Asian Journal of Natural Sciences
Vol. 2, No. 1 2023: 25 - 34

# GLUSENT (Glucose Assistant): Sugar Monitoring System Smart Watch Based on Bioelectronics and Internet of Things to Prevent Diabetes Melitus in The 5.0 Society Era

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A R T I C L E I N F O

*Keywords:* Extraction, Phytochemical Screening, Cinnamon Bark

*Received : 19 December*
*Revised : 10 January*
*Accepted: 22 February*



A B S T R A C T

Diabetics in Indonesia are ranked 5th in the world. According to the International Diabetes Federation (IDF), there were 10.7 million people with diabetes in Indonesia in 2019 and a rapid increase to 19.5 million in 2021. Most cases of diabetes are not diagnosed early, this is the basis for the importance of monitoring blood glucose periodically. Based on our study of people aged 20-40 years, most of them have never done regular glucose monitoring. Lack of public awareness of the dangers of diabetes and fear of needles are the reasons for not monitoring blood glucose. Therefore, an effective non-invasive self-monitoring of glucose levels is needed. The Glusen Smartwatch is a smartwatch that integrates bioelectronics and the Internet of Things (IoT) for monitoring glucose levels through sweat taken from the wrist. If the glucose level exceeds the normal limit, this smartwatch will notify the user through sounds, vibrations and lights on the smartwatch. This smartwatch also provides a solution if the user has glucose above the normal limit, such as telling users if they need to exercise regularly, reduce stress, and lead a healthy diet. The basic components of the Glusen Smartwatch include electrochemical sensors, *flexible photovoltaic cells, flexible* Zn-$MnO_2$ *batteries*, *printed circuit board* (PCB) and *electronic ink* (E-ink). The Glusen Smartwatch is expected to be a solution for continuous early glucose monitoring so as to reduce the number of diabetics in Indonesia. The advantages of this tool can be used independently and non-invasively.

DOI: https://doi.org/10.55927/ajns.v2i1.3266
https://journal.formosapublisher.org/index.php/ajns

## INTRODUCTION

Diabetics in Indonesia are currently ranked 5th in the world and the number continues to increase. According to the International Diabetes Federation (IDF), people with diabetes in Indonesia were 10.7 million in 2019 and increased rapidly to 19.5 million in 2021, and according to this number will continue to increase where in 2030 it is estimated to reach 21.3 million. Most cases of diabetes in Indonesia are undiagnosed, they only know they have diabetes when complications such as coronary heart disease, stroke, kidney failure, diabetic wounds, blindness and nerve damage occur and of course treatment will be more difficult and expensive

Diabetes is a condition in which blood sugar levels are higher than normal or hyperglycemia is caused by the body not being able to secrete or use the hormone insulin sufficiently. Diabetes is a complex chronic disease that requires ongoing medical care with multifactorial risk reduction strategies beyond glycemic control. Patients who are receiving educational support for self-management are very important to prevent acute complications. Diabetes is a metabolic disease caused by problems with insulin secretion. There is less insulin secreted by the pancreas, which causes an imbalance in blood sugar, which causes the concentration of sugar in the blood to increase. The first prevention we can do is adopt a healthy and balanced diet. The diet is categorized as healthy if the total calories and fat are in accordance with the recommended nutritional adequacy rate, simple sugar intake 25 grams per day, and fiber intake 25 grams per day. The next precaution is to do physical activity by exercising regularly so that the striated muscles can work actively. If the striated muscle is passive, the receptors in charge of receiving glucose become inactive so that blood glucose levels will increase.

Treatment is difficult and expensive, of course, becomes the basis for the importance of public awareness for early detection of glucose levels in the blood. With early detection, diabetics can treat it early so that complications can be prevented. In addition, those who are detected with prediabetes can be treated so that they do not develop into diabetes. Testing of blood sugar levels is currently still using invasive techniques, the patient's blood is taken using a syringe. This is one of the reasons why some people are reluctant to check their blood sugar levels. In addition, the test results require a long time (± 2 hours). has designed a blood sugar test device with an invasive method using the TCS3200 color sensor, the weakness of the tool produced by Dinar is that it still uses invasive methods and the level of accuracy is not good, and there is no battery level indicator. In addition, a blood sugar test kit was also developed by [9] which is equipped with data storage that is placed on a PC. The weakness in the tool developed is the same as the tool produced by previous researchers, which is that it still uses invasive methods, the readings are easy to change because the color sensor is easily affected by light intensity.

