Dealing with Diabetes and, To Develop an Artificial Pancreas

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Abstract

This scientific study focuses on developing and implementing advanced technological solutions to enhance diabetes management, specifically in terms of insulin and glucagon administration and blood glucose monitoring. The research investigates the complexities of engineering artificial pancreas systems, which automate blood glucose regulation in individuals with diabetes. These systems integrate insulin pumps, glucagon pumps and glucose sensors in a closed-loop configuration, enabling real-time adjustments of insulin and glucagon delivery based on glucose measurements.

The study explores the intricacies of artificial pancreas technology, including the temporal characteristics of insulin action, algorithm selection for glucose control, and challenges related to individual variability and physiological dynamics. Through an in-depth literature review and a model version of an artificial pancreas system, the research illustrates the system's components, functionalities, and operational framework.

Furthermore, the research examines the scientific principles underlying the closed-loop control mechanism of the artificial pancreas system. It investigates optimal timing and dosage adjustments of insulin and glucagon delivery in response to changes in blood glucose levels, prioritizing safety and efficacy. Advanced computational simulations and mathematical modeling optimize the system's performance.

The study's findings provide insights into the challenges faced by engineers and scientists developing artificial pancreas technologies. Accurate glucose sensing, reliable insulin and glucagon delivery, and robust control algorithms are emphasized for optimal glycemic control. The model version of the artificial pancreas system demonstrates its potential to enhance diabetes management through automation, underscoring the need for further advancements in the field.

In conclusion, this investigation comprehensively analyzes the complexities of developing and implementing artificial pancreas systems. The research advances understanding of the challenges involved in designing and optimizing these systems, with the aim of improving the lives of individuals with diabetes. Continued research and development are crucial for advancing personalized diabetes management solutions.

Keywords: Diabetes management, Artificial pancreas systems, Insulin and glucagon administration, Blood glucose monitoring, Closed-loop control, Glucose sensing

Introduction

Scientists and engineers are driven by a common motivation to contribute to the betterment of society through their work. This drive is particularly evident in the field of biomedical engineering, where extensive research efforts are dedicated to the development of improved medical devices and equipment. Among the myriad areas of focus within biomedical engineering, considerable attention is directed towards enhancing the management of diabetes through the creation of smarter glucose monitoring technologies. Diabetes is a chronic medical condition characterized by high blood glucose levels, also known as hyperglycemia. It occurs when the body either does not produce enough insulin or is unable to effectively use the insulin it produces.

There are three main types of diabetes:

Type 1 Diabetes: Also known as insulin-dependent diabetes or juvenile diabetes, this type occurs when the immune system mistakenly attacks and destroys the insulin-producing cells in the pancreas. As a result, individuals with type 1 diabetes require lifelong insulin therapy to control their blood glucose levels.

Type 2 Diabetes: This is the most common form of diabetes, accounting for the majority of cases. Type 2 diabetes typically develops when the body becomes resistant to the effects of insulin or when the pancreas fails to produce enough insulin to meet the body's needs. It is often associated with factors such as obesity, physical inactivity, and genetic predisposition. In the early stages, type 2 diabetes can often be managed through lifestyle modifications, such as adopting a healthy diet, increasing physical activity, and maintaining a healthy weight. In some cases, oral medications or insulin therapy may be necessary.

Gestational Diabetes: Gestational diabetes is a form of diabetes that develops during pregnancy. It is characterized by high blood glucose levels that occur specifically during pregnancy and usually resolves after childbirth. Gestational diabetes occurs when the body is unable to produce or effectively use enough insulin to meet the increased demands of pregnancy.

The pancreas is a vital organ located in the abdomen, behind the stomach. It plays a crucial role in digestion and blood sugar regulation by producing enzymes and hormones.

Structurally, the pancreas is elongated and has a tadpole-like shape. It is approximately six inches long and is composed of two main sections: the exocrine pancreas and the endocrine pancreas.

Exocrine Pancreas: The exocrine pancreas constitutes the majority of pancreatic tissue and is responsible for producing and secreting digestive enzymes. These enzymes, including amylase, lipase, and proteases, are released into the small intestine through a network of ducts. They aid in the breakdown of carbohydrates, fats, and proteins, facilitating their absorption and utilization by the body.

Endocrine Pancreas: The endocrine pancreas is responsible for producing and releasing hormones directly into the bloodstream to regulate various physiological processes. The endocrine portion of the pancreas is made up of specialized clusters of cells called the islets of Langerhans. The islets contain different types of cells, including:

Beta Cells: These cells produce and secrete the hormone insulin, which regulates blood sugar levels by facilitating the uptake and utilization of glucose by cells in the body.

Alpha Cells: These cells produce and release the hormone glucagon, which acts in opposition to insulin. Glucagon helps increase blood sugar levels by stimulating the release of stored glucose from the liver.

Delta Cells: These cells produce somatostatin, a hormone that inhibits the secretion of both insulin and glucagon, thus playing a regulatory role in blood sugar control.

Other Cells: The islets also contain other types of cells, such as gamma cells that produce pancreatic polypeptide (PP), which helps regulate pancreatic secretions, and epsilon cells that produce ghrelin, a hormone involved in appetite regulation.

An exemplary innovation in this domain is the artificial pancreas, that collaborates with a continuous glucose monitor to automate aspects of blood glucose maintenance and monitoring. Insulin is a hormone that plays a crucial role in regulating blood sugar (glucose) levels in the body. It is produced by the pancreas, specifically by specialized cells called beta cells located in the islets of Langerhans. When we consume food, especially carbohydrates, our digestive system breaks down the carbohydrates into glucose, which enters the bloodstream. Glucagon is a hormone that is produced and released by the alpha cells of the pancreas. It acts in opposition to insulin, serving as a key regulator of blood sugar levels in the body. While insulin lowers blood sugar levels, glucagon raises them.

By efficiently regulating insulin levels and glucagon levels, artificial pancreas systems aim to empower individuals in effectively controlling their blood glucose levels. These technologically advanced systems assume responsibility for critical decisions and calculations related to insulin and glucagon therapy, enabling round-the-clock monitoring and timely adjustments, often implemented every few minutes. By relieving the burden associated with diabetes management, these systems hold the potential to revolutionize the field and enhance overall disease management. Nevertheless, the creation of devices capable of successfully managing blood glucose levels is a highly intricate task, encompassing numerous variables. The pancreas itself undertakes an intricate biological role that necessitates the replication of its functionality through an intricate combination of electronic, chemical, and biological elements.

Engaging in a project of this nature provides an opportunity to explore the intricate complexities that engineers and scientists encounter as they strive to develop artificial pancreas technologies. To appreciate the significance of artificial pancreas technology, it is essential to revisit the fundamentals of diabetes. The human body relies on a simple sugar called glucose as its primary source of fuel, obtained from the food we consume. Both table sugar, known as sucrose, and other types of carbohydrates such as starch, found abundantly in noodles and grain-rich foods, are broken down within our bodies to generate glucose. Consequently, the ingestion of food leads to an increase in the level of glucose present in an individual's bloodstream, commonly referred to as blood glucose level. It is worth noting that blood glucose is usually measured in milligrams per deciliter (mg/dL) in the United States, although different units may be used in other countries.

