INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

Garden of Knowledge and Virtue

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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PREFACE

We are pleased to present the first volume of this Final Year Project (FYP) article compilation from Mechatronics Engineering Program at the International Islamic University Malaysia (IIUM).

This e-book features a selection of projects produced by our final year students that span areas such as automation, robotics, control systems, artificial intelligence and others. Each project reflects the culmination of our students' academic journeys, embodying the technical skills and creative thinking fostered throughout their years at IIUM.

This compilation also highlights the importance of collaboration, with students benefiting from guidance provided by their academic mentors. We extend our heartfelt thanks to all the students and department members whose commitment made this compilation possible.

We hope this first volume provides a useful resource for future students, researchers, and gives a realistic snapshot of the work produced by our students. We also hope it will serve as a source of inspiration and innovation for many more volumes to come.

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Development of Wearable Non-Invasive Continous Glucose Monitoring System

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***Abstract*—The high number of people suffering from diabetes mellitus makes the demand for measuring devices for blood glucose levels increasing. The progress of blood glucose measuring devices from day to day continues to develop. There are many sensors that can be used to monitor blood glucose levels in a wearable, non-invasive and continuous manner. However, the objective of the blood glucose level detector cannot be achieved in certain circumstances. Some of the existing glucose monitor devices are expensive, carry risks and prolonged use of sensors may cause skin irritation. For that reason, this project aims to design a device that is able to non-invasively monitor blood-glucose using infrared sensor, to perform simulation analysis on the viability of infrared sensor to non-invasively measure blood glucose and to develop the complete device and evaluate the performance. In Final Year Project 1, a methodology was conducted by identifying the problems and objectives, analize data, identify literature review, discuss experiment setup, simulation study, conclusion and recommendation and also result. A simulation analysis experiment was developed using COMSOL Multiphysics software. Therefore, an experiment using the IR sensor was conducted for analysis. However, the results of this research still need to be continued to find out the performance of the sensor developed to predict the actual blood glucose level for each person. In this Final Year Project 2, a complete device and evaluation of the performance has been conducted using IR sensor. The results and discussion were shown in this report. There are some factors influencing the results like different Body Mass Index, ages and epidermal thickness were discussed in this Final Year Project 2. Future projects might look into the improvement of the accuracy and precision of the device and increase more understanding of the project in terms of medical studies.**

Keywords*— Infrared sensor, blood glucose, non-invasive, diabetes

I. Introduction

The industry has recently moved forward to IR4.0 where they are improving the way they manufacture and manufacture their products by incorporating new technologies into their production facilities. This refers to the use of sensors, software and robotics for equipment in factories to perform complex tasks. Among the many, Infrared (IR) sensors are chosen in this project due to its ability for non-invasive measurements. For that reason, this project aims to build research and experiments on non-invasive continuous glucose monitoring sensors and appropriate sensors to detect blood glucose levels non-invasively.

There are many sensors that can be used to monitor blood glucose levels in a wearable, non-invasive and continuous manner. However, the objective of the blood glucose level detector cannot be achieved in certain circumstances. For example, Continuous Glucose Monitoring (CGM) systems can be expensive and prolonged use of sensors may cause skin irritation [1]. The same goes for the Implantable Glucose sensors where it involves a minor surgical procedure which carries inherent risks and implantable sensors have a finite lifespan and may require replacement. Therefore, this project attempts to address these issues by developing a device that is wearable and able to non-invasively monitor blood glucose continuously using an IR sensor.

IR sensor glucose monitor devices have several advantages and limitations. One of the advantages of the IR sensor glucose monitor device is that it is able to provide readings of blood glucose levels non-invasively, without requiring a needle prick [4]. This device can provide measurement results quickly and in real time. The use of IR sensors allows for more continuous glucose monitoring without causing the discomfort associated with blood sampling.

Although IR sensor glucose monitor devices provide convenience with non-invasive measurements, users should understand that there are limitations and factors that can affect the accuracy of the results. Although non-invasive, the results of IR sensor glucose monitoring devices can be influenced by external factors such as skin temperature, hydration levels, and individual differences in skin optical properties. The accuracy of this device may decrease under certain conditions, such as during intense physical activity or when drastic changes in the surrounding environment occur.

