Innovative Computing Review (ICR)
Volume 4 Issue 2, Fall 2024
ISSN$_{(P)}$: 2791-0024, ISSN$_{(E)}$: 2791-0032
Homepage: https://journals.umt.edu.pk/index.php/ICR

Article QR

Title: **IoT-enabled Non-invasive Glucose Monitoring and Heart Rate Detection: A Smart Solution for Diabetes Management**

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DOI: https://doi.org/10.32350/icr.42.01

History: Received: November 01, 2024, Revised: November 28, 2024, Accepted: December 20, 2024, Published: December 24, 2024

Citation: M. D. M. Alvi, S. M. F. R. S. Zaidi, K. U. Wara, K. Tariq, M. Arsalan, and J. Hussain, "IoT-enabled non-invasive glucose monitoring and heart rate detection: A smart solution for diabetes management," *Innov. Comput. Rev.*, vol. 4, no. 2, pp. 01–17, Dec. 2024, doi: https://doi.org/10.32350/icr.42.01.

Conflict of Interest: Author(s) declared no conflict of interest

A publication of
School of Systems and Technology
University of Management and Technology, Lahore, Pakistan

IoT-enabled Non-invasive Glucose Monitoring and Heart Rate Detection: A Smart Solution for Diabetes Management

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ABSTRACT Acetone, traditionally considered a metabolic waste product, has been found to play a more significant role in physiological processes. Recent technological advancements enable the detection of acetone in human breath, offering a promising alternative to blood and urine sampling for clinical and research applications. The study aimed to explore the potential of the Internet of Things (IoT)-enabled breath acetone as a non-invasive biomarker, particularly for diabetes detection. The experimental setup involves an Arduino Mega board integrated with a TGS822 gas sensor, SEN-11574 pulse sensor, DHT22 humidity and temperature sensor, and a TFT display to measure acetone levels in exhaled breath. IoT-based system ensures efficient data acquisition and real-time monitoring. This offers a comprehensive non-invasive solution to assess acetone as a biomarker in diabetes management. Findings indicate that acetone concentrations in the breath of diabetic patients consistently exceed 1.7 PPM, while non-diabetic individuals exhibit levels below or equal to 1.6 PPM. Acetone stands out as a potential diagnostic marker for diabetes. This is because its levels show a clear and measurable difference in individuals with diabetes as compared to those without diabetes. This significant variation makes acetone a reliable indicator, which could be useful to diagnose diabetes or monitor its progression. Breath acetone analysis offers a non-invasive, sensitive, and practical approach to diagnose and monitor diabetes. This presents an advantageous alternative to conventional methods. The simplicity and effectiveness of this technique make it an attractive option for continuous monitoring. Further research could expand its applicability to other clinical conditions, enhancing patient care and diagnostic efficiency.

INDEX TERMS acetone, Internet of Things (IoT), non-invasive blood glucose, pulse rate

I. INTRODUCTION

Monitoring blood sugar levels is crucial for diabetic patients who aim to manage their condition effectively. The traditional method involves pricking the finger to draw blood, which is precise, however, also painful, invasive, and potentially dangerous. Therefore, non-invasive continuous glucose monitoring methods are necessary. These include photometric spectrometry, electrical impedance, photoacoustic, light scattering, and ion response to Deion [1], [2].These methods offer a simple and practical process, however, rely on epidermal measurements.

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These measurements are sensitive to changes in the environment and physical and chemical parameters of objects, such as temperature, humidity, skin hydration, and pigmentation [2]. Another method to examine blood sugar levels in diabetics is through a breath test. The study of respiratory acetone associated with diabetes has been a significant area of respiratory research since the 1960s [3]. This is because diabetes is a known cause of elevated ketone [4], and plasma acetone is related to breathing acetone. Human breath contains many volatile organic compounds (VOCs). Out of those, some are associated with various metabolic and neurological symptoms, such as cardiovascular diseases (CVDs), asthma, cystic fibrosis, and diabetic ketoacidosis.

The breakdown of endogenous glucose may cause changes in exhaled gases, such as ethanol and acetone. Although, ethanol is not generated by a vertebrate cell through a biochemical pathway. It may increase exhaled gas mixtures due to alcohol consumption, an extreme overload of carbohydrate-rich foods, and excessive microbial development. Acetone is produced regularly in human beings under certain conditions and is known to be enhanced by a high-fat ketogenic diet [5], diabetic ketoacidosis, and other catabolic states, such as starvation. Small shifts in exhaled ethanol and acetone after meals could provide insights into blood sugar fluctuations. Therefore, analyzing exhaled gas profiles may provide an estimate of circulating glucose levels.

