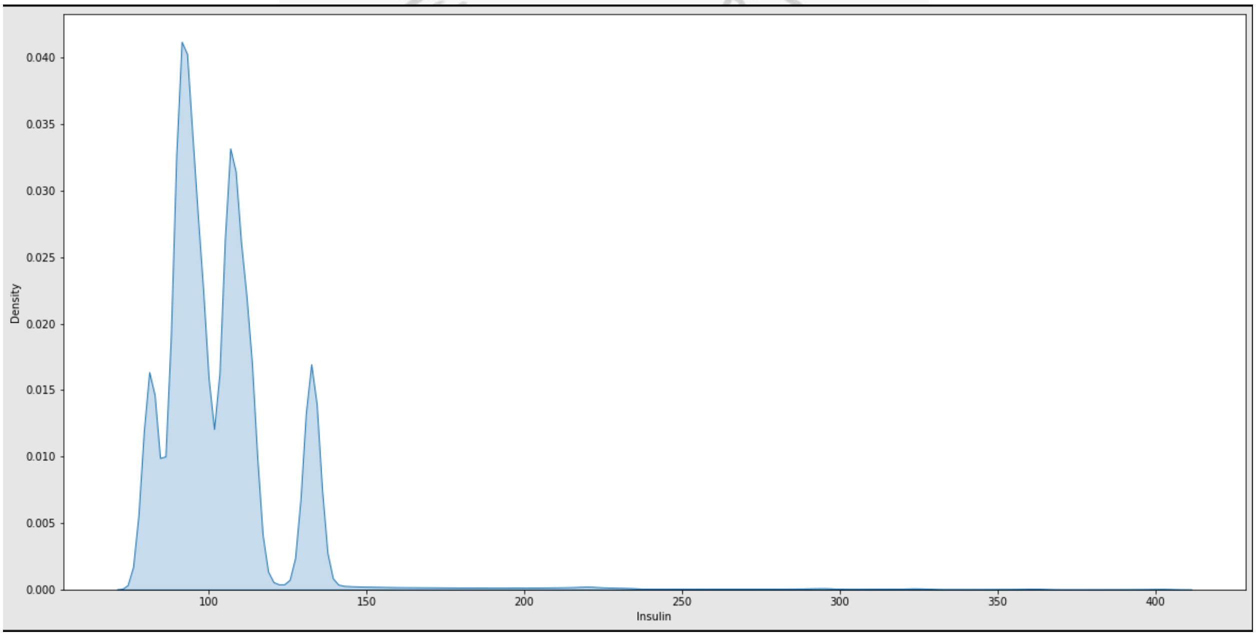


Fig. 14 Insulin density plot (dataset analysis)

**UVA/Padova T1DM Simulator**

The training set for the ML model was generated using FDA Approved T1DMS Software. This software is built upon the Dalla Man's model to represent patient physiology. Using this software involved running simulations of glucose regulations over a period of 1 meal, 1 day (3 meals + 2 snacks) as well as 1 week. This involved using diff hardware setups (IV, SBBG, CGM with error/noise/none). These simulations were done on patients of 3 different age groups, namely: child, adolescent and adult. Moreover, it involved analysis of various BG traces, BG density plots as well as CVGA analysis of patients. Using this data resulted in achieving a model accuracy of 99.94%. The development was done on the google colab server.

