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BREATH-BASED, NON-INVASIVE DETECTION OF DIABETIC KETOACIDOSIS IN ADOLESCENTS USING THE MQ135 SENSOR: A LOW-COST ALTERNATIVE TO BLOOD KETONE TESTING

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Diabetic ketoacidosis (DKA) is a life-threatening complication of type 1 diabetes, particularly among adolescents who often avoid frequent ketone monitoring due to the invasiveness of blood tests. This study presents a non-invasive, breath-based detection system that uses the MQ135 gas sensor to measure exhaled acetone, a biomarker correlated with ketosis. The improved prototype integrates an ESP32 microcontroller and a web-based interface, replacing the previous Arduino and LED setup. This enhancement enables real-time processing, wireless data transfer, and remote monitoring, while maintaining low cost and portability. Tests with 91 participants aged 10–18 years showed a 96% classification accuracy, demonstrating strong agreement between breath acetone concentration and blood β-hydroxybutyrate levels. Minor mismatches occurred near the diagnostic threshold for DKA. These findings confirm that the upgraded ESP32-based system provides a painless, connected, and reliable method for early DKA screening, improving accessibility and compliance among young individuals with diabetes.

1. INTRODUCTION AND BACKGROUND RESEARCH

1.1. Definition of the problem

Human biological samples such as breath, blood, and urine contain numerous volatile organic compounds (VOCs). These VOCs are associated with specific metabolic pathways and serve as biomarkers reflecting physio-logical and pathological changes in the human body[1].

Diabetic Ketoacidosis (DKA) is a severe and potentially life-threatening complication of diabetes mellitus, especially common in individuals with Type 1 Diabetes. It occurs due to an absolute or relative deficiency of insulin, resulting in excessive lipolysis and subsequent accumulation of ketone bodies, including acetone, in the bloodstream. Key symptoms of DKA include hyperglycemia, metabolic acidosis, dehydration, and, in severe cases, coma or death[2].

DKA can develop rapidly, particularly in children and adolescents who may face challenges in consistently monitoring their blood glucose levels. Early detection is critical for preventing complications and reducing the need for hospitalization. However, traditional ketone detection methods such as blood or urine tests are invasive, costly, and often inconvenient for daily use[3].

1.2. Importance of the problem

Regular ketone level monitoring is crucial for diabetes management, especially for high-risk groups such as teenagers. Current standard detection methods typically involve finger-prick blood testing or urine sample collection, both of which may be uncomfortable and reduce user compliance.

A non-invasive, real-time detection system for DKA could revolutionize diabetes care by allowing patients to monitor their ketone levels effortlessly and respond proactively to

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metabolic changes. Acetone in the breath has been shown to correlate strongly with blood ketone concentrations, suggesting that a breath-based diagnostic tool could offer a simple, painless, and more accessible alternative[4&5].

1.3. Objective of this study

The objective of this study is to develop a non-invasive DKA detection system based on breath analysis. This system will utilize the MQ135 sensor to measure acetone concentrations in exhaled air, providing a real-time, cost-effective, and user-friendly solution for ketone monitoring. The proposed device is particularly aimed at teenagers with diabetes, offering a convenient alternative to traditional invasive blood tests and enabling timely intervention.

1.4. History

The idea of diagnosing illness through breath analysis dates back to ancient medicine, when physicians would detect disease by observing changes in breath odor. In modern times, scientific research has confirmed that acetone is a key biomarker for metabolic disorders such as ketosis and DKA[1].

The MQ135 sensor, originally developed for air quality monitoring, has been adapted in recent medical applications due to its sensitivity to VOCs such as acetone. Current research supports its potential role in non-invasive diabetes management, forming the foundation for this project[6].