The presence of a high concentration of acetone in blood and breath gives diabetic breath a distinct "sweet smell". In 1969 [5], GC was used to detect breath acetone and the patients' blood glucose levels after an overnight fast in 251 diabetics [5]. Results indicated a moderate correlation between breath acetone concentration and blood glucose levels. Recent studies have discovered that the corresponding blood sugar values are strongly correlated with ethanol and acetone levels in the breath [6]. Breath analysis offers a promising non-invasive approach to monitor blood glucose levels. The idea is that specific VOC levels in breath correlate with blood glucose levels. This provides a convenient and painless alternative to traditional monitoring methods. To take breath-based glucose monitoring to the next level, more research is required to create reliable and accurate devices. Meanwhile, an increase in personal electronics, such as fitness trackers and smartwatches has also made it easier for people to track their heart rates. These devices use optical sensors to detect changes in blood flow and calculate heart rate. However, heart rate variability (HRV) - the fluctuations in time between each heartbeat - has emerged as a promising indicator of the overall health and stress levels. Higher HRV is typically a sign of better health and lower stress. By harnessing HRV, a valuable tool may be uncovered to monitor health and well-being. The Internet of Things (IoT)-based systems enable continuous monitoring and remote access to glucose data, which can be stored on platforms, such as Thing Speak or displayed on smartphones via Wi-Fi. This integration allows for real-time data analysis and remote monitoring by healthcare providers, enhancing diabetes management [7], [8].

A. RECENT RESEARCH

The concept of breath analysis dates to ancient times, with Hippocrates describing fetor or is and fetor hepaticus. However, scientific research into VOCs in breath began in the late 18th century when John Rollo noted the sweet, fruity odor of acetone in the breath of a diabetic patient.

Despite this discovery, acetone was still mainly thought of as a waste product of metabolism and a feature of diabetic coma until World War II, when radioisotope-labeled compounds were used to study biochemical processes [9]. In the 1940s and 1950s, scientists began to realize the key role of acetone in metabolism, and its oxidation to exhaled carbon dioxide was observed [10]. Although, interest in acetone research declined in the 1990s, recent studies have focused on detecting acetone in exhaled air to better understand the underlying processes and support clinical practice. It shows that research in acetone has gone through periods of fluctuation over the years [11]. Its presence in the breath of individuals with certain medical conditions has been known for centuries. The scientific investigation into its metabolic pathways and potential uses has been a slow process [12]. A fresh perspective on acetone as a possible metabolic mediator emerged with the discovery of radioisotope-labeled molecules in the middle of the 20th century. However, this perspective was opposed by the then-dominant biochemistry dogma. Nonetheless, after more studies in the 1980s, acetone and its metabolic pathways came back into focus. It was discovered that cytochrome P450 enzymes were involved in acetone's breakdown [13].

In recent years, interest in acetone has primarily focused on its detection in exhaled air as a potential diagnostic tool for various medical conditions [14]. Overall, continued research into acetone and its metabolic pathways could provide important insights into human beings.

1) ACETONE PRODUCTION IN MAMMALS

The main source of acetone is acetoacetate which is created during the breakdown of fats and ketogenic amino acids. Acetone is produced when acetoacetate is eliminated through enzymatic or non-enzymatic means. Acetoacetate decarboxylase [15], otherwise called acetoacetatecarboxylase, was first found in Clostridium acetobutylicum. It was later distinguished in rodent tissues, liver, and plasma. However, neither human tissues nor fluids contain it. Low substrate affinity proteins, which are associated with the enzyme activity in rats and are inhibited by iodoacetic acid, urea, and HgCl2, work best at a pH of 4.5 [16]. It has also been discovered that acetone limits its ability to compete [17]. Although, enzyme-mediated decarboxylation has seen some advancements [18]. Despite progress in enzyme research, the protein responsible for acetoacetate decarboxylase activity remains unknown. Until the enzyme is fully analyzed, sequenced, and its coding gene identified, the protein driving its activity will remain a mystery. Surprisingly, there has been no published research on mammalian acetoacetate decarboxylase in the last three decades, leaving this key question unanswered. Acetic acid and other -Keto carboxylic acids have undergone non-enzymatic decarboxylation since 1929 [19]. Moreover, carbon dioxide samples have been enhanced with amines, as demonstrated in the redox process, catalase plays a supporting role, utilizing a mixture of acetone and isopropanol. On the other hand, the blood group I ADH isoenzyme (EC 1.2.1.3) plays a crucial role, taking center stage in the process [20]. Acetone is made by transferring isopropanol hydride to NAD. Afterwards, acetone is made by a two-step DE protonation process governed by the positions of histidine and serine [21]. Ketones can be thought of as being deketoned in the reverse reaction, which reduces acetone to isopropanol. The hydride ion serves as the nucleophilic

carbonyl in reaction pathways. It then follows the protonated water moiety through the resonance form of acetone, providing an alternative alcohol step for the carbon copy chain [22].

Various bacteria can grow on different carbon sources, leading to the production of small organic compounds, such as acetone. Both aerobic and anaerobic bacteria can utilize or generate acetone, and its presence in ruminants' diets is normal. Moreover, research indicates that VOCs, such as acetone, may serve as markers for bacteria [23]. The clinical importance of these discoveries is unclear since they are primarily based on the study of VOCs in plants, and their applicability to clinical contexts is still under exploration.