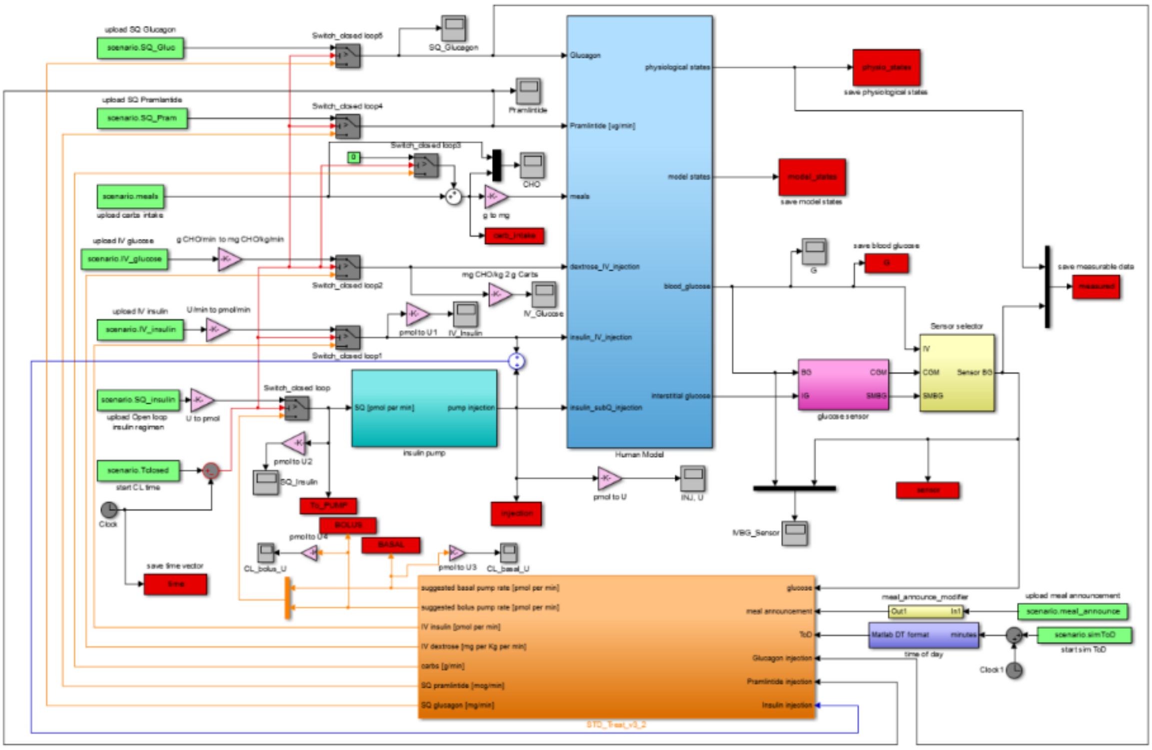

Fig. 15 Simulink Model of the Testing Platform

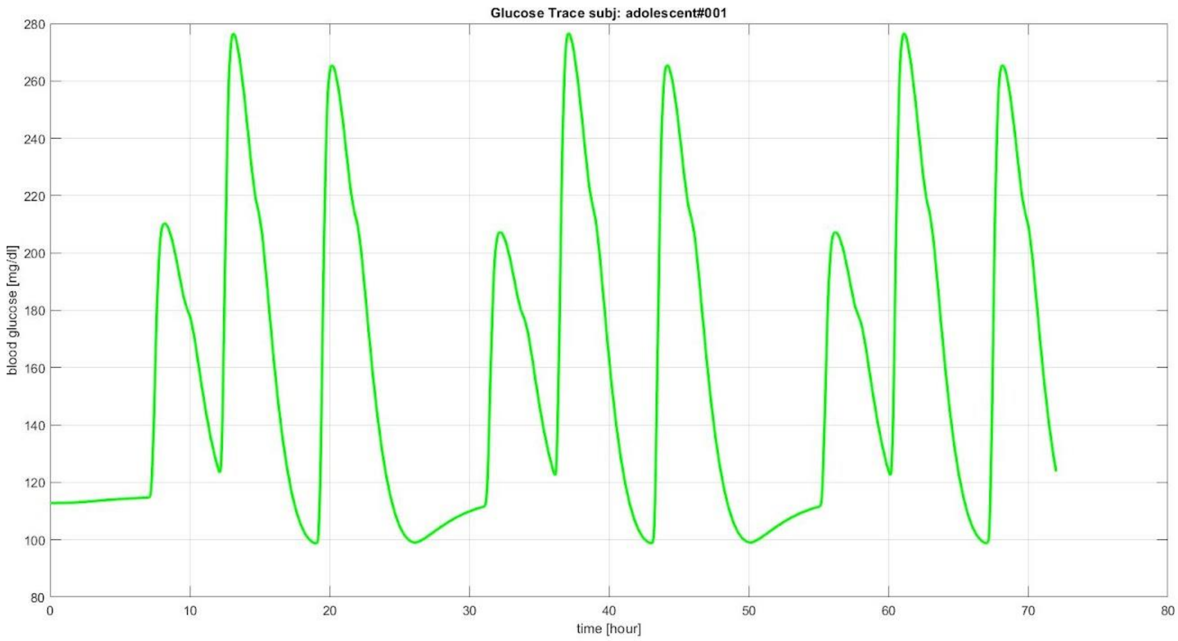


Fig. 16 Glucose trace of 1st adolescent patient

**IoT based Insulin delivery system:**

The predicted insulin dosage is then communicated to the insulin infusion pump (3rd Hardware Iteration Design). To ensure connectivity and wireless communication an ESP8266 module is used. Here the Arduino IoT cloud is being used. We have also created a user friendly dashboard using a function depicting widgets. Here the servo motor is the actuator responsible for driving the crank shaft mechanism for delivery of insulin. The NodeMCU is being used as the actuator controller.

- **Problems faced in developing**

**• Crisis of microcontroller Nvidia Jetson**

The unavailability of NVIDIA Jetson has been a hurdle in our journey so far. The need of this component is important since of the presence of large amounts of data and because of