Similar to numerous chemicals in the bloodstream, glucose necessitates strict regulation. The level of glucose within the blood is meticulously regulated by a hormone known as insulin, which is produced by the pancreas. Following the consumption of a meal, when blood glucose levels rise, the pancreas releases insulin. This hormone prompts cells within the body, including liver, muscle, and fat cells, to actively uptake glucose from the blood, storing it in the form of glycogen for future energy requirements. Conversely, when blood glucose levels begin to decline, the pancreas ceases insulin secretion, resulting in the utilization of the stored glucose for energy purposes. In instances where blood glucose levels become excessively low, the pancreas responds by producing another hormone called glucagon, which functions to elevate glucose levels. This intricate interplay of the pancreas and its hormones exemplifies the mechanisms employed by the body to regulate blood glucose levels.

In the case of individuals with type 1 diabetes, an autoimmune response leads to the pancreas no longer producing insulin. The absence of insulin in the body of a person with type 1 diabetes can result in dangerously high blood glucose levels, a condition known as hyperglycemia. Type 2 diabetes, which accounts for the majority of diabetes cases, manifests as insulin resistance, wherein the body exhibits an inadequate response to insulin or the pancreas fails to produce sufficient amounts of this hormone. At present, individuals diagnosed with type 1 diabetes (and some with type 2 diabetes) must rely on insulin administration to manage their condition. While insulin aids in blood sugar control, its usage is far from a once-a-day medication, and determining the appropriate insulin dosage is a complex undertaking. Numerous factors, including exercise, stress, illness, and the type and quantity of food consumed, influence insulin levels within an individual's body. People with diabetes must calculate insulin doses based on the ratio of carbohydrates they consume, administer additional amounts when blood glucose levels are elevated, and maintain a constant supply of basal insulin throughout the day, even during periods of fasting. (It is important to note that individuals without diabetes possess a pancreas that automatically monitors and computes these variables.)

Maintaining blood glucose levels within the desired range is crucial, as excessively high (hyperglycemia) or low (hypoglycemia) levels can precipitate severe health complications. Consequently, individuals with type 1 diabetes frequently find themselves continuously monitoring their blood glucose levels, considering the potential impact of their actions on these levels, and adjusting their insulin doses to avoid dangerous fluctuations. In the context of artificial pancreas technology, certain systems are often referred to as "loops." Hybrid loop systems, for instance, partially automate insulin delivery, requiring individuals with diabetes to input information about their carbohydrate intake and other factors influencing blood glucose levels. Users must also program the pump with data pertaining to their hourly basal insulin requirements, the insulin-to-carbohydrate ratio at different times of the day, and the quantity of insulin necessary to decrease blood glucose levels by a certain amount. This information, combined with continuous glucose monitor readings and knowledge regarding the duration of insulin activity within the body, contributes to the management of insulin delivery and blood glucose levels. Engaging in an experiment involving the use of an insulin pump and a continuous glucose sensor to manage type 1 diabetes provides valuable insights into the functionality and practicality of artificial pancreas systems. An artificial pancreas comprises three integrated components working synergistically to replicate the intricate control of blood glucose levels found in a healthy pancreas. Such systems primarily benefit individuals diagnosed with type 1 diabetes.

Now equipped with a comprehensive understanding of type 1 diabetes and the concept of an artificial pancreas, you may be contemplating how to conduct a science fair project related to insulin pumps or artificial pancreas technology. In this project, you will explore the automation of insulin delivery in response to blood glucose levels by constructing a simplified model of an artificial pancreas. Distilled water and tap water will be employed to represent blood and insulin, respectively, within the model. The electrical conductivity of the liquids will serve as the measured parameter instead of glucose content. By constructing a circuit that yields a voltage output, variations in the conductivity of distilled water and tap water can be detected.

In summary, biomedical engineering endeavors are fueled by a profound desire to assist individuals in need. One specific area where this motivation is evident is the development of advanced medical technologies, including artificial pancreas systems, aimed at enhancing the management of diabetes. By emulating the biological functions of a healthy pancreas, these systems can revolutionize diabetes care and alleviate the challenges faced by individuals with the condition. Designing and implementing a science fair project involving an artificial pancreas model provides a unique opportunity to explore the intricate complexities and potential solutions within this field of research.

Materials and Methodology

➢ Materials

- Solderless breadboard
- Arduino UNO
- Male-male jumper wires
- USB A-B cable
- 5V peristaltic liquid pump (note: a 12V version of this pump is also available, but it requires an external power supply. The 5V version can be powered directly from your Arduino.)
- N-channel MOSFET
- 100 kΩ resistor
- Alligator clip leads
- Recommended: multimeter

You will also need the following supplies:

- Computer with USB-B port
- Bowls or food storage containers (2)
- Aluminum foil
- Tape
- Corks or packing foam
- Toothpick
- Tap water
- Distilled water
- Optional: food coloring
- Dish towels or paper towels
- Fine-tipped permanent marker

➢ Methodology

• Background

In our research, we have embarked on a novel approach to simulate the intricate workings of an actual pancreas system. By utilizing four substitutes, we aim to create a simplified model that enables us to study and analyze the dynamics of blood glucose levels, with a focus on the regulatory roles of insulin, glucagon, and glycogen. Our unique methodology involves using tap water with added salt to represent blood, distilled water as a substitute for insulin, water with salt (low concentrated) to mimic glucagon, and a distinct representation of glycogen. Through these substitutions, we can observe and evaluate the impact of different scenarios on blood glucose levels within our simulated system.

Tap water with added salt continues to serve as a substitute for blood due to its inherent conductivity, which closely mirrors the conductive properties of actual blood. Blood contains electrolytes, salts, ions, and dissolved substances that contribute to its relatively high conductivity. By introducing salt to tap water, we are able to enhance its conductivity, providing a viable approximation of blood conductivity. This substitution allows us to monitor changes in conductivity as a proxy for blood glucose levels.

In our model, distilled water represents insulin, a critical hormone produced by the pancreas to regulate blood glucose levels. Insulin plays a crucial role in facilitating the uptake of glucose by cells, thereby reducing blood glucose levels. By using distilled water as a substitute for insulin, we can observe the effects of insulin introduction into the system and assess its impact on the conductivity of the tap water solution. As distilled water has a low conductivity, it effectively represents the behavior of insulin in our simulated system.