2) ENERGY PRODUCTION OF HEPATIC ACETONE METABOLISM

Acetone is a byproduct of various metabolic processes taking place in the body and is typically produced in lesser amounts. However, certain conditions, such as diabetes, alcoholism, and prolonged fasting may lead towards increased production of acetone. Although acetone was previously considered as a metabolic waste, recent research has shown that it serves a functional purpose in the body by acting as an energy source. When acetone is metabolized through certain pathways, such as the L pathway, it may yield up to 16 ATP for each fragment metabolized, making it an efficient energy source [24]. Additionally, acetone may provide ATP for additional tissues and improve survival in times of metabolic stress. Acetone has had a long chemical history since the Middle Ages, when it was thought that acetates were dry distilled. Although, acetone was discovered earlier, it was not until the 19th century that Dumas and Liebig accurately determined its chemical composition. Acetone, also known as ‘dimethyl ketone’, has a sweet, fruity flavor and a distinctive apple-like aroma. It is highly volatile and easily dissolves in a variety of solvents including water, ethanol, chloroform, ether, and others [25]. It also quickly evaporates from soil and water. Furthermore, it undergoes photolysis, a chemical reaction involving free radicals, when released into the atmosphere. From a biochemical and toxicological point of view, it is crucial to note that due to its ability to dissolve in lipids, acetone can easily penetrate bio membranes including the blood-brain barrier. Acetone can also form covalent bonds with macromolecules, such as polypeptides and amino phospholipids [26]. Due to the conditions required for the reaction (pH 5 and 60% anhydrous acetone), however, the acetone-oxytocin conformation is regarded as intermediate and is not physiologically significant.

It should be mentioned that measuring acetone levels in the body would vary depending on the technique used, and each technique has its own level of accuracy an d precision. To determine the amount of acetone present in the body, the preferred method is high performance liquid chromatography (HPLC) employing 4-dinitrophenylhydrazine (DNPH) in combination with a flame ionization detector (FID mass spectrometry (MS) [27]. According to studies, acetone levels i n healthy individuals range from 8 to 15 µ M when measured from the headspace abo ve the sample using GC and <30 µM using MS and FID [28]. Using HPLC techniques, acetone levels in healthy individuals were detected to be between 34 and 120 µM. In general, GCMS is the most sensitive technique recommended to detect acetone levels in vivo. In 1971, Trotter used gas chromatography (GC) and

flame ionization detection (FID) to make the first quantitative assessment of acetone in expired air [29]. Only one milliliter of breath was injected directly into the GC column. Pleil and Lindstrom took breath samples in 1995 with vacuum electro-polished canisters and used GC-MS to measure acetone, isoprene, and other VOCs [30]. However, the method is bulky and takes a long time to detect acetone as a single compound. A total of 20 fed subjects' breath contained an average of 0.02 mol/L of acetone, with a standard deviation of 0.01 mol/L. By reducing analysis time and energy consumption, micro-GC systems based on micro-electromechanical systems (MEMS) today have significantly increased the technology's attractiveness. Advanced mass spectrometers, such as PTR-MS and SIFT-MS may rapidly detect volatile compounds in breath [31]. Breath analysis has shed light on changes in acetone and isoprene levels during various physiological processes including exercise and sleep. In a notable study, Prabhakar et al. employed SIFT-MS to explore the correlation between breath acetone levels and blood acetone levels, revealing valuable insights into this relationship. The potential of breath analysis was examined for acetone as a non-invasive diagnostic tool for diabetes and other metabolic disorders. Moreover, the potential of breath analysis was also determined for acetone to detect acetone levels in a healthy population [32].

II. MATERIALS AND METHODS

A. MATERIALS

A breakthrough system was developed to measure acetone in breath with unparalleled accuracy. The system relies on three sensors working together in harmony. One sensor specifically detects acetone levels, while another measures the humidity in the breath sample. A third sensor then analyzes the data from the first two sensors, providing a comprehensive understanding of the breath sample. A special nozzle was designed that houses two of these sensors, which seamlessly transmit their data to a central control board for in-depth analysis. This breakthrough system allows the detection of acetone levels in breath easily and accurately, which could lead towards new non-invasive ways to monitor diabetes. The system is made up of a gas sensor and a humidity sensor connected to a control board, working together to provide precise readings. To use it, a breath sample is added to the sensor's inlet and the humidity sensor measures the moisture levels in the sample. The Arduino Mega board is used to process data from both sensors and display the acetone levels on an LCD display. The SEN-11574 Pulse Sensor is used with Arduino mega with LCD display to measure pulse rate.

VC - Sensor input voltage,

VH - Micro heater voltage,

RL - Load resistor

VC = 5 V; VH = 5 V; RL = 100 K Ω

$$V_{RL} = \frac{V_c * R_L}{R_L + R_S} \quad (1)$$

$$R_s = \left(\frac{V_c}{V_{RL}} - 1\right) * R_L \quad (2)$$

Equation 1 calculates the sensor's resistance based on measured voltage values, which is essential to determine acetone concentration. Equation 2 applies this to calibrate the response under varying conditions. To analyze the sensor's performance, the voltages VRL and RS were calculated from equation 1 and 2 as shown in Figure 1. The sensor's accuracy, particularly at low concentrations, exhibits non-linear behavior and is influenced by

temperature, humidity, and gas properties. Notably, the presence of alcohol vapor in the breath sample can interfere with the test results. Lee and colleagues extensively researched the development and characteristics of SnO2 gas sensor networks for detecting various VOCs. The proposed system's circuit diagram is shown in Figure 1.