This device may not provide the same level of accuracy as direct measurement via traditional blood sampling, especially under certain conditions such as in individuals with certain skin conditions or blood circulation disorders. Users need to be aware that results from IR sensor glucose monitor devices may require regular calibration to ensure optimal measurement accuracy. The results from this device should be considered as a reference and not as a substitute for blood glucose measurements taken directly from a vein.

II. Methodology

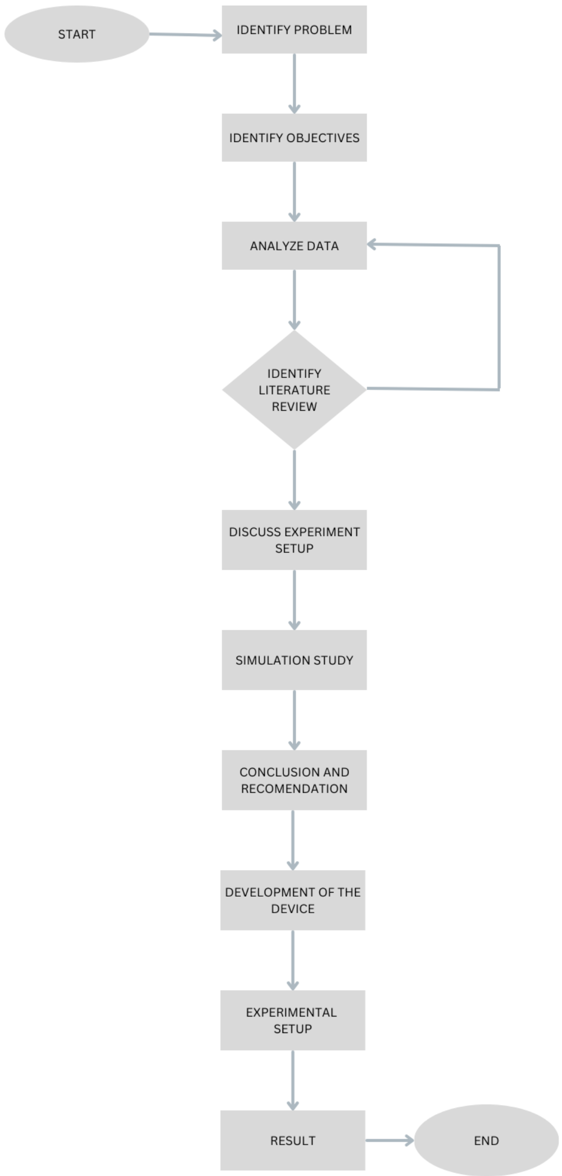

Fig. 1. General Research Methodology

Fig. 1 shows the general research methodology flowchart for this project. Firstly, in identifying problems, recognize and clearly define the problem to solve. This involves a deep understanding of the problem. Once the problem is identified, the next step is to establish the objectives of the investigation. This objective is the expected result of the investigation. Objectives guide research and provide clear direction to researchers in achieving the desired goals. Once the objective is established, collection and analysis of data relevant to the problem and objective of the investigation is conducted. Data analysis helps provide the information needed to understand the issue and support the decision-making process in subsequent steps. This literature review involves investigating and reviewing studies that have been carried out previously regarding the problem and objectives of the investigation. A literature review helps to understand the context of the investigation, assess possible gaps in existing knowledge, and identify appropriate methods to use in the investigation.

After the literature review, the researchers discussed the experimental preparations. This includes designing the experimental methodology, determining the sample, and detailing the experimental procedures. Discussion of the experimental setup is important to ensure that the investigation can be carried out in a systematic and repeatable manner. In these simulation studies, researchers may engage in simulations to test hypotheses or run certain scenarios. Simulation studies help understand how a system or phenomenon behaves under certain circumstances and provide additional insights that can support experimental findings in this FYP 2. After the experiments and simulation studies are completed, formulate conclusions and provide recommendations. This conclusion reflects the findings and objectives set.