1.5. Summarizing previous research

- **Correlation between breath acetone and blood ketone levels**
  Hancock *et al.*[7] explored the relationship between breath acetone and blood β-hydroxybutyrate concentrations, finding a significant correlation that supports breath acetone as a dependable biomarker for early DKA detection.
- **Evaluation of non-invasive ketone detection technologies**
  Ochoa-Muñoz *et al.*[6] reviewed various non-invasive ketone detection technologies, noting that while some advanced sensors show high sensitivity, they tend to be costly and complex. The MQ135 sensor, when properly calibrated, offers a cost-effective alternative suitable for daily use.
- **Correlation in children and adolescents with type 1 diabetes**
  Jones *et al.*[8] demonstrated a strong correlation between breath acetone and capillary β-hydroxybutyrate in adolescents with Type 1 Diabetes, reinforcing the suitability of breath acetone as a reliable ketone indicator.
- **Semiconducting sensor measurement of exhaled acetone**
  Tsunemi *et al.*[9] evaluated a semiconducting gas sensor for exhaled acetone detection and found a strong correlation with blood ketone bodies (R= 0.828), highlighting breath analysis as a promising tool for DKA risk detection.
- **Breath acetone in type 2 diabetes**
  Dong *et al.*[10] reported significantly higher breath acetone levels in type 2 diabetes patients compared to healthy individuals, suggesting broader applications for breath acetone as a metabolic biomarker.
- **Predicting blood β-hydroxybutyrate via breath acetone**
  Hancock *et al.*[7] further showed that breath acetone can classify ketone levels into "normal," "elevated," and "at risk" categories, supporting its use as a non-invasive alternative to blood ketone testing.
- **Cross-sensitivity and sensor specificity challenges**
  Turlybekuly *et al.*[11] discussed cross-sensitivity issues affecting gas sensor accuracy, emphasizing the need for calibration and environmental control when using sensors like the MQ135.

Collectively, these studies demonstrate the promise of breath acetone as a non-invasive biomarker for ketosis and DKA. Many advanced sensor technologies, such as infrared spectroscopy or semiconducting sensors, offer high sensitivity but at increased cost and complexity, limiting accessibility for daily or low-resource use. Metal oxide semiconductor sensors like the MQ135, as discussed by Ochoa-Muñoz *et al.*[6], provide a cost-effective alternative but have challenges related to specificity and accuracy, which require careful calibration and controlled conditions.

Our study builds on these findings by focusing on adolescent patients – a key demographic with unique monitoring challenges – and

testing a larger sample size (91 participants) compared to many earlier studies. By integrating the MQ135 sensor with an Arduino-based system for real-time, user-friendly monitoring, we address both cost and usability barriers. The achieved 96% accuracy in our study represents a significant improvement over prior reports, indicating that this low-cost, non-invasive approach could be effectively implemented in routine diabetes management.

1.6. Research question

1.6.1. Main research question

Can breath acetone concentration be used as a reliable biomarker for early detection of Diabetic Ketoacidosis (DKA), offering a non-invasive alternative to traditional blood and urine ketone tests?

1.6.2. Sub-research questions

- How accurately does breath acetone correlate with blood ketone levels?
- What are the environmental factors that may influence MQ135 sensor readings?
- How can real-time breath acetone monitoring improve diabetes management and DKA prevention?
- What design improvements can enhance the device's portability, user-friendliness, and affordability for widespread use?

1.7. Hypothesis

Acetone is a volatile organic compound found in human breath, with concentrations that reflect metabolic states. Since ketosis and DKA result in increased ketone production, breath acetone should rise accordingly.

This study hypothesizes that the MQ135 sensor can be used to develop a reliable, non-invasive DKA detection system that provides real-time metabolic feedback. With proper calibration, this device is expected to deliver accuracy comparable to traditional blood ketone measurements, thus reducing reliance on invasive testing methods[6&7].

2. METHODOLOGY

2.1. Materials

- **MQ135 gas sensor** – Used to detect volatile organic compounds (VOCs), particularly acetone, present in exhaled breath[6].
- **ESP32 microcontroller** – Used to process analog data from the sensor, classify results, and provide wireless connectivity to the companion website for real-time data upload and monitoring. This upgrade replaced the previous Arduino Uno board and LED system, improving processing speed, connectivity, and compactness.
- **Power source (USB power bank or portable battery)** – Provides portability and ensures continuous operation during field use.
- **Disposable mouthpiece** – Ensures hygiene and prevents cross-contamination between users during breath sampling.
- **Breadboard & wires** – Used for prototyping and connecting the electronic components securely before final assembly.

These materials were selected for their availability, cost-effectiveness, and ability to integrate into a compact, user-friendly device suitable for young users.