B. METHODS

1) ACETONE LEVEL DETECTION

A gas sensor TGS822 and a DHT22 humidity sensor were connected to an Arduino Mega board. The gas sensor has an inlet where a breath sample can be added and the DHT22 humidity sensor measures the humidity level of the breath sample. The data from both sensors is processed by the Arduino Mega board, which also shows the acetone levels on an LCD display, as seen in (Figure 1).

When you breathe into the device, the TGS822 gas sensor detects the gases in your breath, such as acetone and sends the information to the Arduino Mega board. At the same time, the DHT22 sensor measures the temperature and humidity of breath. The Arduino Mega board then collects all this data and displays it on a screen, showing the temperature, acetone levels, and humidity in breath. By comparing the acetone levels to what is normally found in human breath, it can be seen if they are higher than usual, which could be a sign of health issues, such as diabetes. A working prototype of this device was built as shown in Figure 3 and the design was refined into the last version, shown in Figure 2.

The procedure uses an Arduino Mega board, a TGS822 gas sensor, a DHT22 humidity and temperature sensor, and a TFT 2.8 display to measure the acetone level in a simulated breath sample.

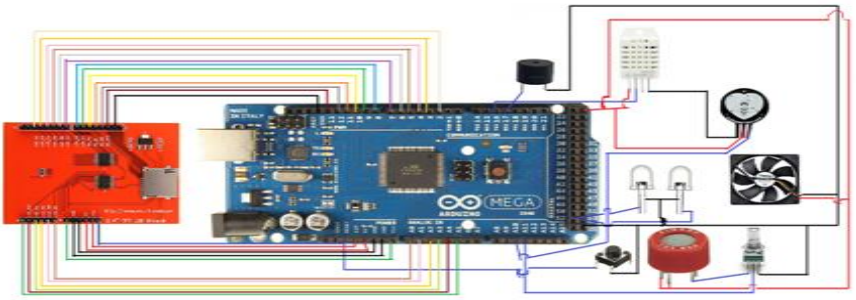

FIGURE 1. Circuit Diagram of the Proposed System

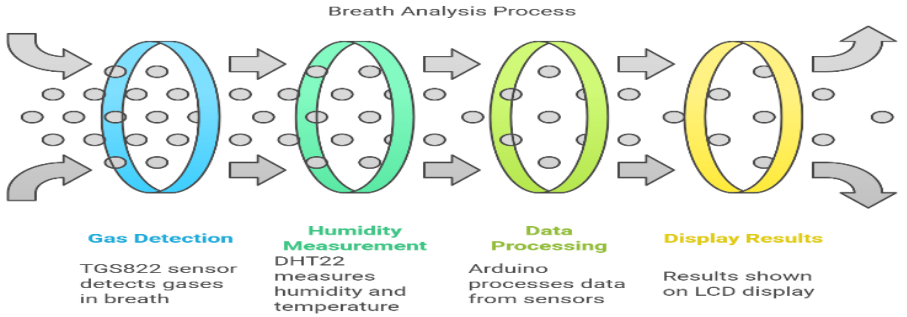

FIGURE 2. Block Diagram of the Proposed System

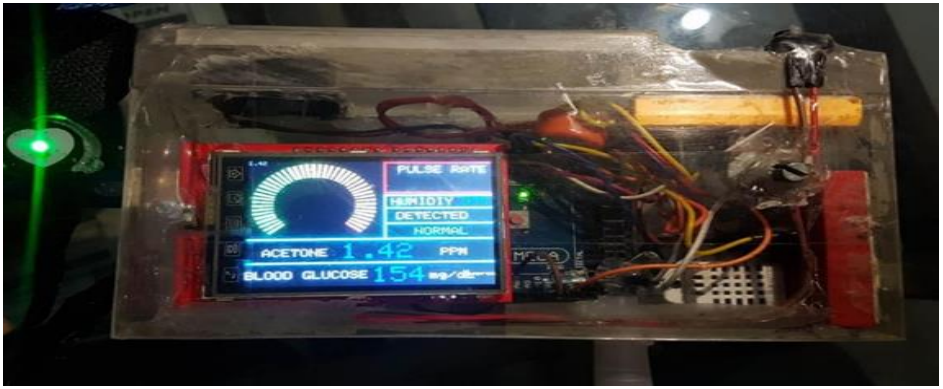

FIGURE 3. Image of Working Prototype

2) PULSE RATE DETECTION

The detection process starts by attaching the SEN-11574 pulse sensor to the finger. This innovative sensor uses infrared light to detect tiny changes in blood flow in the fingertip, allowing it to accurately track the heartbeat. By measuring these changes, the sensor gains valuable insights into heart rate and the overall cardiovascular health. The sensor sends this data to the Arduino Mega board, which uses a special algorithm to analyze the information and calculate pulse rate in beats per minute (BPM). The board then displays the current pulse rate in real-time on the screen, providing a precise reading of heart's activity as shown in Figure 4. This IoT-based setup enables continuous monitoring and efficient data transmission for remote health tracking.