A blood sugar test device using a non-invasive method has been developed by Kemalasari, et al. By measuring the temperature on the tragus and antihelix, the weakness of the tool produced by Kemalasari et al is the error value which is quite large, namely 1-15% compared to blood glucose data measured in the laboratory. Bioelectronic technology is an integrated technology between the disciplines of biology, chemistry, physics, electronics science, materials science, and engineering science, also Bioelectronic technology is very well known in leading research fields because of its promising applications to health care and personalized fitness monitoring. Of the various existing bioelectronic technologies, the recent development of sweat sensors has attracted considerable attention for their potential applications in point of care monitoring and health management in a continuous and non-invasive manner.

Based on research from Stanford University School of Medicine in collaboration with the University of California Brekeley, it is stated that the sweat sensor can diagnose blood glucose levels. Sweat provides a great opportunity for real-time monitoring of individual health conditions at the molecular level. Through sweat sensing, it has been possible to non-invasively detect various species, including electrolytes, metabolites, acids, as well as for applications in health monitoring and disease diagnosis.

## THEORETICAL REVIEW

Diabetes Mellitus is a group of metabolic diseases with Features of hyperglycemia that occurs due to abnormalities in insulin secretion, performance insulin or both (ADA, 2010). Based on Perkeni 2011 Diabetes Mellitus is a disorder disease chronic metabolism characterized by hyperglycemia. Various Complications can arise due to blood sugar levels that are not financed, for example neuropathy, hypertension, coronary heart disease, retinopathy, nephropathy, and gangrene.

Regular blood sugar monitoring is the most important thing you can do to manage type 1 or type 2 diabetes. You'll be able to see what makes your numbers go up or down, such as eating different foods, taking your medicine, or being physically active. With this information, you can work with your health care team to make decisions about your best diabetes care plan. These decisions can help delay or prevent diabetes complications such as heart attack, stroke, kidney disease, blindness, and amputation. Your doctor will tell you when and how often to check your blood sugar levels.

At the first C.E.C. Workshop, in Brussels in November 1991, bioelectronics was defined as 'the use of biological materials and biological architectures for information processing systems and new devices'. Bioelectronics, specifically bio-molecular electronics, were described as 'the research and development of bio-inspired (i.e. self-assembly) inorganic and organic materials and of bio-inspired (i.e. massive parallelism) hardware architectures for the implementation of new information processing systems, sensors and actuators, and for molecular manufacturing down to the atomic scale'. The National Institute of Standards and Technology (NIST), an agency of the United States Department of Commerce, defined bioelectronics in a 2009 report as "the discipline resulting from the convergence of biology and electronics".

Sources for information about the field include the Institute of Electrical and Electronics Engineers (IEEE) with its Elsevier journal Biosensors and Bioelectronics published since 1990. The journal describes the scope of bioelectronics as seeking to : "... exploit biology in conjunction with electronics in a wider context encompassing, for example, biological fuel cells, bionics and biomaterials for information processing, information storage, electronic components and actuators. A key aspect is the interface between biological materials and micro and nano-electronics."

## METHODOLOGY

This study uses a qualitative descriptive method that is a literature study using journals, research reports, relevant books, scientific articles and other sources as the main object. This research produces information in the form of notes and descriptive data contained in the source under study. With qualitative research, it is necessary to do descriptive analysis. The descriptive analysis method provides a clear, objective, systematic, analytical and critical description and explanation of the components and workings of a smartwatch that is integrated with Bioelectronic Technology and the Internet of Things (IoT) for monitoring glucose levels through sweat. The initial step of a qualitative approach begins with collecting the required data, then classification and description are carried out, so that the most appropriate tool is produced.

Based on international journal research from RA Buda and M. Mohd. Addi with the title "A Portable Non-Invasive Blood Glucose Monitoring Device" with an LCD (Liquid Crystal Display) display, and the national journal from Boby Irfanudin Anwar, Raditiana Patmasari, and Hilman Fauzi with the title "Design and Implementation of Non-Measuring Blood Glucose Levels Arduino-Based Invasive". and also based on the international journal from abidin, et al with the title "initial quantitative comparison of 940nm and 950nm infrared sensor performance for measuring glucose non-invasively". Literature from the series contained in Dino Sia's research entitled "design of a near-infrared device for the study of glucose concentration measurements". i.e. measuring blood glucose using an amplifier circuit and also a voltage divider synchronized with an infrared LED (Light Emitting Diode) and photodiode.

We developed a technique for measuring blood sugar levels non--invasive using 940nm infrared LED waves and 940nm photodiode and Arduino UNO. References are also found in the journal conducted by KA Unnikrishna Menon "A survey on non-invasive blood glucose monitoring using NIR". References are also found in the journal conducted by KA Unnikrishna Menon "A survey on non-invasive blood glucose monitoring using NIR", as well as the results of a student thesis from the Bogor Agricultural University regarding "Design of a non-invasive blood sugar level measuring device based on a photodiode sensor" .

