Dealing with Diabetes and, To Develop an Artificial Pancreas

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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 and glucagon pumps or artificial pancreas technology. In this project, you will explore the automation of insulin and glucagon delivery in response to blood glucose levels by constructing a simplified model of an artificial pancreas. Tap water with salt, distilled water and tap water will be employed to represent blood, insulin and glucagon 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.

Aims and objectives

➢ Aim

- An artificial pancreas may help people with type 1 diabetes reach their target blood glucose levels and improve their quality of life. With an artificial pancreas model, inventors and engineers can get an idea about Artificial pancreas to measure glucose. The computer program improves blood glucose control by automatically adjusting the amount of insulin it delivers to keep your blood glucose levels in range.

➢ Objectives

- Creating an Artificial pancreas system that can take in information and can dispense insulin automatically based on real time changes in blood sugar levels.
- Making the operation of such systems easier.
- Creating a system that can help users maintain their blood sugar levels at a favorable condition more accurately and securely.

Problem

About 422 million people worldwide have diabetes, and 1.5 million deaths are directly attributed to diabetes each year. Type 1 diabetes occurs when your immune system, the body’s system for fighting infection, attacks and destroys the insulin-producing beta cells of the pancreas. At present there is no Artificial Pancreas. There are devices make up an artificial pancreas system. Such as Continuous Glucose Monitor (CGM). But they are not 100% accurate. So, where is Artificial Pancreas to reduce deaths and cases of diabetes.

Hypothesis

Constructing a simplified model of an artificial pancreas and exploring the automation of insulin delivery in response to blood glucose levels will demonstrate the feasibility and effectiveness of artificial pancreas systems in regulating and maintaining blood glucose levels, potentially providing valuable insights for the development of advanced medical technologies for diabetes management.

Importance

Most artificial pancreas systems require you to count and enter the amount of carbohydrates you consume at mealtime. These are called “hybrid” artificial pancreas systems, because some of the insulin is given automatically and some is given based on the information you enter. These systems help control blood glucose levels throughout the day and night, making it easier for people with type 1 diabetes to keep their blood glucose level in range. Keeping blood glucose levels in range will prevent other health problems from developing and may improve daily life for people with type 1 diabetes.

An artificial pancreas automatically monitors your blood glucose level, calculates the amount of insulin and glucagon you need at different points during the day, and delivers it.

Tap water with added salt is very conductive. In our model, it will represent blood with high sugar content, which will cause the circuit to output a high voltage. Distilled water is low conductive than that of tap water, so when you add it to tap water with salt, the conductivity decreases. This means you can use distilled water to represent insulin in your model. When you add it to tap water with added salt, the conductivity will decrease, and the circuit's output voltage will drop, corresponding to a decrease in blood sugar in the model. And again, when you add salt added tap water to tap water which the distilled water added and conductivity drops, again the conductivity increases, corresponding to an increase in blood sugar in the model. Following Table summarizes what happens in the real physical system (the human body) and what is used to represent the same parameters and behaviors in the model.

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.

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

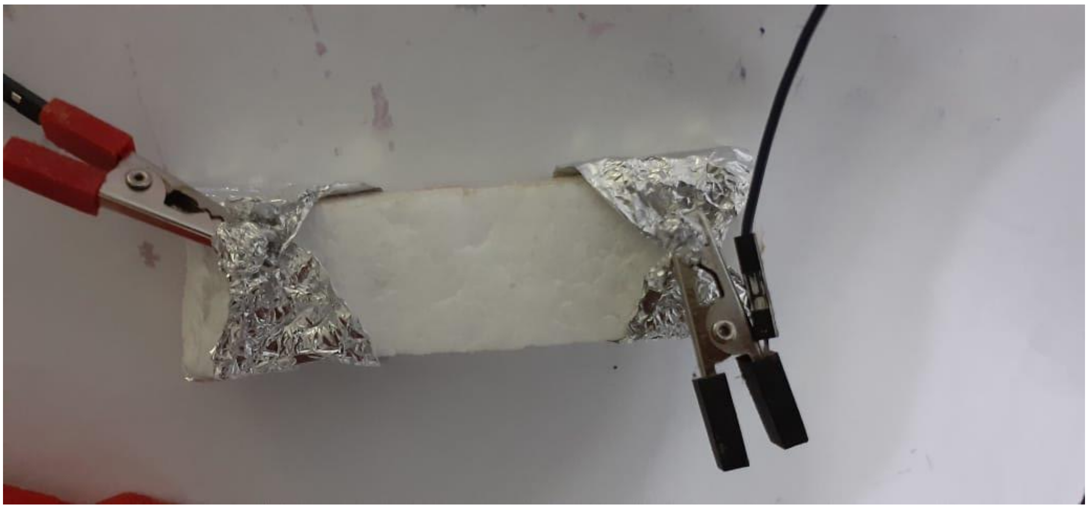
You will also need the following supplies:

- 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

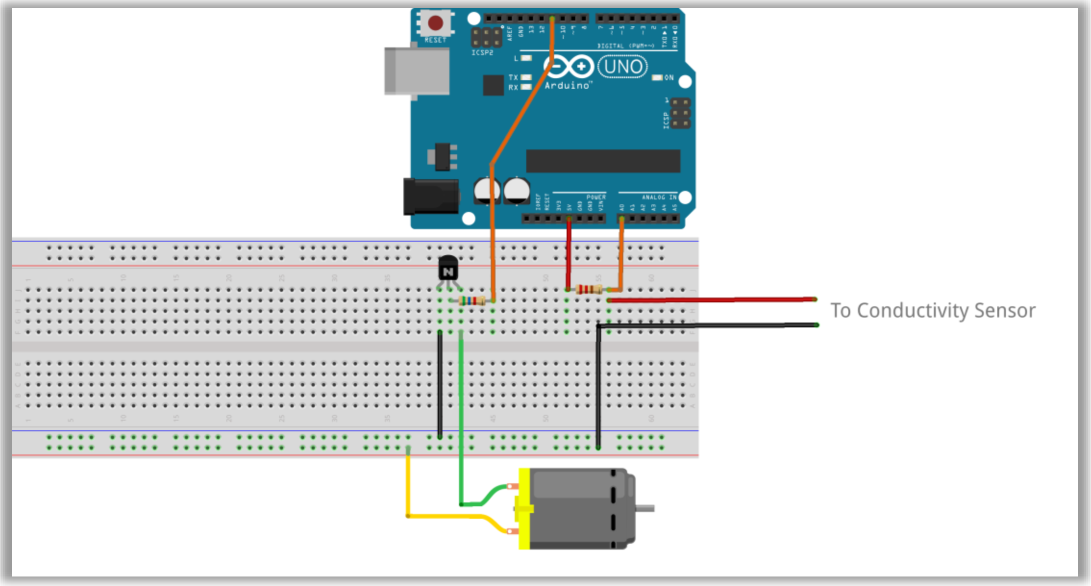
- **Step 1**

Building the conductivity sensor using two strips of aluminum foil and a piece (or pieces) of floating material.

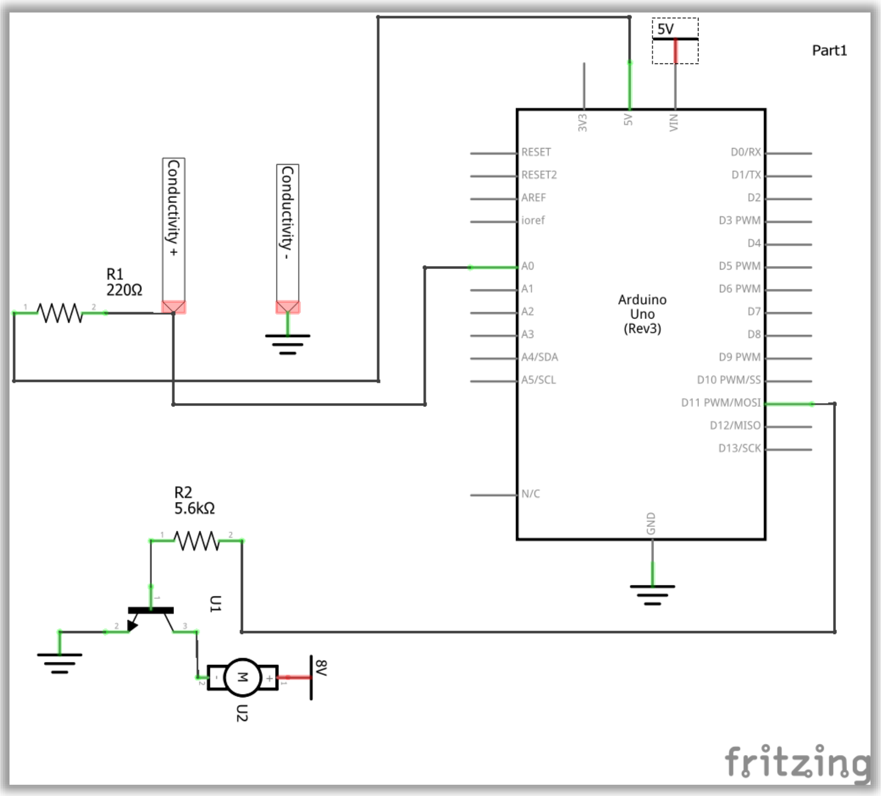


- **Step 2**

Building the Circuit.



2nd test – insulin pump only



Circuit diagram

(2nd test – insulin pump only)

- ## Step 3

Calibrating the Arduino readings.

Upload the [Arduino code] first. Then, remove the pump from the circuit (To avoid it from suddenly turning on). Adjust the values in the code according to the below readings.

A - Calibrating the Arduino readings for tap water with salt (float the conductivity sensor on tap water and measure the voltage that goes to A0. Then, follow the equation, voltage/5*1023 to get the average reading.)

B – Clean the conductivity sensor and follow the same procedure for distilled water.

