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Article

Design and Implementation Low-Power Device for Non-Invasive Blood Glucose

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Abstract: Glucose is a simple sugar molecule. The sugar molecule is chemically symbolised as $C_6H_{12}O_6$. This means that the glucose molecule contains 6 carbon atoms (C), 12 hydrogen atoms (H) and 6 oxygen atoms (O). In human blood, the molecule glucose circulates as blood sugar. Normally after eating or drinking, our body breaks down the sugars in food and uses them to obtain energy for our cells. To do this, our pancreas produces insulin. Insulin "pulls" sugar from the blood and puts it into the cells for use. If someone has diabetes, their pancreas can't produce enough insulin. As a result, the level of glucose in the blood rises. This can lead one to many potential complications, including blindness, disease, nerve damage, amputation, stroke, heart attack and damage to blood vessels etc. In this study, a non-invasive method for monitoring blood glucose has been developed and is therefore easily usable. The device developed can measure the glucose level continuously and eliminates the disadvantages of the invasive system. Near-IR sensors (optical sensors) were used to estimate the concentration of glucose in the blood; these sensors have a wavelength of 940 nm. The sensor is placed on the tip of the finger and the output of the optical sensor is then connected to the microcontroller at the analogue input. Another sensor used, but only to provide more medical information was the heartbeat sensor. After processing and regression analysis, the glucose level is predicted, and data is sent via the Bluetooth network to a developed APP. The results of the implemented device were compared with available invasive methods. The study consists of a hardware platform inserted into an armband and then a small black parallelepiped-shaped box in which the optical sensors are inserted. The hardware consists of a microcontroller, a Near-IR optical sensor, a heartbeat sensor and a Bluetooth module.

Keywords: blood glucose monitoring; embedded systems; heartbeat sensor; Near-IR sensors

1. Introduction

Carbohydrates are molecules of enormous biological importance that have empirical formulas such as $C_n(H_2O)_n$ or $C_n(H_2O)_{n-1}$. These formulas suggest they are "hydrates of carbon" and that is why early chemists gave them the general name carbohydrates. We commonly call carbohydrates sugars, and they are also known as saccharides. They are organic compounds shown by the formula. Since these compounds are synthesized through photosynthesis in plants, they are mostly components specific to plant foods. However, they can also be found as the building blocks of many vital tissues in animals. Glucose is the most important carbohydrate group called simple sugar (monosaccharide) and is abundant in foods. Another area where determining glucose values is very important is the health sector. Measurements to determine blood glucose levels are important in the treatment of patients with diabetes and hyperglycemia [1]. Diabetes Mellitus is a very common hereditary disease today; It causes blindness, heart attack, kidney failure, amputation and, in later stages, death. The rapidly increasing number of patients makes it necessary to control and constantly monitor diabetes. Monitoring diabetes is also extremely important in terms of reducing the progression of the disease

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and healthcare costs [2]. Noninvasive techniques for blood glucose monitoring have gained significant research interest due to high sensitivity and better patient compliance, unlike invasive ones. Typical non-invasive biosensors based on different approaches include iontophoretic extraction of glucose from the skin, surface plasmon resonance, Raman spectroscopy, visible or near-infrared (NIR) spectroscopy, polarimetry, photo-acoustic probes and fluorescence methods. These methods may be an alternative option for continuous glucose measurement [3]. Optical detection of glucose allows for more frequent and better monitoring for people with diabetes. The development and creation of low-cost, non-invasive glucose measuring equipment would generate interest both among people who suffer from diabetes and among people who do not yet suffer but are in risk groups. One advantage of being non-invasive is that there are people who avoid taking the test using conventional invasive equipment, because they don't like the prospect of getting their finger pricked (its uncomfortable and could lead to infections) and others who are very sensitive to the sight of blood, making self-testing by a conventional invasive equipment unlikely for a good part of the population. It would allow the acquisition by everyone of an equipment that would be used regularly at home and at work, allowing continuous monitoring and control and thus preventing a sudden emergency in the population already suffering from this disease (if blood glucose remains too high or is steadily rising, the person will speak with their doctor as they may need to adjust their treatment) or even the increase of the population with this problem.

The environmental aspect cannot be forgotten either, as the fact that we stop using (and throw away) meter blood strips as well as having to periodically change the needles of the conventional equipment's is another point in favor of a change to the use of non-invasive equipment.

The key to a successful noninvasive optical measurement of glucose is the collection of an optical spectrum with a very high signal-to-noise ratio in a spectral region containing significant glucose. Optical sensors exploit different interaction properties of light with glucose molecules in a concentration-dependent manner. Infrared (IR) provides an optical window through which it passes subcutaneously, independent of the epidermis and skin pigmentation [3].

The aim of this study is to demonstrate the detectability of glucose with infrared light and its subsequent improvement so that people can measure blood sugar non-invasively in the future. In this promising experimental study, concentration-dependent determination of glucose was performed, and the results were recorded.