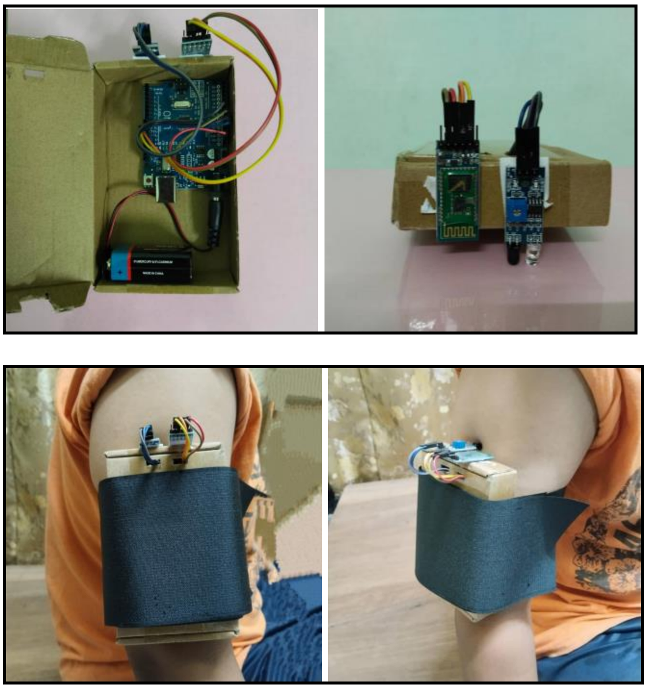

Fig. 2. *Wearable Non-invasive Continuous Glucose Monitor Devive*

In this FYP 2, the project started with the development of a wearable non-invasive continuous glucose monitor device based on the results of analysis and simulation studies. Fig. 2 shows the development of the wearable non-invasive continuous glucose monitor device. The project then continues by preparing and implementing experiments to test the developed device in real conditions. The final step is to present the results of the investigation. This involves presenting data, graphs, and findings in a systematic and clear manner.

A. Device Conceptual

IR light has a longer wavelength than visible light [3]. When IR light passes through the skin and body tissues, some photochemistry can occur. One of the important ones is the absorption of light by molecules such as hemoglobin and glucose. Glucose has the property of absorbing light at certain wavelengths in the IR spectrum. When IR light passes through the epidermis layer and reaches the blood in the capillaries, glucose will absorb a certain amount of IR light. Some of the IR light that is not absorbed by glucose will be transmitted through the tissue. The IR sensor then detects the light that has been transmitted. The detected light intensity changes can be related to the amount of glucose absorbed. The data obtained from the sensor needs to be processed using special algorithms to calculate and interpret the actual glucose levels based on the detected changes in light intensity [5].

B. Device Operation

The glucose concentration is determined using the IR emitter and receiver. The blood's level of infrared emission serves as a proxy for the sample's responsiveness to glycemia. The smartphone displays the overall concentration level of glucose molecules in the proper unit. Place the device against the arm to begin the process. The IR receiver retrieves the reflected signal [2]. The evaluation value that was derived from it will be magnified and display the assessed value on the smartphone immediately. Arduino has been linked to the signal. The output value is finally shown on the smartphone display.

III. Result and Discussion

This experiment involved the development of a non-invasive continuous glucose monitoring system using an Arduino Uno, an IR sensor, and a HC-05 Bluetooth module. This system was tested on 8 respondents with different ages and Body Mass Index (BMI). Blood glucose data obtained from this experimental system is compared with real blood glucose data measured using a more conventional finger stick type monitoring system.