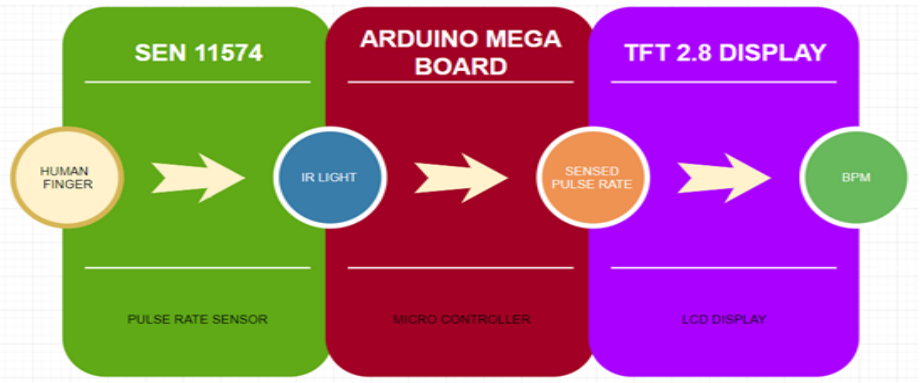

FIGURE 4. Block Diagram of the System

The procedure involves using an Arduino Mega board along with a SEN-11574 Pulse Sensor, infrared (IR) light, and a TFT 2.8 display to measure the pulse rate in a person's finger and display it in beats per minute (BPM).

III. RESULTS

A. BREATH ACETONE ANALYSIS

Firstly, 50 subjects were taken, comprising 25 males and 25 females. In these subjects, half of them were diabetic and the

remaining were healthy. Then results were gathered using their stats. As mentioned above, acetone is a biomarker for the diagnosis of diabetic patients. Acetone concentration in 25 diabetic patients and 25 non-diabetic patients was measured by means of exhaled breath through the median acetone in non-diabetic patients, shown in (Table 1 & Figure 5) which was 0.61 PPM. While, in diabetic breath it was 2.187 PPM. It was determined that acetone in diabetic patient's breathing was greater than 1.71 PPM, while its concentration in normal breathing was less than or equal to 1.62 PPM.

TABLE I

ANALYSIS OF ACETONE LEVELS OF HEALTHY AND DIABETIC PATIENTS

Gender	Acetone level [non-invasively] (PPM)	Blood glucose [invasively] (Mg/Dl)	Status
Female	1.56	200	Diabetic
Female	0.45	94	Normal
Female	1.30	176	Diabetic
Female	1.46	188	Diabetic
Female	0.53	102	Normal
Female	1.38	182	Diabetic
Female	0.32	83	Normal
Female	1.16	159	Diabetic
Female	0.8	128	Normal
Female	1.19	165	Diabetic
Female	0.78	125	Normal
Female	0.69	117	Normal

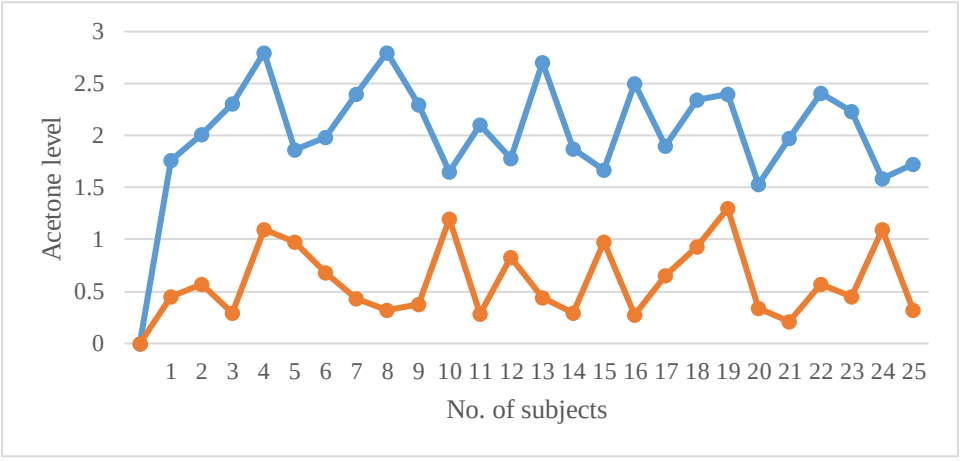

FIGURE 5. Breath Acetone Analysis of the Subjects

B. COMPARISON BETWEEN ACETONE AND GLUCOSE

To compare the concentration levels of acetone in breath with the blood glucose, 50 samples were utilized. Two groups of males and females were formed, each containing 6 healthy and 6 diabetic individuals. Furthermore, tests were performed on two occasions on each group once they were in fasting state and then in random.