2. Research and System Design

This section explains the elements that make up the architecture of this project: microcontroller (Arduino Uno), optical sensors, heartbeat sensor and wireless communication via the Bluetooth network. The firmware flowchart and its explanation are also presented. As well as the experimental tests and all the results obtained, which prove the functionality of the work as defined.

2.1. Ligth Spectrum and 940nm Infrared Spectrum

Within the vast electromagnetic spectrum, beyond the boundaries of human vision, lies the enigmatic realm of infrared radiation. Among its myriad wavelengths, the 940nm infrared spectrum stands out for its diverse applications across various fields, from telecommunications to healthcare [4] [5]. In this work, we embark on a journey to explore the intricacies of the 940nm IR spectrum, shedding light on its properties, practical uses, and significance in contemporary science and technology.

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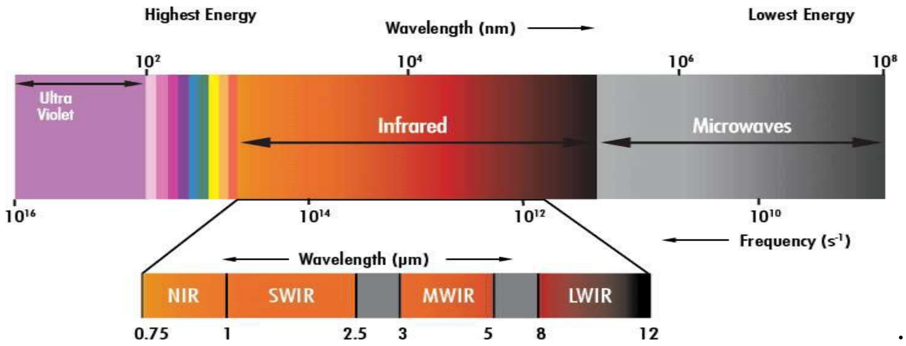

Figure 1. Light spectrum [6].

The electromagnetic spectrum encompasses a broad range of wavelengths (the wavelength is the distance between repetitions of a wave), including those of visible light and beyond. Situated adjacent to the visible spectrum, the infrared region comprises wavelengths longer than those of visible light. Within this domain, the 940nm wavelength occupies a special place, offering unique characteristics that make it indispensable for numerous applications [4] [5].

The versatility of the 940nm infrared spectrum lends itself to a wide array of applications, each harnessing its distinct properties to achieve specific objectives. Let's delve into some key domains where the 940nm IR spectrum plays a pivotal role:

Telecommunications and Data Transmission: The 940nm wavelength serves as a cornerstone for optical communication systems, enabling high-speed data transmission over fiber optic networks. Its ability to travel through optical fibers with minimal attenuation ensures efficient and reliable communication over short/medium distances (e.g. LAN). **Vertical Cavity Surface Emitting Lasers (VCSELs), for example, operates at 940 nm.**

Sensing and Imaging Technologies: In fields such as surveillance, medical diagnostics, and environmental monitoring, the 940nm infrared spectrum is instrumental in enhancing sensing and imaging capabilities. Night vision cameras, for instance, utilize 940nm IR illuminators to capture clear images in low-light conditions, while medical devices leverage near-infrared spectroscopy (NIRS) for non-invasive tissue analysis.

Biomedical and Healthcare Applications: Researchers and healthcare practitioners harness the 940nm infrared spectrum for various biomedical applications, including diagnostics and therapeutic interventions. Near-infrared light, at 940nm wavelength, exhibits excellent tissue penetration properties, making it suitable for deep tissue imaging and photo biomodulation therapy [4] [5].

Security and Defense Systems: In the realm of security and defense, infrared technology, including the 940nm spectrum, plays a critical role in surveillance and threat detection. Infrared surveillance cameras equipped with 940nm IR illuminators enable covert monitoring and perimeter protection, enhancing security measures in both civilian and military contexts.

In resume, 940nm infrared spectrum represents a fascinating intersection of science, technology, and innovation, offering a glimpse into the invisible forces that shape our world. From facilitating high-speed communication to advancing medical diagnostics and bolstering security, its applications are as diverse as they are profound. As we continue to unlock the potential of the 940nm IR spectrum, it serves as a testament to human ingenuity and our relentless quest to explore the unseen [5].

2.2. System Design

This section explains the elements that make up the architecture of this project: microcontroller (Arduino Uno), optical sensors (near IR), heartbeat sensor and wireless communication via the Bluetooth network.

Figure 2 shows the project's block diagram, which consists of a microcontroller (Arduino Uno), the main component as it receives information from the optical Near IR sensor and the heartbeat sensor, the two sensors used in the project. The Arduino is powered by 5 VDC so that it can work,

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receive data from the sensor and send it via the Bluetooth module. The Bluetooth module communicates this data with the application.