its exceptionally good computing performance. This product is unavailable for sale on a pan india basis. Currently the product is available only on the US website with the lead time 53-60 weeks.

**• Difficulty in designing**

One of the active challenges remains coming up with an innovative product design for the insulin delivery system

**• Collection of relevant data**

Finding verified data sources has been one of the major comebacks in our project till now. The data encountered till now was either incomplete or insufficient to train our model for the desired precision. To make this system available to the indegenious population there is a need to collect data of Indian patients. This can be made possible only by requesting collaboration with hospitals.

- **Coding & outputs**

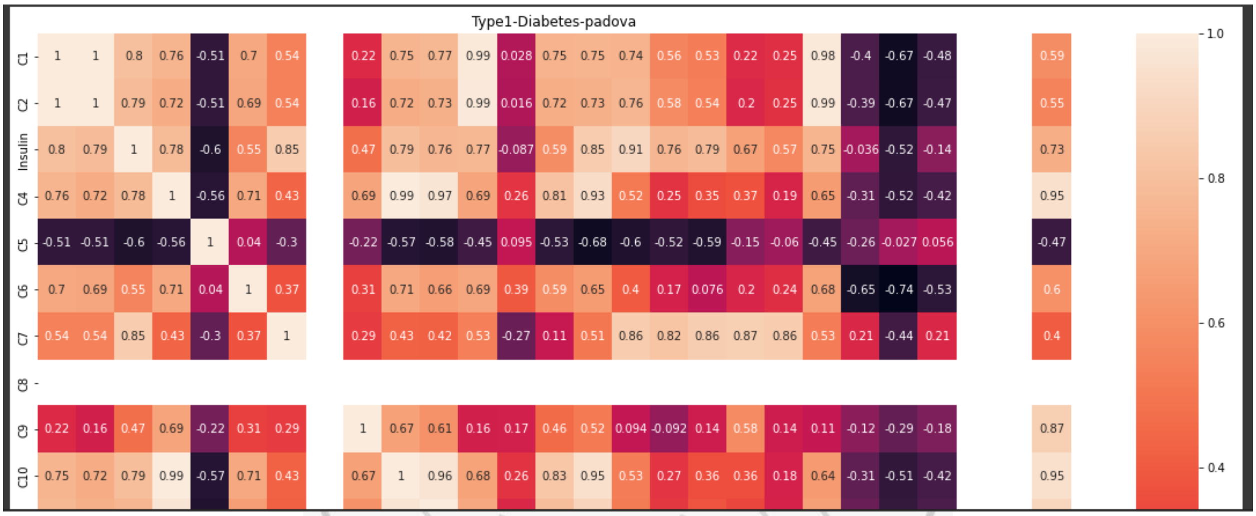




Fig. 17 Heatmap depicting correlation between different parameters of the physiological model used to represent T1D patient