To expand the scope of our model, we have introduced a separate substitute for glucagon. Glucagon is an essential hormone that counteracts the actions of insulin. It is responsible for raising blood glucose levels by promoting the release of stored glucose from glycogen reserves. In our simulation, water serves as a substitute for glucagon. While water may not capture the full complexity of glucagon's biochemical properties, it allows us to simulate its function of releasing stored glucose and increasing blood glucose levels. The addition of water to the system represents the introduction of glucagon and its subsequent impact on blood glucose levels.

Moreover, we have incorporated a distinct representation for glycogen, a complex carbohydrate that acts as a storage medium for glucose in the liver and muscles. In our model, we introduce a medium that mimics the characteristics and behavior of glycogen. This substitute can be water or any other suitable solution that allows us to simulate the storage and release of glucose from glycogen reserves. By manipulating the presence or absence of this substitute, we can observe the storage and release of glucose in our simulated system.

The voltage difference that occurs when we combine the tap water solution with added salt, distilled water (representing insulin), water (representing glucagon), and the glycogen substitute enables us to evaluate the blood glucose levels within our simulated system. This voltage difference can be seen as a reflection of the overall conductivity of the solution, representing the concentration of glucose and the presence of insulin, glucagon, and glycogen. Changes in the voltage difference indicate variations in blood glucose levels within our model. To simulate scenarios where blood glucose levels are elevated, we introduce the glucagon substitute (water) to the tap water solution with added salt. This addition emulates the introduction of glucagon into the system, triggering the release of stored glucose and ultimately raising blood glucose levels. By monitoring changes in conductivity and the resulting voltage difference, we can assess the effectiveness of the simulated glucagon in increasing blood glucose levels.

Conversely, to simulate scenarios where blood glucose levels decrease, we can introduce distilled water (representing insulin) to the tap water solution with added salt and low concentrated salt water (representing glycogen). The addition of distilled water dilutes the solution, reducing overall conductivity and leading to a decrease.

Human Body	Artificial Pancreas
Blood	Tap water with salt (high concentration)
Insulin	Distilled water
Glucagon	Tap water with salt (low concentration)
Blood glucose level	Voltage
Adding insulin to blood with high glucose levels, cause glucose levels to decrease.	Adding distilled water to tap water with salt causes the voltage to decrease.
Adding glucagon to blood with low glucose levels, cause glucose levels to increase.	Adding tap water with salt to tap water with salt causes the voltage to increase.

- **Factors To consider**

  Within our model, three key factors contribute to the functionality and effectiveness of our simulation: conductivity of the solution, the voltage divider, and the pump. Each of these elements plays a crucial role in the dynamics of our system, allowing us to measure blood glucose levels, provide input to the microcontroller, and actuate decisions through the pumps.

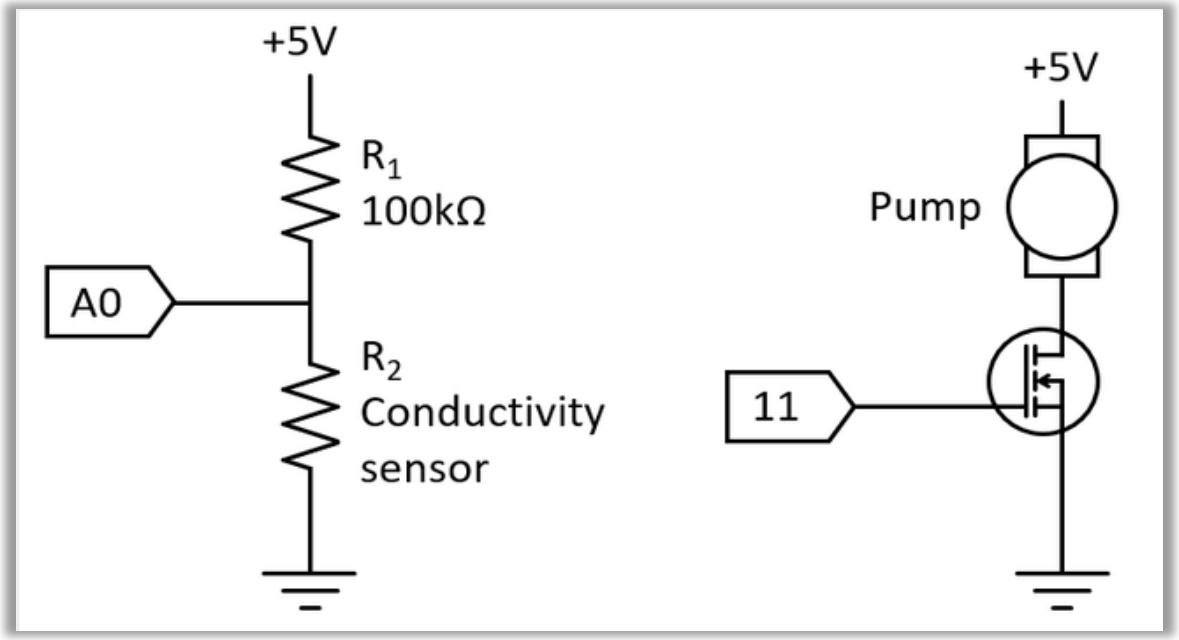
  First and foremost, the conductivity of our solution serves as a vital metric for determining blood glucose levels within our simulated system. As mentioned earlier, we have carefully selected substitutes that mimic the conductive properties of blood, such as tap water with added salt representing blood, distilled water for insulin, and water for glucagon. By closely monitoring changes in conductivity, we can gain insights into the variations in blood glucose levels. Conductivity acts as a surrogate measure, reflecting the concentration of glucose and the presence of insulin and glucagon in our simulated system. Following tables shows different conductivity ranges of different types of water.

Water Type	Conductance Range (µS/cm)
Distilled water	0.5 – 3
Snow (melted)	2 – 42
Tap water	50 – 800
Potable water	30 – 1,500
Fresh water streams	100 – 2,000
Sea water	55,000

To capture and interpret conductivity values effectively, we employ a voltage divider mechanism. The voltage divider is a crucial component that allows us to feed conductivity values to the microcontroller, enabling precise measurements and data collection. This setup consists of resistive elements and appropriate connections that divide the input voltage across different points, generating an output voltage proportional to the conductivity of the solution. By leveraging the voltage divider, we can effectively convert conductivity changes into measurable electrical signals for further analysis.

$$v_{out} = v_{in}\left(\frac{R_2}{R_1 + R_2}\right)$$

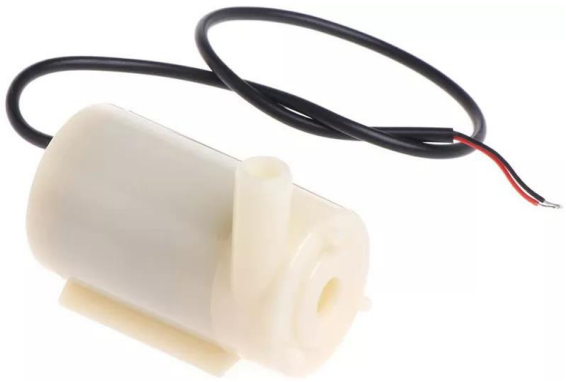
Voltage Divider Law



Voltage Divider of our system

The microcontroller, which receives input from the voltage divider, plays a pivotal role in processing and interpreting the obtained data. Equipped with algorithms and decision-making capabilities, the microcontroller analyzes the conductivity values to derive information about blood glucose levels within our simulated system. Based on these assessments, the microcontroller triggers specific actions to regulate blood glucose levels through the use of pumps.