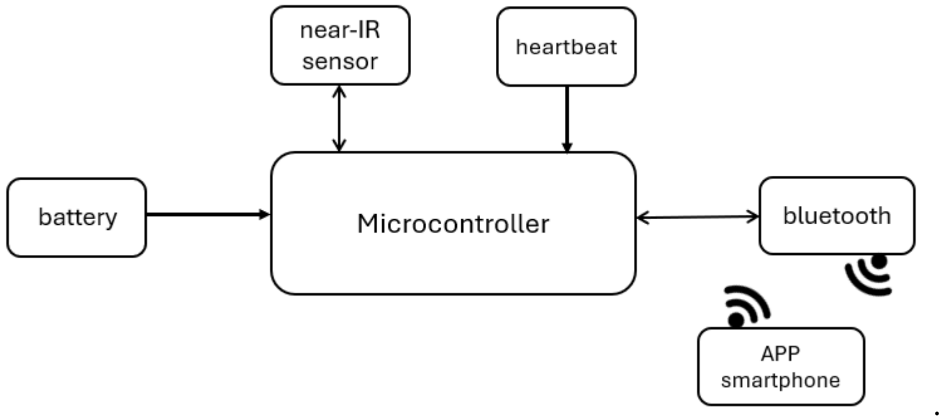

Figure 2. System architecture.

The development board used for this project is Arduino Uno [7], with the ATMega328 microcontroller [8]. The ATMega328 is a low-power chip, so it only needs 1.8-5.5 VDC to work, which is one of the main advantages of implementing it on Arduino boards, making power consumption extremely low [8]. This microcontroller has an Analogue-to-Digital Converter (ADC) with ten-bit resolution. With this ADC it is possible to measure analogue signals and convert them into digital values for processing. Some of the features of the ADC in the ATMega328 are:

- Ten-bit resolution: Converts analogue signals into digital ones allowing through this resolution to produce 210 (1024) possible values for each conversion.
- Input voltage range: Possibility of measuring input voltages in the 0 V to 5 V range.
- Input channels: This ADC offers six input channels, labelled ADC0 to ADC5, each of which can be individually selected for conversion.
- Sample rate: The ADC's maximum sample rate is 15,000 samples per second.

In addition to these features, the ADC uses the process of successive approximations to carry out the conversion. This process consists of a binary search algorithm to determine the digital representation of the analogue input signal. In this process, the ADC compares the analogue input voltage with a reference voltage and determines whether this voltage is higher or lower than the reference voltage. This process is repeated until the digital representation of the input voltage is determined within the desired resolution, which in the case of this microcontroller is 10 bits. The process of successive approximations is an efficient ADC conversion method for producing precise results with relatively low power consumption. However, there are other methods that are faster and more effective, such as flash conversion, which can provide a conversion time in just one clock cycle. Unfortunately, flash converters consume more power and need many comparators, making them impractical for precisions greater than 8 bits.

Sensors are devices which, using energy from the medium being measured, provide the output with a processable signal that is a function of a measurement variable. A sensor is classified as a device which, when subjected to the action of a non-electrical physical quantity, produces a characteristic of an electrical nature. Although the concept is broader, the concept of sensor and transducer is often confused. Transducers are devices that convert a signal of one physical form into another of a different physical form; in short, they convert one type of energy into another. The physical quantities associated with transducers are mechanical, thermal, magnetic, electrical, optical, and chemical. There are three classes of sensors: passive, active, and digital Sensors. Passive (analogue) sensors are those whose variation in the property to be measured is reflected in variations in impedance. Active (analogue) sensors are those whose energy is directly used by the process to be measured. Digital sensors are those that measure discrete quantities such as logic states and devices with a frequency output.

Non-invasive methods can generally be categorised as thermal, electrical, optical and nanotechnology. Much current research concentrates on optical methods, mid- and near-infrared spectroscopy in particular [9-12].

Near-infrared spectroscopy (NIRS) is a form of vibrational spectroscopy in which electromagnetic radiation causes vibrations such as stretching and bending of bonds in a chemical species [6]. Each molecule consists of several different bonds that absorb radiation in different specific characteristic spectra. The absorption of radiation by a molecule leads to an increase in the energy level from an electronic ground state to a higher electronic excited state. The absorption of infrared radiation makes the transition from the energy level to the electron excited state. The NIR spectrum consists of harmonics and combined absorption bands of fundamental vibrations of **C-H**, **O-H**, **N-H** and **S-H** bonds [1]. More in detail:

C-H Bonds (Carbon-Hydrogen): C-H bonds are present everywhere in organic molecules. They appear as distinctive bands in NIR spectra between **2050nm** and **2180nm**.

O-H Bonds (Water): Water molecules exhibit strong absorption in the NIR range. Their absorption bands are broad and dominant. The main absorption bands from liquid water are located around **1450nm** and **1940nm**.

N-H Bonds (Protein): Protein content is challenging to spot at lower concentrations, but it manifests as two distinctive bands. These bands occur at **2050nm** and **2180nm**.

S-H Bonds (Thiols): S-H bonds represent the presence of thiols, which are sulfur- containing organic compounds. Thiols are commonly found in proteins, amino acids, and other biological molecules. The absorption bands associated with S-H bonds typically occur around **2500nm** in the NIR spectrum.