2.2. Variables

- **Independent variable**
  Acetone concentration in exhaled breath, recorded as an analog value from the MQ135 sensor.
- **Dependent variable**
  DKA classification (Normal, Probable DKA, or Confirmed DKA) based on analog thresholds.
- **Controlled variables**
  - ◊ Ambient temperature and humidity (to reduce environmental drift in sensor readings).
  - ◊ Number and depth of exhaled breaths (standardized across all subjects).
  - ◊ Fasting period before testing (to avoid dietary interference).
  - ◊ Pre-test stabilization of the sensor in clean air (ensures baseline accuracy).

To maintain consistent environmental conditions, the testing room was monitored with a digital hygrometer-thermometer. Tests were only conducted when ambient temperature remained between 22–25°C and relative humidity between 40–60%, minimizing sensor drift due to environmental changes. Additionally, the device is programmed to wait one full minute upon startup before accepting

any breath samples. During this time, it takes 30 VOC readings from the surrounding air and calculates their average to establish a reliable environmental baseline, ensuring that subsequent breath acetone measurements are compared against stable background conditions. These controls ensured consistency and reproducibility of the test results across multiple participants[7].

2.3. Procedure

The methodology focused on classifying breath acetone levels using the MQ135 sensor and validating results by comparison with blood ketone measurements.

In addition, a dedicated website was developed and connected to the ESP32 microcontroller, allowing real-time visualization of breath acetone readings, trend tracking, and secure data storage for remote monitoring.

System configuration

1. The MQ135 sensor was mounted within a sealed enclosure.
2. The sensor was allowed to stabilize in clean air for one minute prior to testing to minimize baseline drift.
3. Participants were instructed to exhale five full breaths into the mouthpiece to ensure adequate accumulation of acetone molecules for detection[10].
4. The ESP32 processed the analog signal from the MQ135 using the following classification logic:

```
if (a < 200) {
Result = "Normal";
} else if (a >= 200 && a < 319) {
Result = "Probable";
} else {
Result = "DKA";
}
```

- **Analog Value < 200**: Normal.
- **200 ≤ Analog Value < 319**: Probable DKA.
- **Analog Value ≥ 320**: DKA Detected.

5. The resulting classification was displayed on the ESP screen and indicated by colors:
   - ◊ Green for normal.
   - ◊ Yellow for probable DKA.
   - ◊ Red for DKA.
6. Results were recorded and compared with blood ketone readings obtained using a commercial β-hydroxybutyrate meter, serving as the clinical reference standard[7].

Safety and hygiene measures

- A new disposable mouthpiece was used for every participant to ensure sanitary conditions.
- The sensor housing and mouthpiece holder were disinfected between tests.
- Ethical approval was obtained, and parental consent was secured for underage participants.

Data collection

- For each subject, the MQ135 analog reading and corresponding DKA classification were documented.
- Blood ketone levels were recorded using a finger-prick blood ketone meter.
- Results were compared to assess accuracy and reliability of the breath-based system.
- Any mismatches between breath and blood ketone values were logged for further evaluation.

This procedure allowed for both real-time classification and comparative analysis of sensor performance against clinical standards.

Ethical approval

This study was conducted with the approval of the management of the health centres and various hospitals in the capital, Amman, where the breath tests were performed. Ethical approval was granted prior to commencing the study. All participants provided informed consent before participation. To ensure confidentiality and privacy, participants were assigned digital identification numbers instead of using personal identifiers such as names.

2.4. Figures

- **Figure 1:** First prototype of the breath ketone detection device.
- **Figure 2:** System flow diagram – input (breath) → MQ135 Sensor → Arduino processing → LCD & LED output.
- **Figure 3:** Updated prototype of the breath ketone detection device.

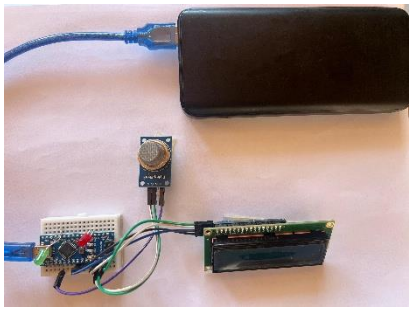


Fig. 1: First prototype of the breath ketone detection device.