The sample of their breath was taken, and the acetone level was measured through the device. Similarly, samples of blood were taken from the same people as well as their blood glucose level was measured through CE marked invasive blood glucose meter. It was found that the increase in acetone

concentration was directly proportional to the increase in blood glucose level.

TABLE II

ACETONE CONCENTRATION FOUND IN BREATH AND GLUCOSE LEVEL IN BLOOD OF DIFFERENT FEMALE SUBJECTS DURING FASTING

Diabetic Patients	Acetone level PPM	Healthy people	Acetone level PPM
1	1.76	1	0.45
2	2.01	2	0.57
3	2.31	3	0.29
4	2.8	4	1.1
5	1.86	5	0.98
6	1.98	6	0.68
7	2.4	7	0.43
8	2.8	8	0.32
9	2.3	9	0.38
10	1.65	10	1.2
11	2.1	11	0.28
12	1.78	12	0.83
13	2.7	13	0.44
14	1.87	14	0.29
15	1.67	15	0.98
16	2.5	16	0.27
17	1.9	17	0.65
18	2.34	18	0.93
19	2.4	19	1.3
20	1.53	20	0.34
21	1.97	21	0.21
22	2.41	22	0.57
23	2.23	23	0.45
24	1.59	24	1.1
25	1.72	25	0.32

1) FASTING RESULTS

The first test was performed during fasting on 12 females and 12 males. These tests provided the following data as shown in (Table 2 and Figure 6. (A, B), (Table 3 and Figure 7. (A, B)) for females and males, respectively.

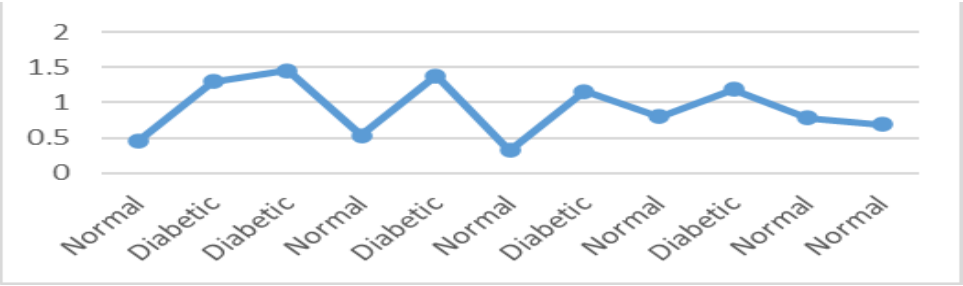

FIGURE 6 (A). Acetone Levels in Fasting Female Subjects, Categorized by Diabetic Status.