There are essentially three bands which are the second or upper harmonic band (750-1400nm), the first harmonic band (1400-2000nm) and the combined harmonic band (2000-2500nm). Detailing:

Second (Upper) Harmonic Band (750-1400nm): This band corresponds to the second harmonic of fundamental vibrations.

- **Key Features**:
  - **Overtone Absorptions**: In this range, we observe overtone absorptions related to fundamental vibrations of various chemical bonds.
  - **C-H Bonds**: The second harmonic band includes overtones (multiples of the fundamental frequency) of C-H bonds, which are prevalent in organic compounds.
  - **Protein and Lipid Content**: Researchers often use this band to assess protein and lipid content in samples.

When analyzing food products or biological tissues, the second harmonic band provides valuable information about their composition.

First Harmonic Band (1400-2000nm): The first harmonic band corresponds to the fundamental vibrations of specific bonds.

- **Key Features:**
  - **O-H Bonds (Water):** Water molecules exhibit strong absorption in this range. Monitoring water content is crucial for various applications.
  - **Protein Bands:** The first harmonic band includes absorption features related to protein content (e.g., amide bonds).
  - **Starch and Sugar Bands:** Starch and sugar content also contribute to the absorption in this region.

By analyzing the first harmonic band, researchers can assess hydration levels, protein concentrations, and carbohydrate content.

Combined Harmonic Band (2000-2500nm): This band combines both fundamental vibrations and overtones.

- **Key Features:**
  - **C-H, N-H, and O-H Bonds:** The combined harmonic band includes absorption features related to C-H, N-H, and O-H bonds.
  - **Thiols (S-H Bonds):** Thiols (sulfur-containing compounds) also contribute to absorption in this range.

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When studying biological samples or assessing chemical reactions, the combined harmonic band provides insights into various functional groups.

As reported in [12], the region has a series of optical windows where there is low absorption of water, hemoglobin, and lipids. This allows NIR radiation to reach areas with a higher concentration of blood under the skin, as well as being non-destructive. Most importantly, the NIR method has a relatively low cost, as the materials can be purchased at affordable prices, e.g. 940nm Near-IR emitter and receiver LEDs. NIR can also penetrate deeper into the skin than mid-range IR radiation, making it the right option.

940nm was chosen for this experiment because, even though glucose has light absorption peaks at other wavelengths belonging to the NIR range (e.g. 970nm, 1197nm and others) it is at this wavelength that has the lowest signal attenuation by other biological components, such as red blood cells, water and platelets. Other possible choices related with higher peak absorptions of glucose on other regions, like the first harmonic or the combined region, were trade by the area of the second harmonic, by the crucial fact that the second allows deeper penetration in the biological tissue. Also, for lower wavelengths the absorption of deoxyhemoglobin, oxyhemoglobin and melanin increases, while for larger wavelengths water absorption as an increasing impact.

In addition, there is no need for prior sample preparation with this method and it provides rapid results.

However, shorter NIR wavelengths cause a high level of scattering in the tissue. Other disadvantages include poor sensitivity to low blood glucose concentrations, which makes accurate detection difficult, and interference from compounds with similar absorption characteristics to glucose.

The optical sensor detects transmitted infrared radiation and converts it into electrical signals. Arduino Uno is connected to the Near-IR emitter and collect the data from the Near-IR receiver via the 10-bit analogue digital converter (ADC) that is part of the microcontroller's architecture, with an accuracy per bit of 4.8 mV, after which the glucose level was calculated using a linear regression based on the measured values (this point is developed in section 3).

$$blood_{glucose_{level}} = -0{,}03 \times ADC_{level} + 221{,}45 \quad (1)$$

The Near-IR emitter and receiver have been integrated into a black housing to reduce the noise that can be caused by ambient light. A set of two emitter LED and receiver photodiode were arranged opposite each other, with a small space in the middle to allow the finger to be placed. Among the various places where we could place our NIR sensor and get our measurements are the lips, tongue, earlobes or fingertips, all of which are rich in blood vessels. The fingertip ended up being chosen for practical reasons relating to the construction of the black box that houses the NIR sensor. In the figure 3 we can see the image of an IR Led of 940nm (TSAL6200) as well as the photodiode used as optical receiver (BPV22NF) with peak sensitivity at 940nm, both from Vishay, used in our experiment.

Figure 3. NIR emitter LED (left) and Optical Receiver (right)

Another sensor used in the experiment, the MAX30102 (Figure 4 and 5), is not relevant for measuring glucose levels, but is used to provide the user with more information, such as a heartbeat.

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The MAX30102 is an integrated pulse oximeter and heart rate sensor IC, from Analog Devices. It combines two LEDs (IR and Red LEDs), a photodetector, optimized optics, and low-noise analog signal processing to detect pulse oximetry (Saturation of Peripheral Oxygen, SpO2) and heart rate signals.

Figure 4. MAX30102 Board (5 pin version).

Figure 5. MAX30102 Board (7 pin version).

In our experiment we use the version of the MAX30102 with 5 pins.