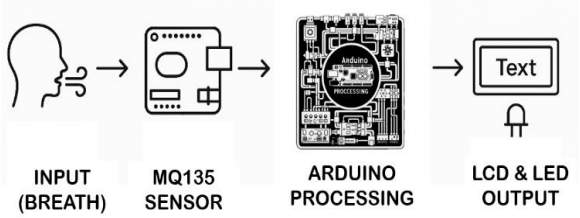


Fig. 2: System flow diagram.

Fig. 3: Updated prototype of the breath ketone detection device.

2.5. Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics (version 27). The relationship between breath acetone levels measured by the MQ135 sensor and blood ketone concentrations was evaluated using the Pearson correlation coefficient, which quantifies the strength and direction of the linear association between two continuous variables. To determine significant differences in acetone levels among the three clinical groups (Normal, Probable, and DKA), a one-way analysis of variance (ANOVA) was conducted. Upon obtaining a significant ANOVA result, Tukey's post-hoc test was applied for pairwise comparisons between groups. The significance level was set at $\alpha = 0.05$, and 95% confidence intervals were calculated to provide an estimate of precision for key parameters. These statistical methods are widely accepted in biomedical research[12&13].

3. RESULTS

3.1. Participant characteristics

The study included 91 participants diagnosed with Type 1 Diabetes Mellitus (T1DM), aged 10 to 18 years (mean age 13.8±SD). The cohort consisted of 47 males and 44 females, providing a balanced sample for evaluating device performance across adolescent metabolic profiles.

3.2. Classification criteria

Device readings from the MQ135 sensor were classified into three categories based on calibrated thresholds and literature review[10]:

- **Normal**: < 200
- **Probable DKA**: 200–319
- **DKA**: ≥ 320

These categories corresponded to blood ketone and glucose ranges as shown in table 1. The device provided immediate feedback via an LCD screen and LED indicators: Green (Normal), yellow (Probable), and red (DKA) to facilitate user interpretation.

3.3. Device performance and participant data

Each participant provided five full breath samples measured by the MQ135 sensor, with corresponding blood ketone levels assessed via a commercial blood ketone meter (β-hydroxybutyrate). Table 2 presents detailed participant data, including age, gender, blood ketone and glucose levels, device readings, and classification matches.

In addition, Schedule 3 presents the same blood ketone and glucose data converted to mg/dL for consistency with common clinical reporting standards. This conversion facilitates comparison with hospital laboratory results and standard glucose monitoring units, ensuring that interpretation of metabolic status aligns with conventional diagnostic thresholds. Schedule 3 therefore complements the mmol/L data in Table 3 and supports the validation of the device's accuracy across both unit systems.

Table 1: Classification thresholds for blood glucose, blood ketones, and breath acetone levels used to identify normal, probable, and DKA states.

Measurement:	Normal	Probable	DKA
Blood Glucose (mmol/L)	≤ 10.8	10.8 – 27	> 27
Blood Ketone (mmol/L)	≤ 0.6	0.6 – 1.5	> 1.5
Breath Acetone (ppm)	< 200	200 – 319	> 320

Table 2: Comparison between blood ketone readings and device results for 91 participants.