In our research, we have implemented two pumps: one for insulin and the other for glucagon. The primary purpose of these pumps is to actuate decisions made by the microcontroller in response to the observed blood glucose levels. If the conductivity readings indicate high blood glucose levels, the microcontroller activates the insulin pump. This pump delivers the simulated insulin substitute (distilled water) into the solution, mirroring the action of insulin in reducing blood glucose levels by facilitating glucose uptake into cells. Conversely, when the conductivity readings suggest low blood glucose levels, the microcontroller activates the glucagon pump. The glucagon pump introduces the glucagon substitute (water) into the solution, simulating the function of glucagon in promoting the release of stored glucose from glycogen reserves, thereby increasing blood glucose levels.



Industrial pump which used for consistency

Homemade pump used in test 1

Through the coordinated functioning of the voltage divider, microcontroller, and pumps, our model demonstrates an autonomous and dynamic regulation of blood glucose levels. As the conductivity values change, the microcontroller receives the input, interprets the data, and triggers the appropriate pump to maintain or restore the desired blood glucose levels within our simulated system.

- **Procedure**

  Creating the model involves several steps. Firstly, the construction of a conductivity sensor is necessary. This involves assembling the required components and designing the circuit that can accurately measure the conductivity of the solution. The conductivity sensor serves as a fundamental tool for assessing the blood glucose levels in our simulated system.

  Next, the circuit needs to be built to connect the conductivity sensor to an Arduino or similar microcontroller. This circuit ensures the proper transmission of data from the sensor to the microcontroller, enabling real-time monitoring and analysis of conductivity values. It is crucial to follow the circuit design carefully and make appropriate connections to ensure the accuracy and reliability of the measurements.

  Once the circuit is set up, it is essential to calibrate the Arduino readings. Calibration involves establishing a reference point or standard conductivity values to which the readings can be compared. This step helps in ensuring the accuracy and precision of the measurements taken by the conductivity sensor. By calibrating the Arduino, we can account for any inherent variations or deviations in the sensor's output.

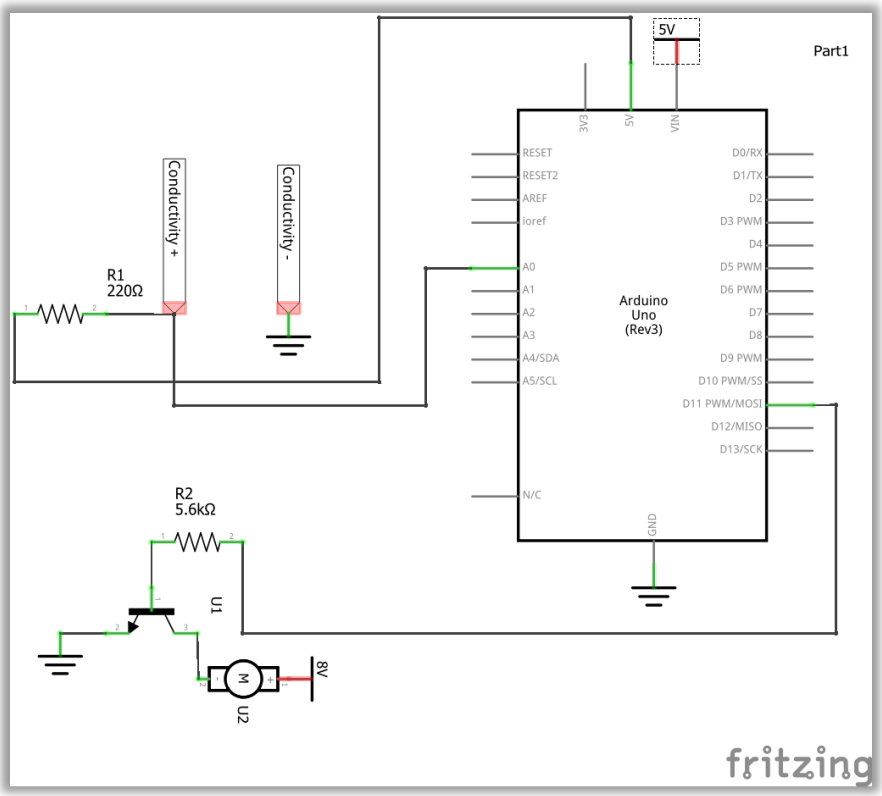
  After calibration, the conductivity sensor can be activated, and the measurements can be initiated. Starting the conductivity sensor involves providing power to the circuit, initializing the Arduino, and ensuring that the sensor is in contact with the solution whose conductivity is to be measured. This step allows us to collect real-time conductivity data, which is vital for monitoring and analyzing blood glucose levels within our simulated system.

  Simultaneously, it is crucial to ensure that the direction of the pump is correct. The pump's functionality and directionality must align with the intended action based on the conductivity readings. If the readings indicate high blood glucose levels, the pump should be set to deliver the simulated insulin substitute to the solution. Conversely, if the readings indicate low blood glucose levels, the pump should be set to introduce the simulated glucagon substitute into the solution. Verifying the correct direction of the pump is essential for accurately simulating the actions of insulin and glucagon in regulating blood glucose levels.

  By following these steps, we can create an artificial pancreas model that utilizes a conductivity sensor, a calibrated Arduino, and appropriate pump actions to simulate the regulation of blood glucose levels. This model provides a valuable tool for studying and understanding the dynamics of glucose regulation and the potential effectiveness of different therapeutic interventions in managing diabetes.