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predicted Insulin Value in pmol/L:  [93.25154509]
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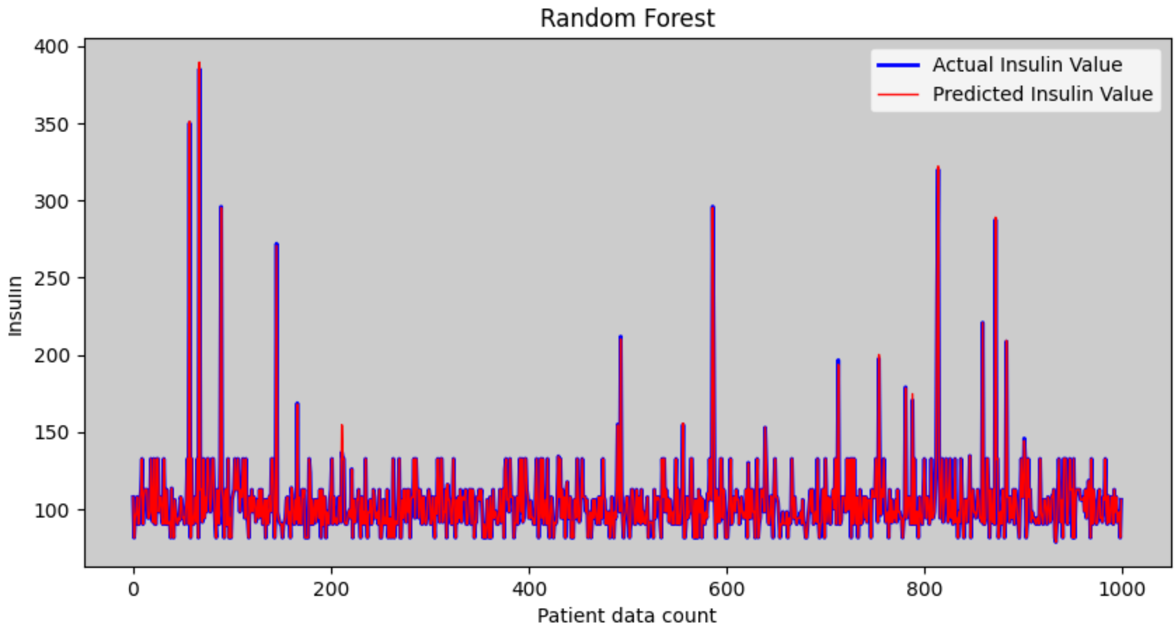
Fig. 18 output insulin value predicted for one of the test data




- **Conclusion & future aspects**

Till the time being, we have come to the conclusion of developing a semi autonomous artificial pancreas system. It involves the process of AI based insulin prediction methodology and smart systems methodology to build up an IoT enabled insulin delivery unit. Our whole project work at this stage is on prototype status and is capable of providing research experimental results.

In the upcoming days, we aim to pick up our prototype unit to a stage so that it can be used for research laboratory testing and clinical trials. To make the device this much efficient we will incorporate the usage of an AI-Edge device (for eg. Nvidia jetson nano developer board). For increasing the efficiency of the AI based insulin prediction system, the goal is to implement reinforcement learning and boost the accuracy of our controller. Implementation of an Edge device in our project will help us to not only increase the self-intelligence capabilities of the aps device but will also help in automating the whole closed loop aps process. The major goal is to collect the Indian T1D patients' data and to create a data driven insulin prediction system for Indian T1D patient's region wise and age wise.

Being an IoT enabled device and working on the Edge network, the aps device will be prone to various cyber attacks. There are major physical units or physical systems which can be easily attacked and manipulated by a cyber attacker, to overcome this we aim to impose a data driven cyber-attack prediction, detection and mitigation algorithm, so as to make this whole device secure from cyber-attacks/ threats.



5. **Want to work on it further?**

yes, we would like to work on this further.

**On which part do you want to work?**

- To automate the whole process by incorporating an Al-Edge device in our Artificial Pancreas System.
- To implement the controller in the form of a Data Driven Reinforcement Learning model to increase the efficiency of the Insulin Prediction Model.
- Collection of Indian T1D patients' data and creating India's first ever T1D insulin Prediction model for Indian T1D patients (region wise and age wise).

**If Need of more fellows than for which part?**

Yes, we require 1 more fellow for making our device AI enabled incorporating reinforcement learning capabilities and automating the whole process on an Edge device.