The board has two voltage regulators, 3.3 VDC to power the LEDs and 1.8 VDC to power the IC of the MAX30102. Communication with the Arduino Uno is via I2C. One of the most important features of the MAX30102 is its low power consumption: the MAX30102 consumes less than 600μA during measurement (in standby mode only 0.7μA). The IR Led Wavelength is of 880nm (figure 6).

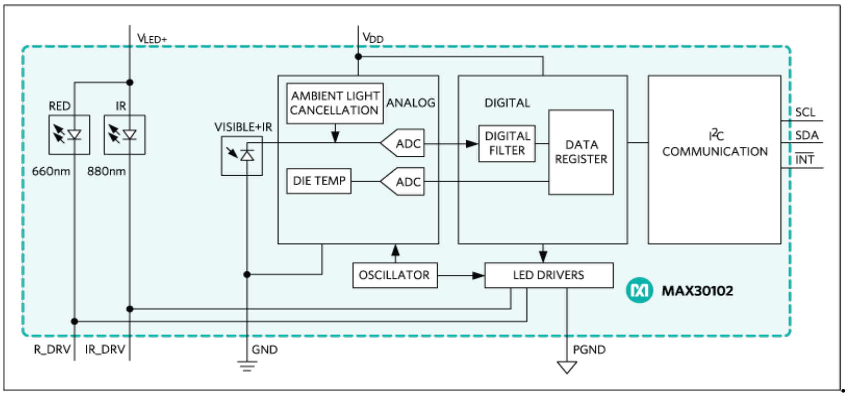

Figure 6. MAX30102 Block Diagram.

Our body is made up of veins and arteries, with the veins visually represented by blue lines (see Figure 7) and the arteries by red lines. In the veins, blood travels through the body's tissues towards the heart, while in the arteries, blood flows from the heart towards the rest of the body. Structurally, arteries are blood vessels with thick, resistant walls, and blood flows through them at high pressure. In contrast, veins are less thick and blood flows through them at lower pressure. Structurally, arteries are blood vessels with thick, resistant walls and blood flows at high pressure through them. In contrast, veins are less thick and blood flows through them at lower pressure. The blood that flows through the arteries is rich in oxygen and can be called oxyhemoglobin (a complex formed by the binding of oxygen (O_2) to hemoglobin). Arteries are more absorbent of infrared light compared to other tissues. The blood that runs through the veins is low in oxygen and is known as deoxyhemoglobin (form of hemoglobin that has released its bound oxygen**).** When it comes to light absorption, deoxyhemoglobin has a particular affinity for red light. This affinity is what contributes to the purplish-blue appearance of deoxygenated blood. As light passes through our tissues, deoxyhemoglobin selectively absorbs red wavelengths, allowing other colors to pass through.

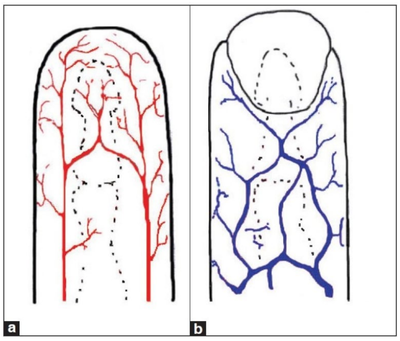

Figure 7. Blood circulation example: Arteries (a) and veins (b).

By comparing the absorption levels of oxyhemoglobin and deoxyhemoglobin the sensor will calculate the SpO2 percentage.

The blood that runs through the arteries is rich in oxygen. The more oxygenated the blood, the more hemoglobin it contains, so the blood is redder and consequently absorbs more infrared light. In short, the more oxygenated the blood, the greater the amount of infrared light absorbed. As was said previously the sensor IR and red LEDs are used to generate the light that penetrates the skin and red-colored tissues. The infrared LED penetrates the skin and are predominantly absorbed by the arteries, while the red LED penetrates even further away and are predominantly absorbed by the veins. When the light passes through the skin, it encounters reflection from the flowing blood in the blood vessels. The sensor employs a photodiode (along with a photonic filter-ambient light cancellation), to measure the amount of light reflected by the blood. The photodiode receives the light reflected signals and convert them into analog data. This data is then converted into digital data by the ADC (Figure 6). As the heart pumps, the reflected light (that which is not absorbed) is altered, generating a wave reading on the photo detector, which then generates a waveform that correlates the heartbeat rate.

The Bluetooth module used in this work is the HC-05. It has a range of up to ten meters without obstacles and can be configured in two modes, Master, and Slave.

This work uses two programming languages, C/C++ and block programming. The C/C++ programming language is used to develop the firmware for the Arduino Uno. Block programming (APP Inventor) is used to program the application (APP) resident on the smartphone.

2.3. Algorithm Design

Figure 8 shows the flowchart of the firmware developed for the microcontroller. Figure 9 shows the programming blocks that were developed for the APP that resides on the Android smartphone.