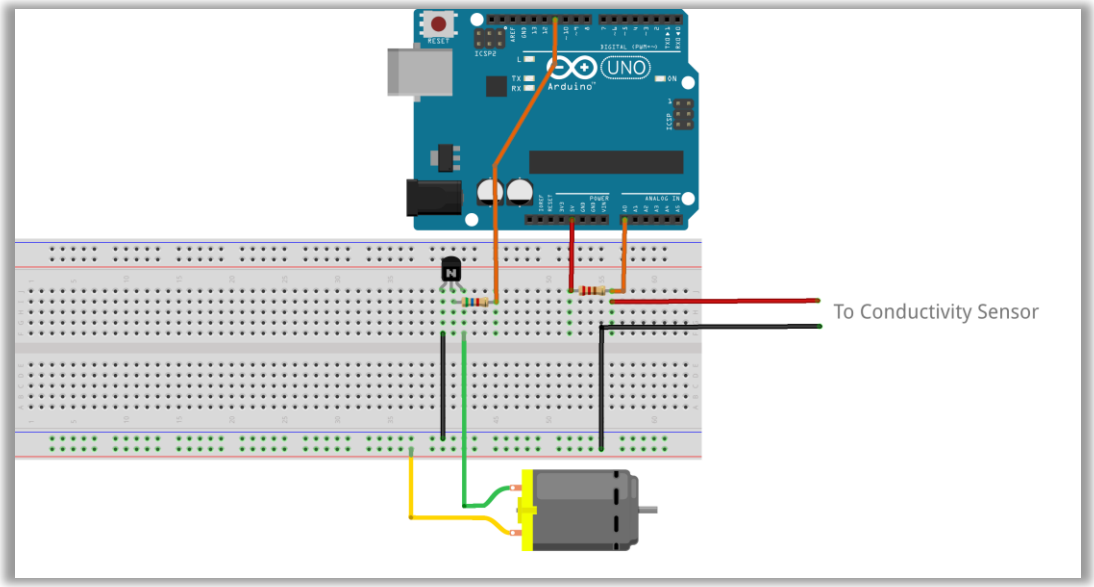
- **Circuit**

The circuit is composed of a voltage divider that convers the conductivity readings of the sensor to a value readable by the microcontroller. Two motors are present to control the pumps accordingly in order to regulate the blood glucose levels.



Circuit diagram

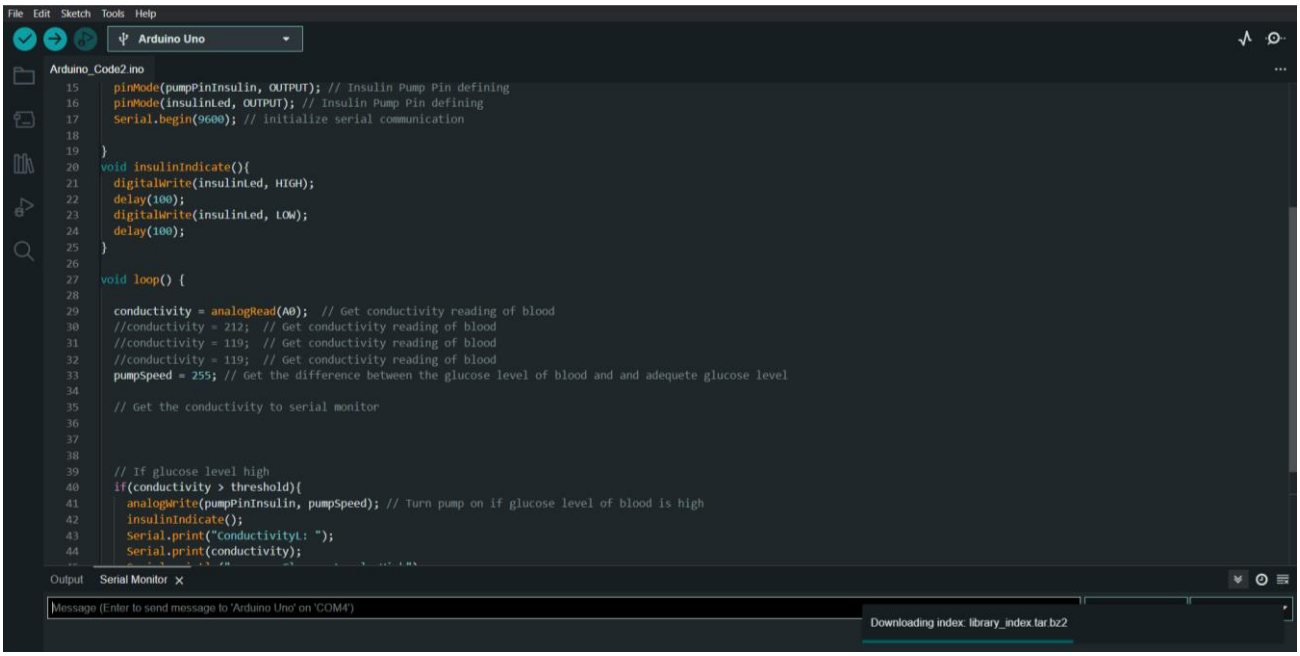
(2nd test – insulin pump only)



2nd test – insulin pump only

- **System Code**

  The system code (Arduino code) consists of 2 if comparators which read the conductivity of the solution. They both have a given threshold value (One for high blood glucose levels and the other for low levels) and if the reading is above or below these values, the pumps will be turned on to bring them to that value. Following picture is an image taken while uploading the code to the Arduino board (Brain of our Artificial Pancreas).



Discussion

In this experiment, it is important to consider the differences in density between the substitutes used and actual blood, insulin, and glucagon. The substitutes may not perfectly mimic the properties of real blood, insulin, and glucagon, which can affect the action of the pump and the response time. It is crucial to acknowledge this potential variation in the results.

Furthermore, the reaction time of insulin and glucagon is a critical factor to consider. Some insulins take several hours to complete their processes, whereas the reaction in this experiment is almost immediate. This difference in reaction time can lead to disparities in the results obtained. The rate at which insulin and glucagon are injected also plays a significant role. If the injection rate is too low, the system may take an extended period to respond. Conversely, if the rate is too high, it can overwhelm the system and cause malfunctions. It is essential to test and adjust the injection rate to ensure an appropriate and optimal response.

The accuracy of the experiment relies heavily on the precision of data entry. It is crucial to enter the data accurately and include all the necessary information. Any errors made during data entry can result in misleading or inaccurate results, emphasizing the importance of careful and meticulous data handling. Conducting the experiment in a controlled environment is necessary. Maintaining a constant room temperature is particularly critical, as even slight temperature fluctuations can influence the experimental outcomes. Close monitoring of the experiment is essential to track any changes in the environment or the test subject. It is vital to record any deviations or alterations that occur during the experiment to establish a comprehensive understanding of the potential influences on the results.