### Component Analysis

Component analysis as a consideration of the most suitable component used as a basic component in the design of glusen based on the quality of the component and the ease of processing it. The component analysis used is as follows:

1. Glucose Sensor
   Sensor is one of the implementations of the Internet of Things (IoT). The sensor component contained in the glusen has the main function of detecting glucose and can detect pH and humidity. The advantages of this component are that it can measure quickly, has a high level of accuracy, and is easy to carry everywhere.

**Figure 1**. Glucose Sensor

2. E-ink display
   This component can display text digitally. The advantage of this component is that it can display text that can be refreshed many times.

**Figure 2**. E-ink Display

3. Flexible Cell Photovoltaic
   Photovoltaic cells, also known as solar cells, are semiconductor devices that can create electrical energy where the main source comes from sunlight. The advantages of this component are that it is rechargeable, environmentally friendly, and becomes an alternative energy source.

**Figure 3**. Flexible Cell Photovoltaic

4. Zn-$MnO_2$ Battery
   This component is known as the primary battery material that is widely used. The advantages of this component are that it has a low impact on the environment, the cost is quite affordable, and has a high level of security.

**Figure 4**. Zn-$MnO_2$ Battery

5. Small Trumpet Loudspeaker
   This innovation uses an 8Ω 0.5W Small Trumpet loudspeaker with a diameter of 50mm.

**Figure 5**. Small Trumpet Loudspeaker

## RESULTS AND DISCUSSION

### Components and Design Glusent

Glusent is a smart watch tool that monitors glucose levels using sweat non-invasively that integrates bioelectronics and the Internet of Things (IoT). Glusent consists of several components, namely, *flexible photovoltaic cells* to capture and convert energy from sunlight, *flexible Zn-MnO$_2$ batteries* which are rechargeable batteries as intermediate energy storage devices, electrochemical sensors for monitoring glucose levels through sweat, *printed circuit boards* (PCBs).module a controller *electronic ink* (E-ink) as a direct monitoring device in real time.


**Figure 6.** Components and Design Glusent

Glusent, which integrates bioelectronics and the Internet of Things (IoT), generates energy through harvesting/conversion of photovoltaic flexible cells in the form of a watch strap. Rapid advancement of energy harvesting/conversion devices, development of self-powered systems that utilize clean and sustainable energy from the surrounding environment (eg, solar energy, mechanical vibration and friction, biofluids, etc.). The obtained amorphous silicon (a-Si) is stored in the battery and can provide sufficient power for the operation of the entire system, including real-time signal processing and data display, without an external power source. In addition, there is also a Zn-MnO$_2$ functions as an intermediate energy storage unit and the use of a quasi-solid-state aqueous electrolyte to eliminate safety concerns in the battery, providing high energy storage capacity, long cycle life, light weight, environmentally friendly as well as high output voltage, can be one of the most promising alternatives to conventional batteries.

In addition, the glucose sensor used is capable of demonstrating outstanding sensitivity and stability for non-invasive sweat glucose monitoring. Glusent has the high flexibility of power devices and sensors, so it can be worn comfortably on the wrist.PCB (*printed circuit board*) is designed with the entire circuit based on the Tinyduino (TinyCircuits) microcontroller (Akron, OH) with accompanying analog circuitry for signal conditioning, processing, and controlling the e-ink display. Real-time sweat glucose in the body and continuous monitoring is demonstrated by different sweat generation methods, including iontophoresis sweat extraction, and indoor and outdoor exercise. The presented Glusent integrated bioelectronics and Internet of Things (IoT) realize energy harvesting/storage, biosensing, signal processing, and display in one platform to achieve self-sustaining sweat glucose monitoring and fitness management systems as well as clinical research non-invasively.

**Glusent Layout Design**

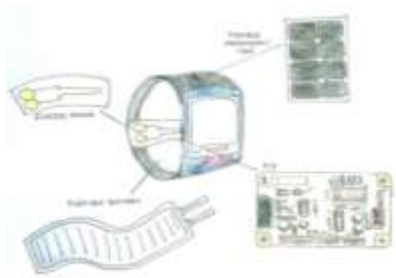

**Figure 7.** Glusent Layout Design

That integrates bioelectronics and the Internet of Things (IoT) for non-invasive sweat glucose monitoring. This Glusen Smartwatch power supply module consists of two flexible photovoltaic cells connected in parallel facing outward for efficient energy harvesting with three flexible $Zn\text{-}MnO_2$ battery cells connected in series placed on the inside. Glusent can be charged up to 6.0 V within 1 hour under outdoor sunlight (around AM 1.5), the solar energy will be stored in the battery and last up to 8 hours with a 3V disconnection potential. A customized PCB located below the E-ink display allows signal processing/filtering, sensor conditioning and output display control. The sensor is constructed on a mechanically flexible polyethylene terephthalate (PET) substrate and can be directly inserted into the PCB via the connector, which provides easy sensor replacement.