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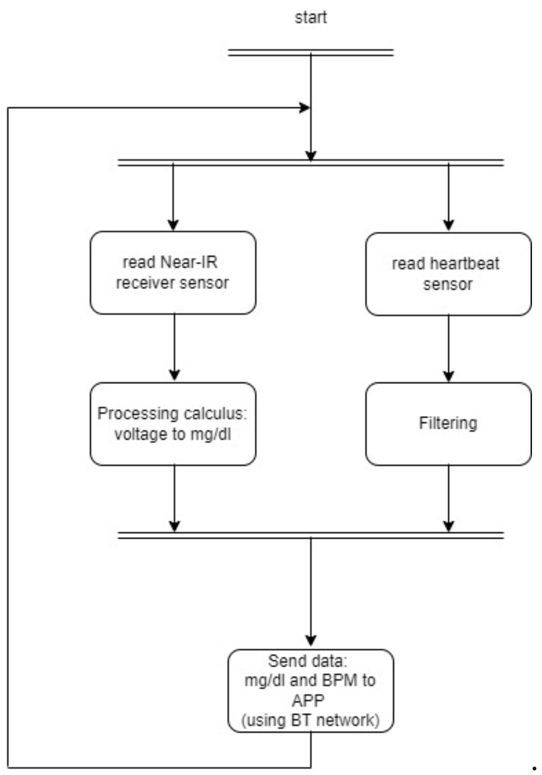

Figure 8. Firmware flow chart.

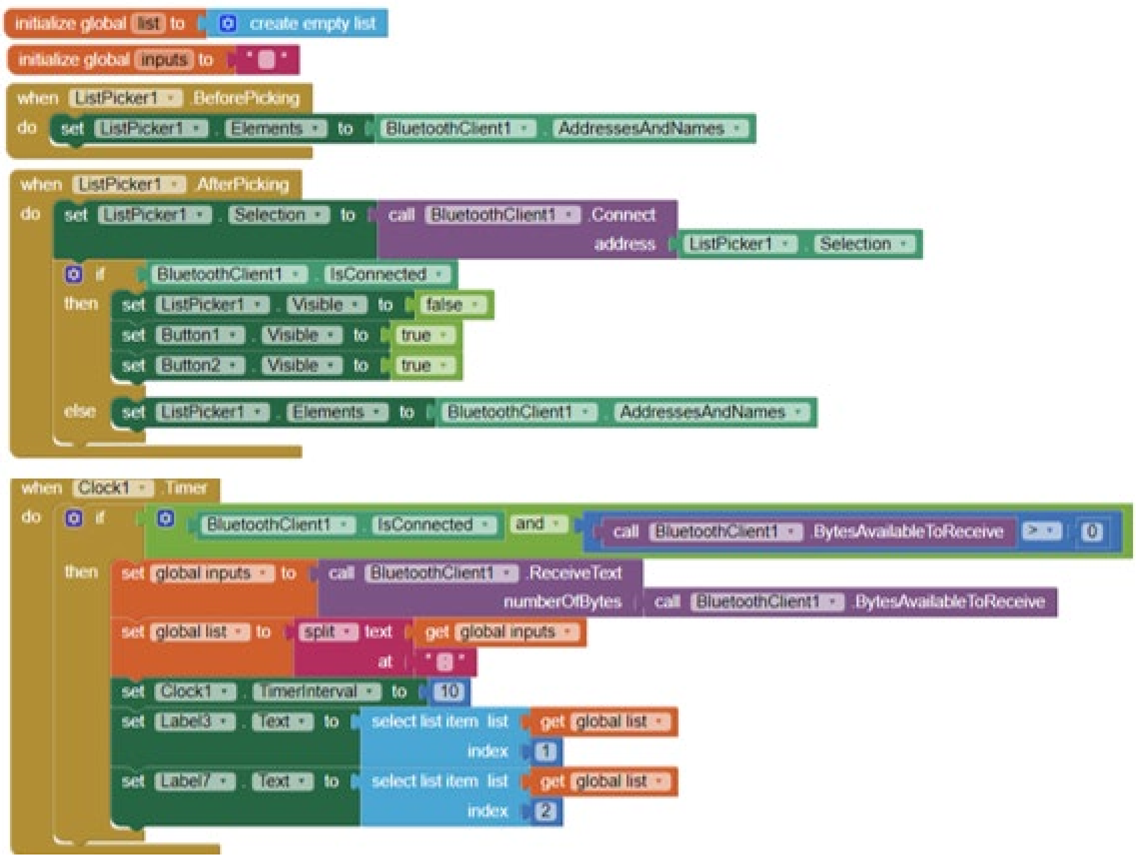

Figure 9. Programming blocks for APP developed.