- **Step 4**

The above A and B readings are the maximum and minimum blood sugar levels for the model experiment. Our goal is to start the conductivity sensor out in a container of tap water with salt (which represents high blood glucose). The code will measure the voltage from the conductivity sensor and automatically turn on the insulin pump to start adding distilled water to the container (to simulate adding insulin). This will cause the voltage to start dropping. When the voltage drops below a certain threshold that is defined, the code will automatically turn the pump off. And after adding more distilled water to it manually, automatically turn on the glucagon pump to start adding tap water with salt to the container (to simulate adding glucagon). This models the behavior of an artificial pancreas, which would monitor blood glucose levels and apply insulin until glucose levels dropped (or were predicted to drop) and glucagon until glucose level increased to an acceptable level.

- **Step 5**

Make sure that the direction of the pump is correct (1st inlet should be in distilled water and 2nd inlet should be in low concentrated tap water with salt while both the outlet should be in high concentrated tap water with salt.) Put the conductivity sensor again to the container with tap water after cleaning it.

- **Step 6**

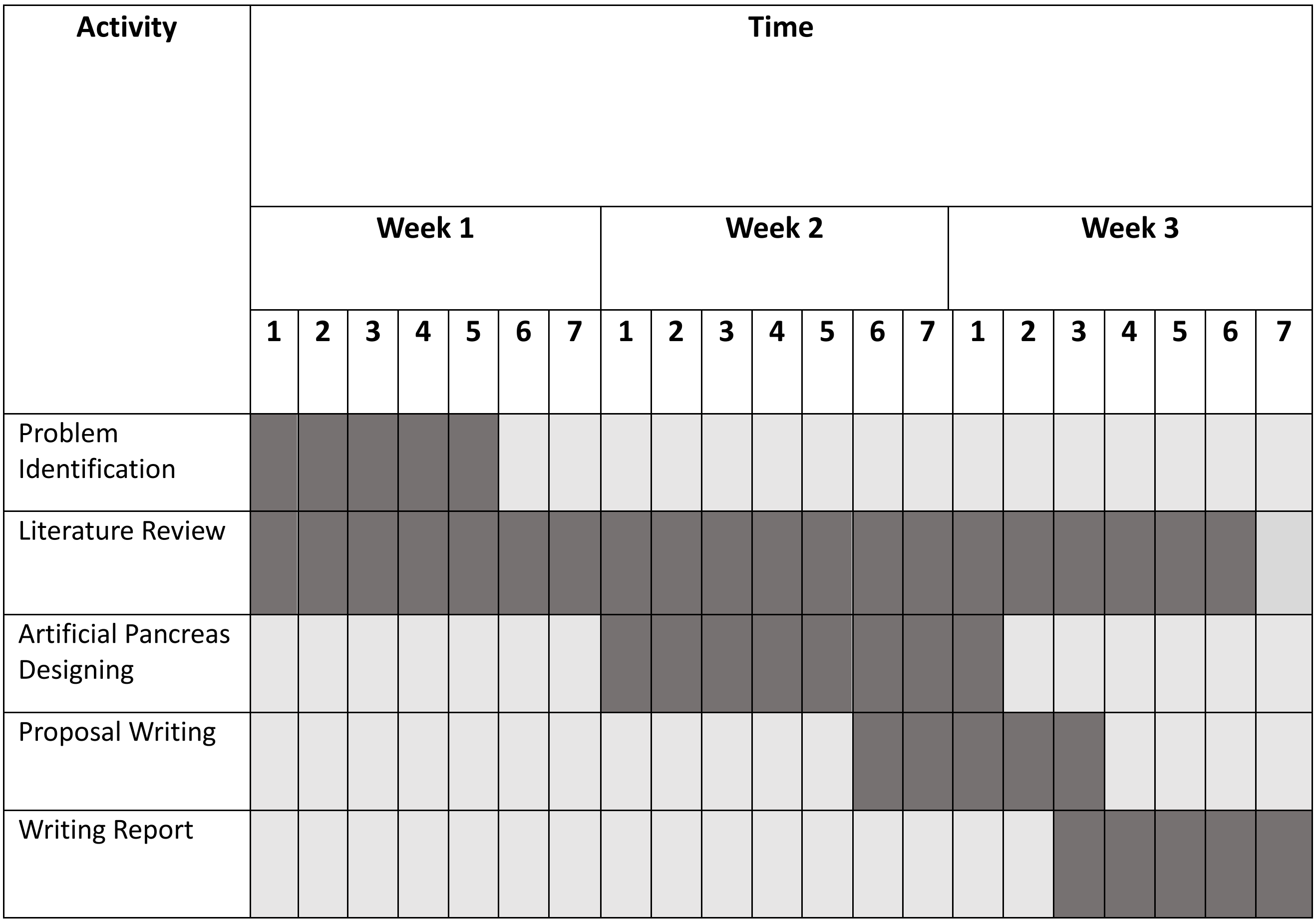
Connect the pumps again. It should start working instantly. This is because it is in tap water with salt (High blood glucose). The pump will automatically stop working after the reading from the conductivity sensor reaches the threshold value defined by the Arduino code.

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.

Gannt chart



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Research links

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