TABLE I. Experiment Data

Respondent	Age	BMI (kg/m^2)	Actual Glucose (mmol/L)	Experimental Glucose (mmol/L)	Diffenrence (mmol/L)
1	47	21.5	5.8	5.65	-0.15
2	15	23.3	5.0	5.35	0.35
3	40	23.9	7.6	7.35	-0.25
4	49	24.7	4.4	4.25	-0.15
5	56	29.1	6.2	6.55	0.35
6	32	31.2	4.5	4.35	-0.15
7	37	36.7	4.4	4.56	0.16
8	36	44.4	4.2	4.44	0.24

Fig. 3. Actual Glucose Results

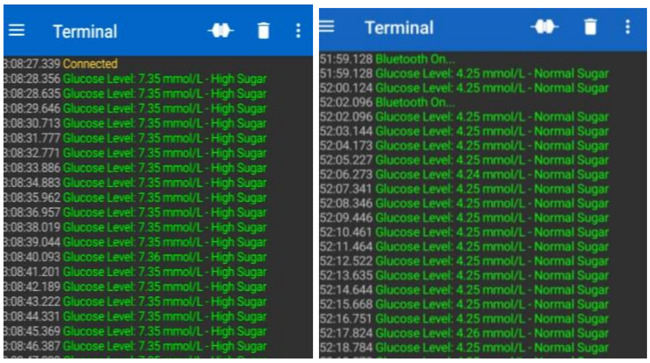

Fig. 4. Experimental Glucose Results

Table 1, Fig. 3 and Fig. 4 show an almost exact result between the actual blood glucose value and the value obtained through a non-invasive continuous glucose monitoring system. The difference between these two values is calculated and shown in an additional column in the table above. This difference ranges from -0.25 mmol/L to 0.35 mmol/L. For example, for the first respondent, the actual glucose value was 5.8 mmol/L and the experimental value was 5.65 mmol/L, with a difference of -0.15 mmol/L. This shows that the developed system is able to measure glucose values with good accuracy, although there is a slight variation. The biggest difference was found in the second and fifth respondents with a difference of 0.35 mmol/L.

Overall, this system has great potential as a glucose monitoring tool that is more comfortable and less invasive compared to the conventional finger stick method. However, to ensure its reliability, additional improvements and tests are needed, especially with larger and more diverse sample groups.

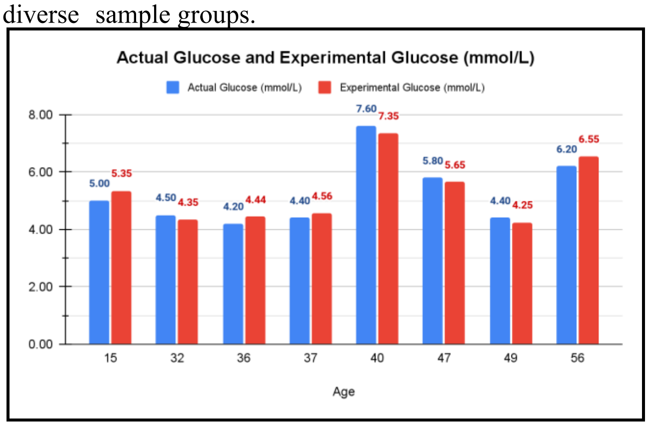

Fig. 5. Graph of Actual Glucose and Experimental Glucose based on Ages

Fig. 5 shows the age of the respondents involved ranged from 15 to 56 years old. Age can affect the accuracy of glucose readings by non-invasive glucose monitoring systems, especially in relation to physiological changes in the skin and epidermal layer. Human skin consists of several layers, including the epidermis, dermis, and hypodermis. With age, the epidermal layer undergoes changes, such as thinning, decreased sebum production, and decreased moisture. Thinning of the epidermis can affect the absorption and reflection of infrared light used by the IR sensor in this system. For example, older respondents may have thinner and less elastic skin, which can cause variations in glucose readings. The 56-year-old respondent showed a difference in glucose readings of 0.35 mmol/L, one of the highest in this study. This may be due to skin changes associated with ageing. Conversely, younger respondents, such as 15-year-olds, may have a thicker and more elastic epidermis, which can provide more consistent glucose readings. In this study, 15-year-old respondents showed a reading difference of 0.35 mmol/L. Although this difference is also relatively high, it may be due to other factors such as the instability of glucose levels in adolescence that experience significant hormonal changes.