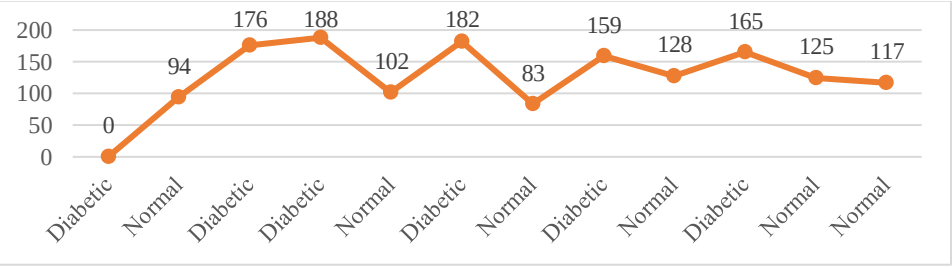

FIGURE 6. (B) Corresponding Blood Glucose Levels Measured Invasively

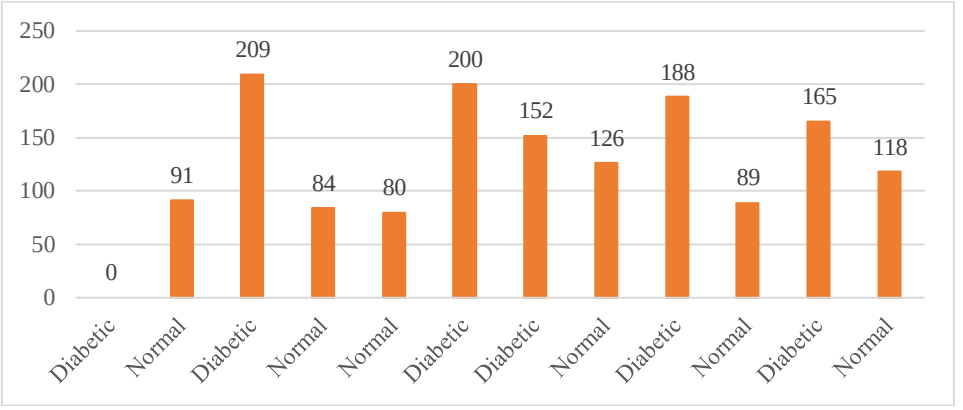

FIGURE 7. (A) Blood Glucose Level of Female Subjects

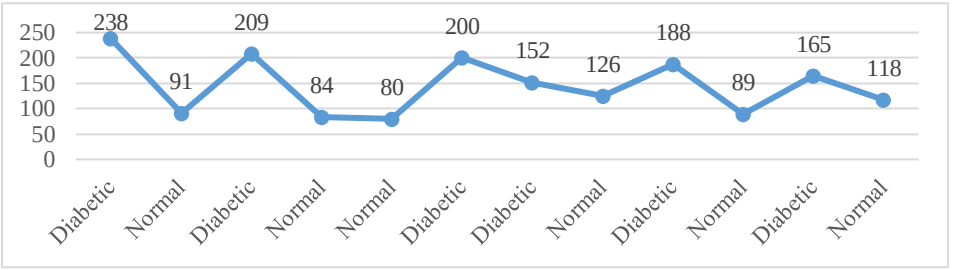

FIGURE 7. (B) Blood Glucose Level of Female Subjects

TABLE III

ACETONE CONCENTRATION FOUND IN BREATH AND GLUCOSE LEVEL IN BLOOD OF DIFFERENT MALE SUBJECTS DURING FASTING

Gender	Acetone Level [Non-Invasively] (PPM)	Blood Glucose [Invasively] (Mg/Dl)	Status
Female	1.95	238	Diabetic
Female	0.9	137	Normal
Female	2.2	262	Diabetic
Female	2.6	302	Diabetic
Female	0.9	125	Normal
Female	2.8	320	Diabetic
Female	0.78	113	Normal
Female	1.97	243	Diabetic
Female	1.5	178	Normal
Female	2.4	276	Diabetic
Female	1.27	169	Normal
Female	0.94	139	Normal

2) RANDOM TEST RESULTS

Again, a second test was performed on the same group of subjects. However, this time, it was random, providing the following data (Table 4 and Figure 8). (A, B), (Figure 9. (A, B)) for females and males, respectively.

3) PULSE RATE RESULTS

For pulse rate readings, 10 subjects' readings were taken as samples from proposed device. Similarly, 10 readings were taken from the device available in market from the same subjects to determine the device's accuracy. Resultantly, the device's values were found approximate to the conventional device as shown in (Table 5 and Figure 10)

TABLE IV

ACETONE CONCENTRATION FOUND IN BREATH AND GLUCOSE LEVEL IN BLOOD OF DIFFERENT FEMALE SUBJECTS RANDOM

Gender	Acetone leveL [Non-Invasively] (PPM)	Blood Glucose [Invasively] (Mg/Dl)	Status
Male	1.95	238	Diabetic
Male	0.43	91	Normal
Male	1.65	209	Diabetic
Male	0.32	84	Normal
Male	0.29	80	Normal
Male	1.55	200	Diabetic
Male	1.05	152	Diabetic
Male	0.76	126	Normal
Male	1.43	188	Diabetic
Male	0.40	89	Normal
Male	1.19	165	Diabetic
Male	0.72	118	Normal