3. Results and Discussion

During this work, tests were carried out on the optical sensors (emitter Near IR led and receiver Near IR photodiode), reading the voltage at the receiver Near IR photodiode, so that the values could then be acquired by the microcontroller ADC resident on the Arduino Uno board. As mentioned above, this ADC has a resolution of 10 bits. To implement a process that reads glucose levels, measurements had to be taken and compared with commercial meters, namely the OneTouch Select Plus. The OneTouch Select Plus is a conventional equipment where we apply blood to a test strip. It will associate the custom interval limit before or after the meal with our result, depending on whether we have added a corresponding meal marker. Between the several choices of tests that we must detect diabetes (e.g. Glucose tolerance test (GTT), Random blood sugar test, Fast blood sugar test), the Fast Blood sugar test, also known by **Fasting Plasma Glucose test (FPG)** its typically the best option by their ability to provide a stable baseline (they are not influenced by recent meals or physical activity). This stability allows for accurate assessment of glucose metabolism. Fasting means after not having anything to eat or drink (except water) for at least 8 hours before the test. This test is usually done first thing in the morning, before breakfast. Diabetes is diagnosed at fasting blood glucose of greater than or equal to 126 mg/dl [13]. To have an idea of what type of results we should expect (interval limits):

- **Normal**: less than 100 mg/dl
- **Prediabetes:** Between 100 to 125 mg/dl
- **Diabetes**: 126 mg/dl or higher

For a different type of population groups, such as children or pregnant women, other levels than these should be considered.

In our experiment and to achieve a range of values that is robust and wide enough to be able to establish the connection between the infrared optical receiver voltage supplied to the Arduino and the glucose values, we used the values of 10 different persons aged 18 to 24 and whose physical condition was considered healthy. These 10 people measured their glucose values on the commercial conventional equipment (One Touch Select Plus meter) and then on our experiment. The values were recorded before and after meals and their average is presented in the table 1.

The implementation in programming terms required linear regression to obtain the expression in (1), which is the result of an empirical process.

Linear regression is an equation used to estimate the expected value of a y variable. To obtain the equation, it is necessary to have real measured values and what the equation gives us, graphically, is a linear line that approximates the measured values. For our project, linear regression was important to obtain a glucose value in mg/dL according to the value in mV obtained by the sensor.

According to Lambert's law, the intensity of light decreases exponentially as the thickness of the absorbing medium increases arithmetically.

When infrared radiation passes through the finger and is received by the infrared receiver (Figure 10), it is attenuated by the blood glucose molecules present in the blood and, depending on the amount of glucose, the value of IR light received by the infrared diode (photodetector) can be higher if there is a low level of glucose (this means that more of the NIR light is absorbed or scattered by glucose molecules in the blood) or lower in the if the opposite is the case (Figure 11). An integrated image of our glucose meter can be seen in figure 12.

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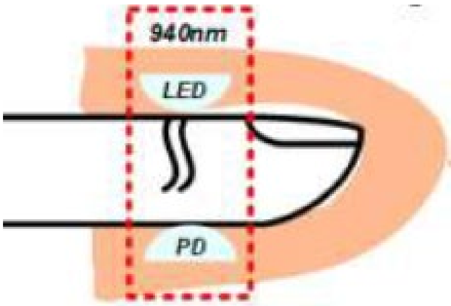

Figure 10. Measuring glucose level with NIR Led Emitter and Photo Detector.

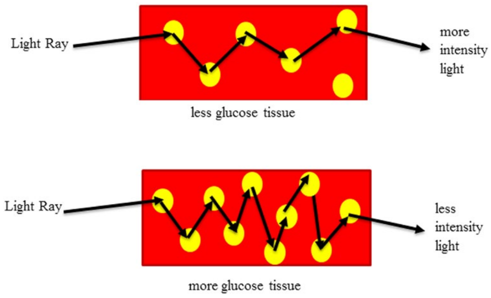

Figure 11. Influence of light propagation in glucose molecules.

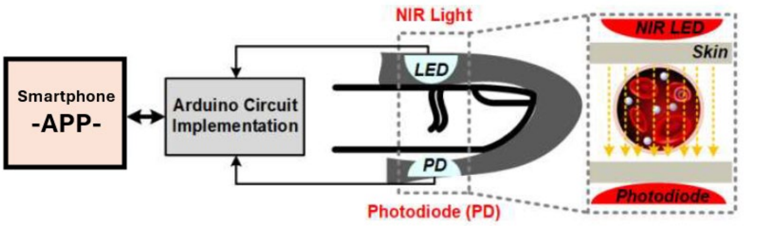

Figure 12. Experimental Diagram of the Glucose Meter.

Table 1. Values measured in mV and commercial meter.

Values obtained by IR (mV)	OneTouch Select Plus meter (mg/dL)
4354.98	89
4174	92
3841.71	103
3499.6	110
3465.3	116
3200	125

Based on the results in Table 1, a linear regression was implemented in Geogebra, as shown in Figure 13. The expression in (1) was then implemented in the C/C++ programming language for the microcontroller in the Arduino Uno. This expression can be seen in Figure 13 in the bottom left-hand corner. Table 2 shows the average values measured by the Arduino and the glucose level values measured by the One Touch Select Plus commercial meter.