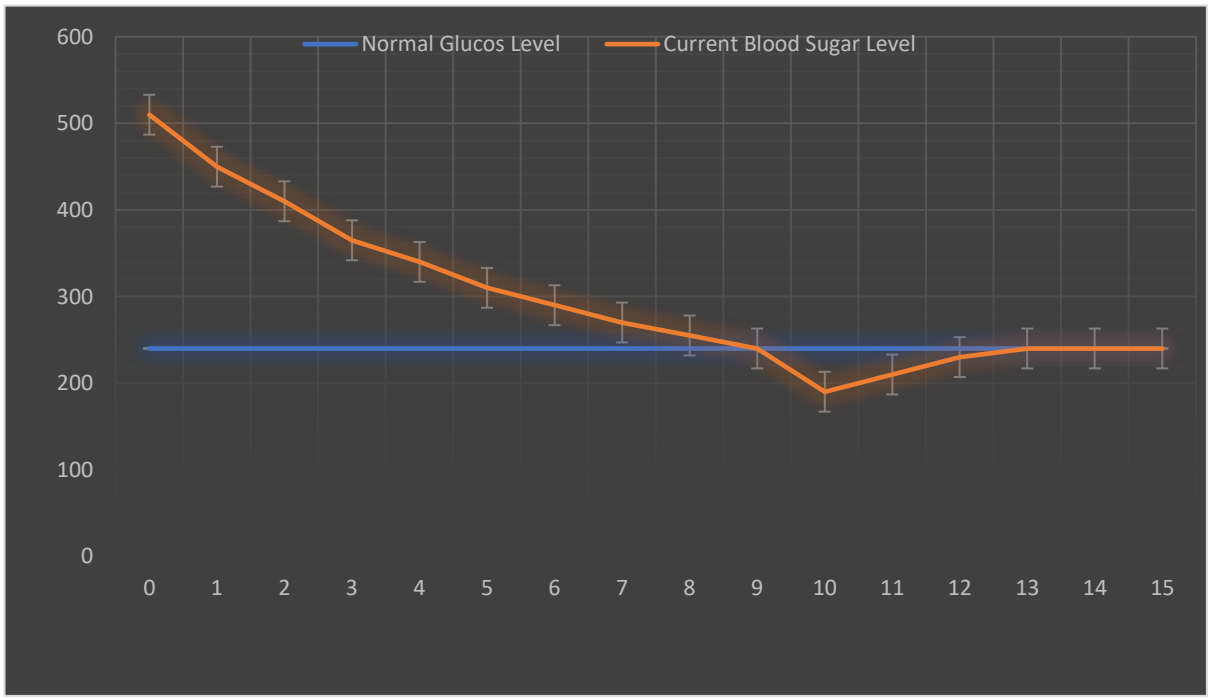
To ensure reliability, the experiment should be repeated multiple times to assess its consistency. Any inconsistencies in the results should be thoroughly investigated to identify potential sources of error or variation. If the results consistently align, they can be considered accurate and reliable. In advancement of this research, we are planning to test this with actual blood, insulin and glucagon as a self-clinical trial and using CGM technology apply this to CGM and make the pump starts automatically pumping. Also using the refractometer technology by measuring concentration of sugar in blood, we planned to do some clinical tests to make this possible to install into human body externally. In conclusion, this experiment demands careful attention to detail and precision. It is imperative to consider all the relevant factors and variables to ensure accurate results. Adhering to rigorous scientific practices and conducting further testing in clinical trials can provide valuable insights and validation for the application of the artificial pancreas system in the human body. The system has been tested in clinical trials and has been found to be effective. However, there are still some issues to be addressed as we have mentioned in the above section there is a potential for errors as well. Scientists around the world are working on systems that can solve these issues as well.

Results

The current treatment for diabetes involves the administration of insulin or glucagon through injections, along with regular monitoring of blood glucose levels. In our experiment, we aimed to develop an Artificial Pancreas System that can help individuals with diabetes regulate their blood glucose levels more effectively.

Our Artificial Pancreas System consists of a sensor that continuously monitors the blood glucose levels and triggers the appropriate response based on the changes detected. In response to high blood glucose levels, the system automatically initiates the pumping of insulin to bring the levels back to a normal range. Similarly, when the sensor detects low blood glucose levels, the system activates the glucagon pump to increase the levels.

During the experiment, we successfully observed the functionality of the system. The pump started injecting insulin when the sensor readings indicated high blood glucose levels and ceased automatically once the desired target value was reached. Additionally, to test the efficiency of the glucagon pump, we manually increased the conductivity by adding more distilled water (acting as insulin substitute) and observed the response of the system. The glucagon pump effectively started pumping tap water mixed with salt (acting as glucagon substitute) when the sensor readings indicated low blood glucose levels and stopped when the defined target value was attained. Following graph shows how the blood glucose level(conductivity) was regulated by the artificial pancreas system.



By demonstrating the successful operation of our Artificial Pancreas System, we aim to provide a potential solution for individuals with diabetes to better manage their blood glucose levels. It offers the advantages of continuous monitoring and automatic response, reducing the need for frequent manual interventions. However, even this system tested in clinical trials, further refinement and testing are necessary before implementing such a system in real-world clinical settings.

In the case of Type 1 diabetes, where the body fails to produce sufficient insulin, our system can provide the necessary insulin supplementation, emulating the function of a healthy pancreas. By closely monitoring glucose levels and administering the appropriate amount of insulin, the system can help individuals with Type 1 diabetes maintain more stable blood glucose levels.

Similarly, for gestational diabetes, which occurs during pregnancy and is characterized by insulin resistance, our Artificial Pancreas System can adaptively respond to the changing glucose levels and administer the required amount of insulin. This can help manage gestational diabetes more effectively, reducing the risks associated with high blood glucose levels during pregnancy.

By focusing on treating this 10% subset of people with diabetes, our Artificial Pancreas System aims to provide a specialized solution tailored to the specific needs and challenges faced by individuals with Type 1 and gestational diabetes. However, it is important to note that further research, testing, and clinical validation are necessary before widespread implementation of the system. Rigorous evaluation and collaboration with healthcare professionals will be crucial in ensuring its safety, efficacy, and suitability for the intended population.

To provide visual evidence of the experiment, we have included some images showcasing the test setup and the functioning of the system.