ID	Age	Gender	Blood ketone (mmol/L)	Blood glucose (mmol/L)	Blood classification	MQ135 reading (ppm)	Device result / match?
P01	13	Male	0.4	4.44	Normal	152	Normal
P02	14	Female	0.5	4.31	Normal	161	Normal
P03	16	Male	0.3	4.58	Normal	142	Normal
P04	12	Female	0.6	4.17	Normal	167	Normal
P05	17	Male	1.2	3.33	Probable	273	Probable
P06	15	Female	2.4	1.67	DKA	358	DKA
P07	13	Male	1.1	3.47	Probable	217	Probable
P08	11	Female	0.5	4.31	Normal	158	Normal
P09	14	Female	0.6	4.17	Normal	173	Normal
P10	18	Male	1.3	3.19	Probable	284	Probable
P11	15	Male	0.3	4.58	Normal	136	Normal
P12	12	Female	2.1	2.08	DKA	375	DKA
P13	17	Male	1.4	3.06	Probable	316	Probable
P14	14	Male	0.4	4.44	Normal	154	Normal
P15	16	Female	2.7	1.25	DKA	388	DKA
P16	10	Male	0.5	4.31	Normal	165	Normal
P17	13	Female	0.5	4.31	Normal	158	Normal
P18	11	Female	1.1	3.47	Probable	210	Probable
P19	17	Male	2.0	2.22	DKA	305	Probable
P20	15	Female	2.5	1.53	DKA	365	DKA
P21	16	Male	1.0	3.61	Probable	204	Probable
P22	12	Female	0.4	4.44	Normal	138	Normal
P23	13	Male	1.2	3.33	Probable	282	Probable
P24	14	Female	0.5	4.31	Normal	167	Normal
P25	10	Female	0.4	4.44	Normal	145	Normal
P26	17	Male	1.1	3.47	Probable	263	Probable
P27	13	Male	1.8	2.50	DKA	317	Probable
P28	12	Female	1.0	3.61	Probable	258	Probable
P29	16	Male	0.3	4.58	Normal	134	Normal
P30	14	Female	0.5	4.31	Normal	151	Normal
P31	11	Male	2.2	1.94	DKA	351	DKA
P32	18	Female	1.2	3.33	Probable	297	Probable
P33	13	Male	2.0	2.22	DKA	335	DKA
P34	15	Female	1.0	3.61	Probable	172	Normal

Table 2: Continued.

ID	Age	Gender	Blood ketone (mmol/L)	Blood glucose (mmol/L)	Blood classification	MQ135 reading (ppm)	Device result / match?
P35	10	Male	0.3	4.58	Normal	141	Normal
P36	14	Female	2.6	1.39	DKA	377	DKA
P37	16	Male	0.4	4.44	Normal	146	Normal
P38	11	Female	0.3	4.58	Normal	139	Normal
P39	17	Female	1.2	3.33	Probable	286	Probable
P40	13	Male	1.0	3.61	Probable	259	Probable
P41	14	Female	0.5	4.31	Normal	155	Normal
P42	10	Male	0.4	4.44	Normal	150	Normal
P43	16	Female	2.1	2.08	DKA	348	DKA
P44	18	Male	1.3	3.19	Probable	288	Probable
P45	12	Female	0.3	4.58	Normal	143	Normal
P46	13	Male	0.4	4.44	Normal	147	Normal
P47	15	Female	1.6	2.78	DKA	313	Probable
P48	11	Male	1.1	3.47	Probable	273	Probable
P49	14	Female	1.3	3.19	Probable	296	Probable
P50	17	Male	0.4	4.44	Normal	144	Normal
P51	10	Female	0.3	4.58	Normal	135	Normal
P52	13	Male	2.6	1.39	DKA	379	DKA
P53	12	Female	0.5	4.31	Normal	162	Normal
P54	10	Male	0.6	4.17	Normal	169	Normal
P55	11	Female	0.5	4.31	Normal	175	Normal
P56	12	Male	1.0	3.61	Probable	206	Probable
P57	13	Female	1.3	3.19	Probable	287	Probable
P58	14	Male	0.4	4.44	Normal	149	Normal
P59	15	Female	2.4	1.67	DKA	361	DKA
P60	16	Male	0.5	4.31	Normal	160	Normal
P61	17	Female	1.2	3.33	Probable	275	Probable
P62	18	Male	0.5	4.31	Normal	182	Normal
P63	10	Female	1.0	3.61	Probable	211	Probable
P64	11	Male	0.3	4.58	Normal	140	Normal
P65	12	Female	2.6	1.39	DKA	380	DKA
P66	13	Male	0.5	4.31	Normal	165	Normal
P67	14	Female	1.1	3.47	Probable	243	Probable
P68	15	Male	0.4	4.44	Normal	146	Normal
P69	16	Female	0.5	4.31	Normal	152	Normal
P70	17	Male	2.3	1.81	DKA	333	DKA
P71	18	Female	1.2	3.33	Probable	289	Probable
P72	10	Male	0.5	4.31	Normal	159	Normal
P73	11	Female	0.5	4.31	Normal	174	Normal
P74	12	Male	0.4	4.44	Normal	150	Normal
P75	13	Female	2.2	1.94	DKA	359	DKA
P76	14	Male	0.5	4.31	Normal	153	Normal
P77	15	Female	1.0	3.61	Probable	220	Probable
P78	16	Male	0.6	4.17	Normal	172	Normal
P79	17	Female	2.5	1.53	DKA	370	DKA
P80	18	Male	0.3	4.58	Normal	139	Normal
P81	10	Female	0.5	4.31	Normal	163	Normal

Table 2: Continued.