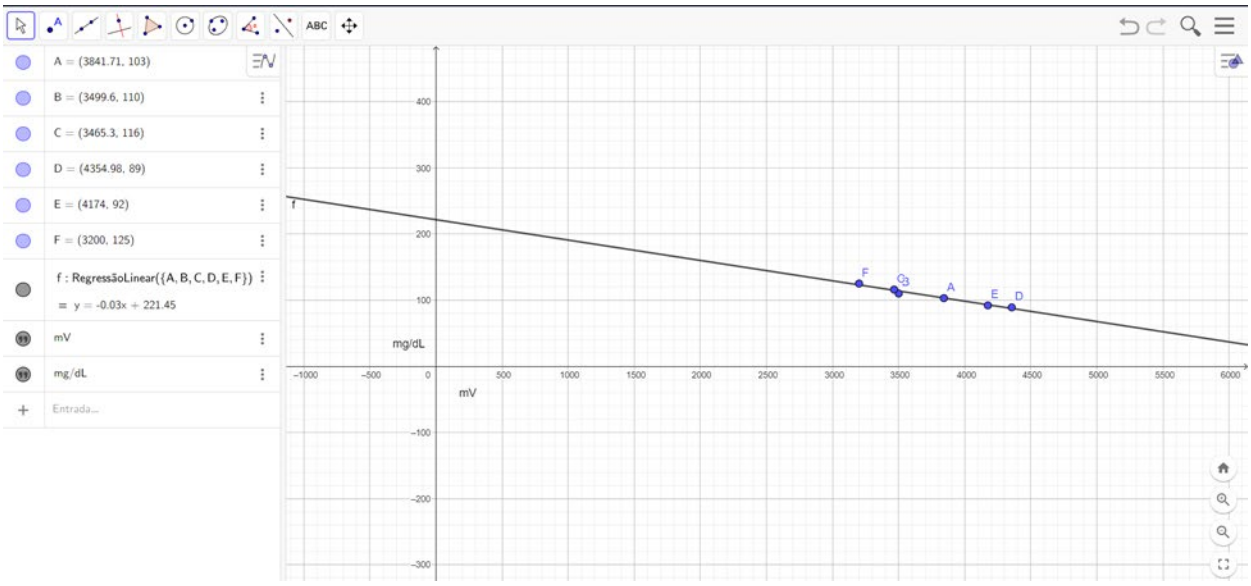

Figure 13. Point cloud and linear regression obtained.

Table 2. Comparison between measured values and commercial meter.

OneTouch Select Plus meter (mg/dL)	Values calculated using the expression (mg/dL)	Error (%)
89	90.8	2.02
92	96.23	4.59
103	106.19	3.09
110	116.46	5.87
116	117.49	1.28
125	125.45	0.36

For the heartbeat sensor, the results shown in Table 3 were obtained.

Table 3. Measured heart rate values.

Values obtained Heart rate (BPM)	Average Value (BPM)
56.79	57
56.87	57
54.79	55
54.88	55
56.79	57
56.79	57

Figures 14 and 15 shows our experiment during the testing phase and the APP developed with experimental results.

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Figure 14. Physical appearance of the experimental prototype.

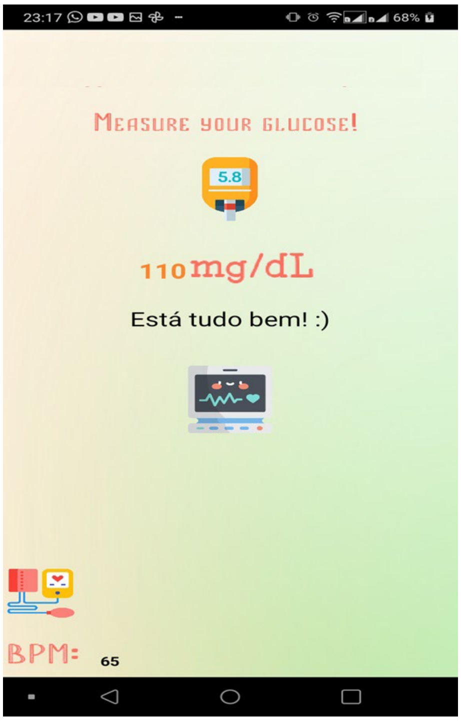

Figure 15. Appearance of the APP.

4. Conclusions

In this academic and experimental work, we were able to achieve an average error of 2.86 per cent when compared to commercial glucose meters, which we are very pleased about, as we were able to develop a system that is low cost (around 8 euro) in terms of hardware and low consumption, as in use it consumes around 50 mA. The possibility of the user and/or doctor being able to visualize the data collected via an APP is an added value, as is the addition of the heartbeat. An attempt was made to encapsulate the work to make it easier to use during tests.

In terms of improvements, clearly the physical aspect, as it was not very ergonomic. The next steps will be to do more extensive tests looking at different types of population (and diabetics). Integrating screenings carried out by the Ministry of Health or by private clinics with the aim of alerting and preventing this type of disease, would also be an objective as we would then have access to a sample of the wider population and could compare it with the values obtained by various commercial equipment used in these screenings.

Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflicts of interest." Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. Any role of the funders in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results must be declared in this section. If there is no role, please state "The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision.

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