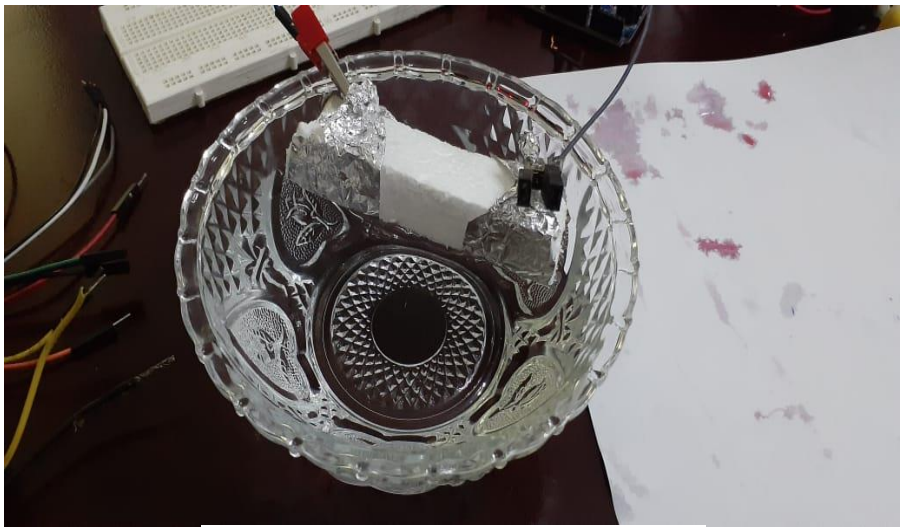


Photo of the conductivity sensor

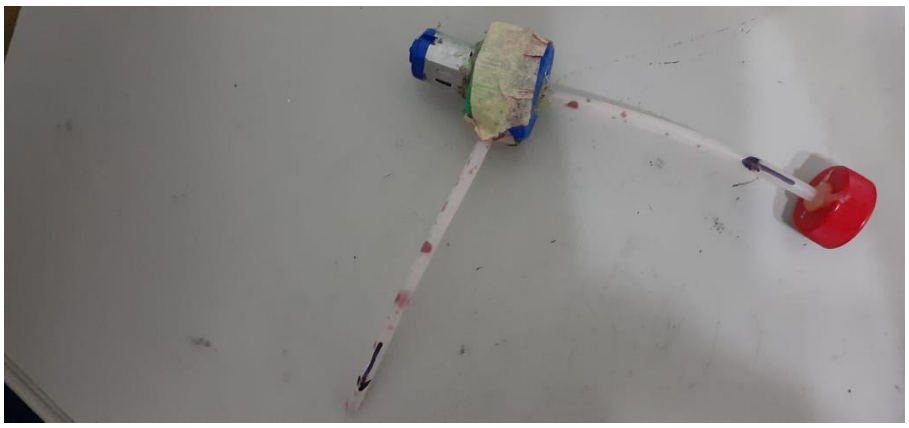


Photo of the homemade water pump

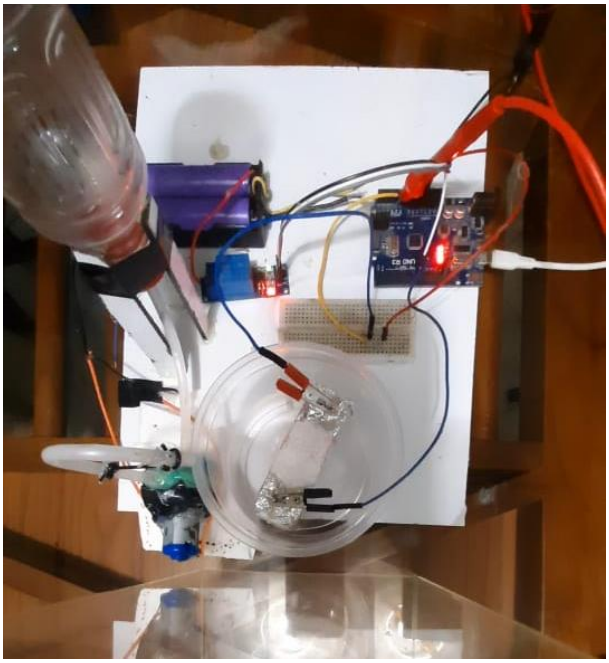


Photo before pumping
1st test (without glucagon pump)

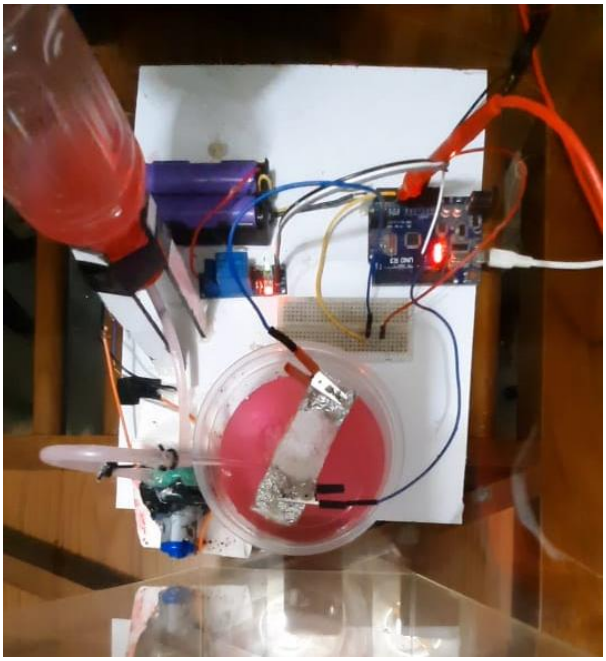
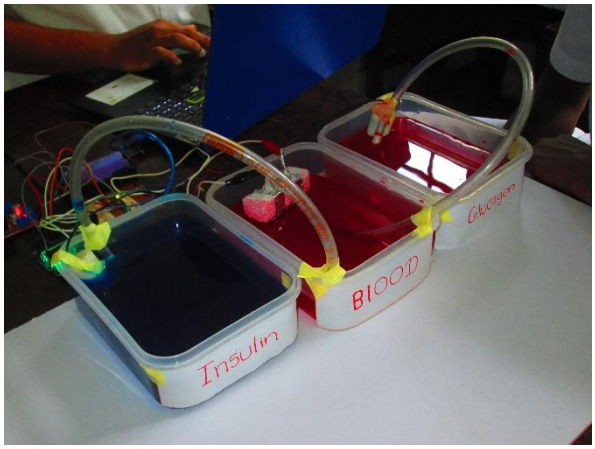
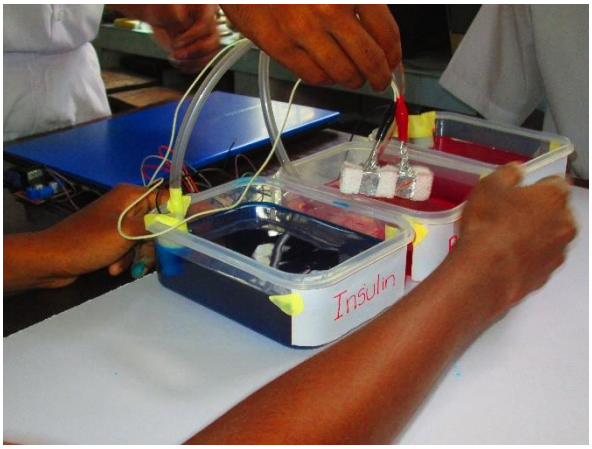


Photo while pumping
1st test (without glucagon pump)



3rd test (with glucagon pump)



3rd test (with glucagon pump)

Implementation

Based on data provided by Health Data Research UK and the British Heart Foundation, it is estimated that approximately 8% of individuals diagnosed with diabetes worldwide have Type 1 diabetes, while around 90% have Type 2 diabetes. Additionally, approximately 2% of people experience gestational diabetes during pregnancy.

Our developed Artificial Pancreas System holds the potential to address the needs of 10% of individuals with diabetes, encompassing both Type 1 and gestational diabetes. By implementing this system, we aim to provide an effective treatment approach for this specific subset of the diabetic population.

The Artificial Pancreas System operates by continuously monitoring blood glucose levels and autonomously administering insulin or glucagon, as required, to maintain glucose levels within a target range. This automated and adaptive approach offers potential benefits for individuals with both Type 1 and gestational diabetes, helping to regulate blood glucose levels more effectively and reducing the burden of manual interventions. The system has been tested in clinical trials and has been found to be effective. However, there are still some issues to be addressed as we have mentioned in the above section there is a potential for errors as well. Scientists around the world are working on systems that can solve these issues as well.