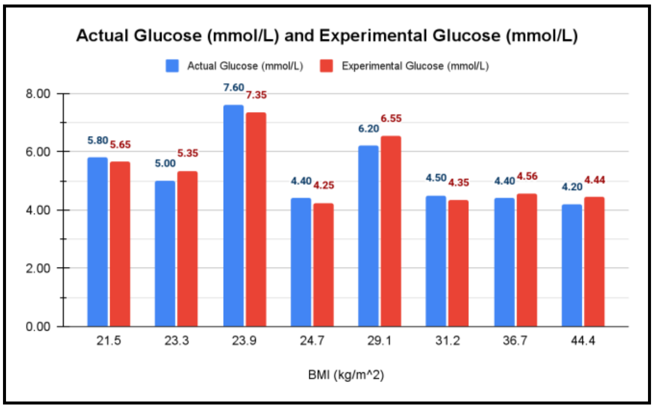

Fig. 6. Graph of Actual Glucose and Experimental Glucose based on BMI

BMI or Body Mass Index, which reflects the percentage of body fat, can also affect the accuracy of glucose readings by non-invasive monitoring systems. In this study, the respondents' BMI ranged from 21.5 to 44.4. Fig. 6 shows the respondents with a higher BMI may have a thicker layer of subcutaneous fat, which can affect the absorption and reflection of infrared light. Thicker subcutaneous fat can absorb more light, which can reduce the accuracy of glucose readings. For example, respondents with a BMI of 44.4 showed a reading difference of 0.24 mmol/L. Although this difference is not too large, it still shows the potential influence of the fat layer on glucose readings. Conversely, respondents with a lower BMI may have a thinner layer of subcutaneous fat, which may result in more consistent reflection of infrared light. In this study, respondents with a BMI of 21.5 showed a reading difference of -0.15 mmol/L. This difference was one of the smallest in this study, suggesting that a thinner layer of fat may provide a more accurate reading.

Overall, the results of the study show that both age and BMI can affect the accuracy of glucose readings by non-invasive glucose monitoring systems. Skin physiological changes associated with ageing and variations in the thickness of the subcutaneous fat layer due to differences in BMI are key factors to consider. Thinning of the epidermis in older respondents and a thicker subcutaneous fat layer in respondents with a high BMI may account for the variation in glucose readings. Therefore, adjustments to the measurement algorithm or additional calibration may be required to improve the accuracy of the glucose monitoring system for various age groups and BMI. Further tests with larger and diverse samples could provide more comprehensive data to confirm these findings.

A. *Abbreviations and Acronyms*

BMI	- Body Mass Index
CGM	- Continuous Glucose Monitoring
FYP	- Final Year Project
IR	- Infrared

IV. Conclusion

Throughout the research on IR sensor, it can be concluded that IR sensor can be used as an appropriate sensor and characterization for this project. It is because the IR sensor is immune to external interference and has high accuracy compared to other sensors. In addition, compared to the CGM systems can be expensive and prolonged use of sensors may cause skin irritation. The same goes for the Implantable Glucose sensors where it involves a minor surgical procedure which carries inherent risks and implantable sensors have a finite lifespan and may require replacement.

Therefore, the aim of this project is to design a device that is able to non-invasively monitor blood-glucose using IR sensor and to perform simulation analysis on the viability of IR sensor to non-invasively measure blood glucose. The first and second objectives of this project have been successfully achieved in FYP 1. IR sensor has fulfilled the requirement of this project which measures glucose level and it will be used for designing development of wearable non-invasive continuous glucose monitoring system.

In this FYP 2, the third objective of this project is to develop the complete device and evaluate the performance achieved. The experiment on development of wearable non-invasive continuous glucose monitoring systems were conducted using the specified components and following the flowchart of the experiment. The data acquisition process related to IR sensor input and output has been performed to analyse the findings and objectives of this project. Therefore, understanding and proficiency in using COMSOL Multiphysics and conducting this experiment were further enhanced to facilitate the data analysis tasks.

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