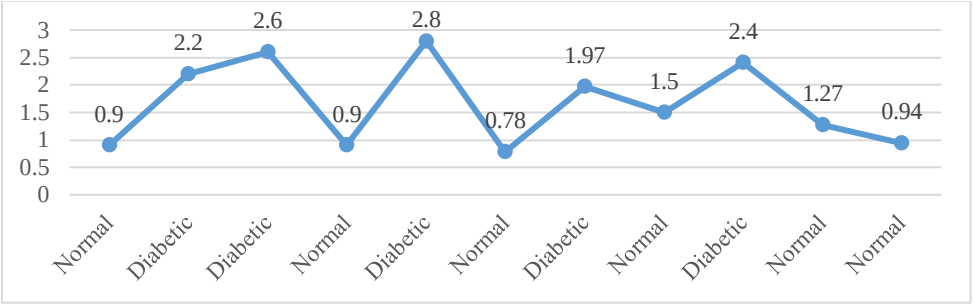

FIGURE 8 (A). Acetone Level of the Random Test Results for Males

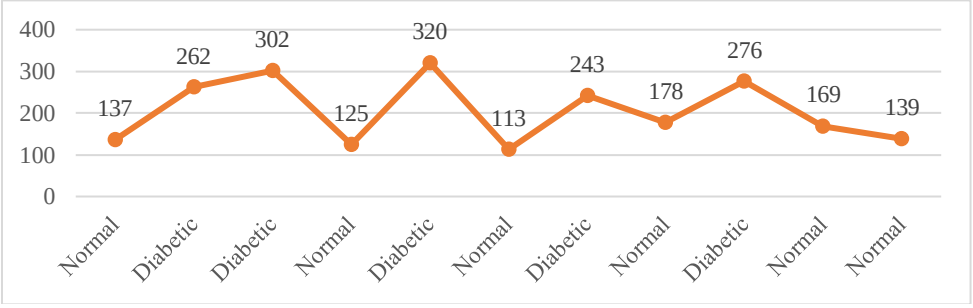

FIGURE 8 (B). Blood Glucose Level of the Random Test Results for Males

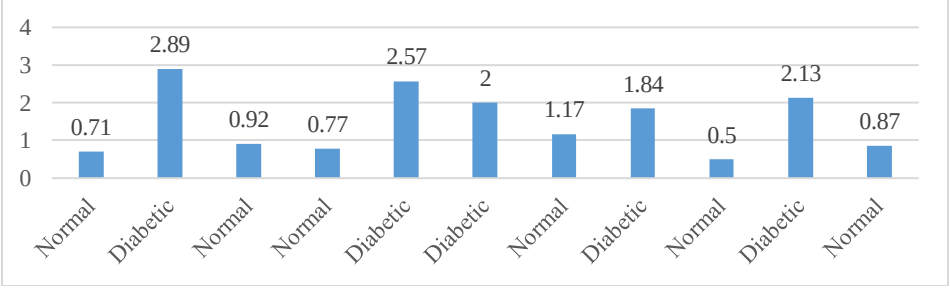

FIGURE 9. (A) Acetone Level of Female Subjects

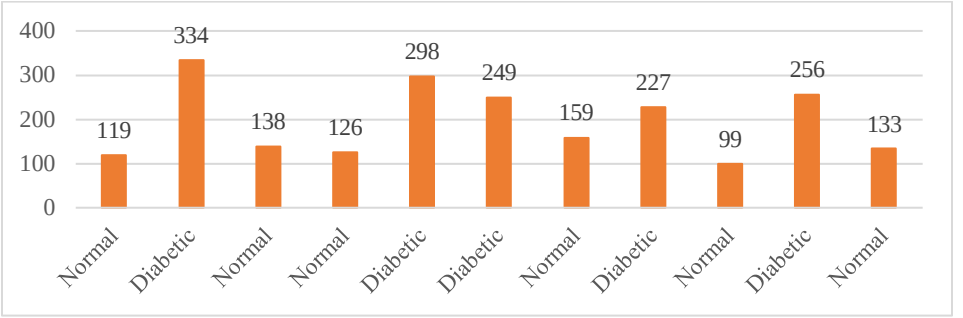

FIGURE 9. (B) Blood Glucose Level of Female Subjects

TABLE V
PULSE RATE COMPARISON OF CE-MARKED DEVICE AND PROPOSED DEVICE

Samples	CE Marked Device (bpm)	Proposed Device (bpm)
1	96	95.5
2	84	83
3	64	65
4	110	108
5	75	76
6	79	77
7	81	81.5
8	92	93
9	68	68.9
10	115	112

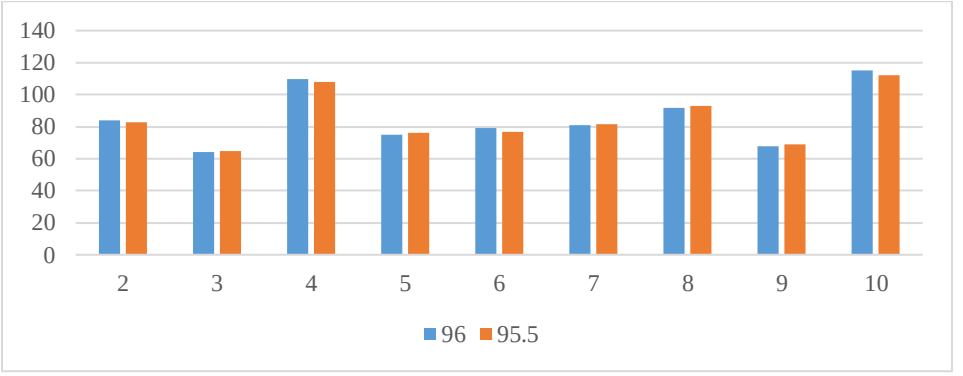

FIGURE 10. Comparison of Pulse Rate Measurements from the Proposed Device and a CE-marked device

IV. CONCLUSION

In summary, IoT-enabled breath acetone analysis offers a non-invasive, sensitive approach to detect and monitor various clinical conditions. These include diabetes, obesity, and metabolic disorders. Using advanced gas detection techniques, such as GC, GC-MS, SIFT-MS, PTR-MS, and IMS, combined with real-time data acquisition through IoT systems, breath analysis provides accurate results for clinical applications. This technology may also serve as a motivational tool for

individuals in weight loss programs by tracking metabolic changes in real time. Recent advancements in IoT technology allow researchers to explore acetone sensors to monitor blood glucose levels through breath analysis. By leveraging IoT-based sensors, researchers tested both healthy individuals and pre-diabetics, considering factors, such as pressure, temperature, and humidity. Results indicated that breath analysis could accurately measure blood glucose levels, with potential for further improvements through expanded datasets. A key achievement of the study was the creation of a low-cost, IoT-enabled, and high-performance device using affordable components, highlighting its potential for scalable healthcare solutions. Overall, the study presented promising findings to integrate IoT in breath analysis for glucose monitoring.

CONFLICT OF INTEREST

The author of the manuscript has no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

DATA AVALIABILITY STATEMENT

The data associated with this study will be provided by the corresponding author upon request.

FUNDING DETAILS

No funding has been received for this article.

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