**Schematic Diagram of Glusent Signal Conditioning**

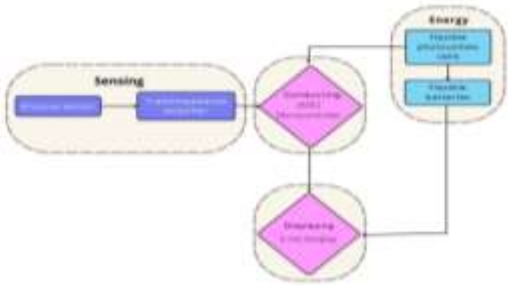

**Figure 8.** Schematic Diagram of Glusent Signal Conditioning

Sensing and power supply operating system is shown in Figure 8. The enzymatic sensor enables a selective redox reaction with glucose in sweat secretion and generates an amperometric signal, which is amplified by a transimpedance amplifier (TIA) and subsequently converted to digital signal by the analog-to-digital (ADC) port in the microcontroller. Next, the microcontroller analyzes this digital signal, filters out high-frequency noise, and sends the processed results to the E-ink display in real-time. The E-ink module provides the advantages of stable viewing without continuous power supply, ultra-low power consumption, wide viewing angles, and high visibility and contrast. The energy harvested/converted from photovoltaic cells can support system operation, or it can be stored in batteries and released to compensate for insufficient power supply with fluctuations in illumination. In addition, because sweat usually contains a wide variety of chemicals that have the potential to interfere with glucose detection, the selectivity of the sweat sensor is also an important factor. The artificial glucose sensor provides good selectivity for glucose sensing in the presence of other biomolecules (including lactate, ascorbic acid, uric acid, and NaCl).

**Verification of The Accuracy of Monitoring Glucose Levels Inuce Sweat From Exercise Over Different Time Spans**

The accuracy of glucose levels displayed on Glusent was verified with sweat samples collected from subjects during ergometer-based cycling exercises. The glucose concentration of the original sweat sample can be calculated based on the sensor output current. The glucose concentration in sweat samples collected over a 15−25 minute timeframe during exercise was calculated to be 74 micrometers, with the Glusen Smartwatch showing a “Mid” sweat glucose level. The Glusent display will change to "High" when the glucose concentration increases by 50 micrometers. After 32 minutes of exercise, the glucose concentration in the collected sweat samples decreased to 34 micrometers, and Glusent displayed "Low", simultaneously. Such a downward trend is consistent with previous studies and the reliability of glucose monitoring using Glusent is well demonstrated.

## CONCLUSIONS

Components consist of, *flexible photovoltaic cells* to capture and convert energy from sunlight, *flexible Zn-MnO2 batteries* which are rechargeable batteries as intermediary energy storage devices, electrochemical sensors for monitoring glucose levels through sweat, *printed circuit board* (PCB) as controller module, and *electronic ink* (E-ink) as a direct monitoring device in real time. Glusent sweat hits the glucose sensor, the enzymatic sensor enables a selective redox reaction with glucose in sweat secretion and generates an amperometric signal, which is amplified by a transimpedance amplifier (TIA) and further converted into a digital signal by an analog-to-digital (ADC) port in the microcontroller. Next, the microcontroller analyzes this digital signal, filters out high-frequency noise, and sends the processed results to the E-ink display in real-time. The display on the E-ink screen is “Low”, “Mid”, and High” according to the glucose concentration and sensor output current. Glusent is also expected to be able to prevent diabetes mellitus from an early age in the era of *society 5.0*

**ACKNOWLEDGMENT**

With this, we would like to express our gratitude to God Almighty because it is because of His blessings and grace that this research can be carried out and completed properly. We also want to thank Mr. Hilman Qudratuddarsi, M. Ed, Mrs, Talitha Widiatningrum, M. Si., Ph.D, and Prof. Dr. Ir. Subiyanto, ST, MT as the supervisor who has taken the time and energy to guide and provide suggestions and input during the process of making this work. We also do not forget to thank our family, relatives, and friends who cannot be mentioned one by one for their sincerity in providing encouragement and input to us during the work of this research paper. Last but not least. Our say thank you to Hanifatul Umami, Fadhila Isna, Rayfaldi Ananda An-Naafi, and Putri Yuni Kharunnisa who have participated in providing suggestions and input during this paper.

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