Conclusion and recommendations

In conclusion, the development of an artificial pancreas system, comprising a hybrid loop system, holds immense potential in revolutionizing the management of diabetes. Through the integration of a continuous glucose monitor, insulin pump, glucagon pump, and sophisticated computer algorithms, this autonomous technology empowers individuals with diabetes to effectively monitor and regulate their blood glucose levels. The continuous glucose monitor provides real-time measurements, enabling timely interventions, while the insulin and glucagon pumps deliver the necessary hormones to maintain glucose homeostasis. The computer algorithm processes the data collected from the monitor and pumps, making calculated decisions on the required dosage adjustments.

Extensive clinical trials have demonstrated the effectiveness of artificial pancreas systems in reducing the risks of hypoglycemia and hyperglycemia, as well as alleviating the burden of manual monitoring for patients. However, it is crucial to address certain challenges associated with these systems. The potential for errors, such as inaccurate glucose measurements and improper hormone delivery, highlights the need for continuous advancements in sensor technologies, algorithm optimization, and personalized approaches.

Researchers worldwide are actively engaged in refining and enhancing artificial pancreas systems to address these challenges. Ongoing studies explore novel sensor technologies, including optical coherence tomography and wearable biosensors, to improve glucose measurement accuracy and reduce calibration requirements. Algorithmic approaches, such as model predictive control and fuzzy logic-based algorithms, are being refined to achieve optimal insulin delivery and precise glucose regulation. Moreover, the integration of personalized approaches, considering individual insulin sensitivity and responsiveness, holds promise in tailoring treatment to the specific needs of each patient.

In conclusion, the development and optimization of artificial pancreas systems represent a significant step forward in diabetes management. By harnessing advancements in sensor technologies, algorithms, and personalized approaches, these systems have the potential to enhance the quality of life for individuals with diabetes, ensuring better glucose control and reducing the risks of long-term complications. Further research and development efforts are essential to address the remaining challenges and realize the full potential of artificial pancreas technology in transforming diabetes care.

It is recommended to follow established protocols and guidelines while conducting further experiments and recreating the hybrid loop system. Attention should be given to rigorous calibration procedures, data validation, and ensuring accurate hormone delivery to ensure the reliability and safety of the artificial pancreas system. In furtherance of this research, our proposed plan involves conducting a comprehensive investigation utilizing genuine blood samples, encompassing insulin and glucagon components, as part of a self-clinical trial. Additionally, we intend to leverage Continuous Glucose Monitoring (CGM) technology to seamlessly integrate our findings and enable automatic initiation of the pumping mechanism. Moreover, we aim to employ refractometer technology to accurately measure the sugar concentration in the blood for conducting rigorous clinical tests, thereby establishing the feasibility of external installation of this system within the human body. Through following link, you can see the working artificial pancreas system (2nd test without glucagon pump) with serial printer of Arduino IDE application.

Test 2.mp4

Literature Review

Diabetes management has witnessed significant advancements with the development of artificial pancreas systems. These systems aim to automate insulin delivery based on real-time blood glucose measurements, providing individuals with diabetes a more streamlined and effective approach to maintaining stable blood glucose levels. In this literature review, we will explore existing research on optimizing insulin delivery algorithms for artificial pancreas systems to enhance their performance and improve diabetes management.

1. Current State of Artificial Pancreas Systems: Several studies have demonstrated the potential benefits of artificial pancreas systems in improving glycemic control. For example, Hovorka et al. (2016) conducted a randomized controlled trial that showed superior glucose control with closed-loop systems compared to conventional insulin pump therapy. The study emphasized the importance of accurate insulin delivery algorithms in achieving optimal glucose regulation.
2. Algorithm Development and Optimization: Researchers have focused on developing and refining insulin delivery algorithms for artificial pancreas systems. Breton et al. (2012) proposed a model predictive control (MPC) algorithm that utilized real-time continuous glucose monitoring (CGM) data to predict future glucose levels and adjust insulin delivery accordingly. Their study demonstrated improved glucose control and reduced hypoglycemic events compared to open-loop insulin pump therapy.
3. Personalization and Adaptation: Personalizing insulin delivery algorithms based on individual characteristics and physiological responses is another area of active research. Chernavvsky et al. (2017) presented an adaptive algorithm that incorporated patient-specific parameters, such as insulin sensitivity and meal absorption rates, to optimize glucose regulation. Their results showed enhanced glucose control and minimized postprandial excursions.
4. Sensor Technologies for Improved Glucose Monitoring: Accurate and reliable glucose monitoring is crucial for the performance of artificial pancreas systems. Recent advancements in sensor technologies, such as the development of more accurate and minimally invasive continuous glucose monitors (CGMs), have further improved the capabilities of these systems. For instance, Bergenstal et al. (2016) evaluated the performance of a next-generation CGM system and found it to be highly accurate, enabling precise insulin delivery adjustments.
5. Machine Learning Approaches: Integration of machine learning techniques into insulin delivery algorithms has shown promise in improving glucose control. Del Favero et al. (2018) developed a hybrid model combining MPC and machine learning to adapt to individual patient responses over time. Their study demonstrated enhanced glucose control, reduced hypoglycemia, and improved patient satisfaction.

Bibliography

- Khan Academy. (n.d.). Blood sugar levels. Retrieved July 27, 2022.
- Beyond Type 1 (2018, June 29). WHAT IS TYPE 1 DIABETES?. Retrieved July 27, 2022.
- Juvenile Diabetes Research Foundation (JDRF). (2013, July 31). JDRF: Artificial Pancreas. Retrieved July 27, 2022.
- U.S. Food and Drug Administration (2018, August 30). What is the pancreas? What is an artificial pancreas device system?. Retrieved July 27, 2022.
- National Institute of Diabetes and Digestive and Kidney Diseases (2021, October). Artificial Pancreas. Retrieved July 27, 2022
- The Dale Tribe (2016, November 14). A DAY IN THE LIFE OF A TYPE 1 DIABETIC. Retrieved July 28, 2022.

References

- **https://www.niddk.nih.gov/health-information/diabetes/overview/managing-diabetes/artificial-pancreas#:~:text=These%20systems%20help%20control%20blood,people%20with%20type%201%20diabetes**
- **https://learn.sparkfun.com/tutorials/voltage-current-resistance-and-ohms-law/electricity-basics**
- **https://learn.sparkfun.com/tutorials/voltage-current-resistance-and-ohms-law/electricity-basics**
- **https://www.sciencebuddies.org/science-fair-projects/references/how-to-use-an-arduino**
- **https://www.arduino.cc/reference/en/**

*Note: By clicking with Ctrl key (Ctrl + click) on links provided in references, bibliography and Arduino code you can visit the website or the code.