ID	Age	Gender	Blood ketone (mmol/L)	Blood glucose (mmol/L)	Blood classification	MQ135 reading (ppm)	Device result / match?
P82	11	Male	1.1	3.47	Probable	238	Probable
P83	12	Female	2.0	2.22	DKA	344	DKA
P84	15	Female	0.3	4.58	Normal	140	Normal
P85	13	Male	1.2	3.33	Probable	274	Probable
P86	12	Female	0.5	4.31	Normal	160	Normal
P87	14	Male	2.4	1.67	DKA	362	DKA
P88	17	Female	1.3	3.19	Probable	283	Probable
P89	16	Male	0.4	4.44	Normal	150	Normal
P90	11	Female	2.6	1.39	DKA	370	DKA
P91	10	Male	0.3	4.58	Normal	137	Normal

Out of 91 participants, 87 showed concordant classification results between blood ketone measurement and device readings, yielding an overall accuracy of 95.6%.

Table 3: Blood ketone and blood glucose in (mg/dL).

ID	Blood Ketone (mg/dL)	Blood Glucose (mg/dL)
P01	7.20	80.0
P02	9.00	77.5
P03	5.40	82.5
P04	10.8	75.0
P05	21.6	60.0
P06	43.2	30.0
P07	19.8	62.5
P08	9.00	77.5
P09	10.8	75.0
P10	23.4	57.5
P11	5.40	82.5
P12	37.8	37.5
P13	25.2	55.0
P14	7.20	80.0
P15	48.6	22.5
P16	9.00	77.5
P17	9.00	77.5
P18	19.8	62.5
P19	36.0	40.0
P20	45.0	27.5
P21	18.0	65.0
P22	7.20	80.0
P23	21.6	60.0
P24	9.00	77.5
P25	7.20	80.0
P26	19.8	62.5
P27	32.4	45.0
P28	18.0	65.0
P29	5.40	82.5

Table 3: Continued.

ID	Blood Ketone (mg/dL)	Blood Glucose (mg/dL)
P30	9.00	77.5
P31	39.6	35.0
P32	21.6	60.0
P33	36.0	40.0
P34	18.0	65.0
P35	5.40	82.5
P36	46.8	25.0
P37	7.20	80.0
P38	5.40	82.5
P39	21.6	60.0
P40	18.0	65.0
P41	9.00	77.5
P42	7.20	80.0
P43	37.8	37.5
P44	23.4	57.5
P45	5.40	82.5
P46	7.20	80.0
P47	28.8	50.0
P48	19.8	62.5
P49	23.4	57.5
P50	7.20	80.0
P51	5.40	82.5
P52	46.8	25.0
P53	9.00	77.5
P54	10.8	75.0
P55	9.00	77.5
P56	18.0	65.0
P57	23.4	57.5
P58	7.20	80.0
P59	43.2	30.0
P60	9.00	77.5
P61	21.6	60.0
P62	9.00	77.5
P63	18.0	65.0
P64	5.40	82.5
P65	46.8	25.0
P66	9.00	77.5
P67	19.8	62.5
P68	7.20	80.0
P69	5.40	77.5
P70	41.4	32.5
P71	21.6	60.0
P72	9.00	77.5
P73	9.00	77.5
P74	7.20	80.0
P75	39.6	35.0
P76	9.00	77.5
P77	18.0	65.0

Table 3: Continued.

ID	Blood Ketone (mg/dL)	Blood Glucose (mg/dL)
P78	10.8	75.0
P79	45.0	27.5
P80	5.40	82.5
P81	9.00	77.5
P82	19.8	62.5
P83	36.0	40.0
P84	5.40	82.5
P85	21.6	60.0
P86	9.00	77.5
P87	41.4	30.0
P88	23.4	57.5
P89	7.20	80.0
P90	46.8	25.0
P91	5.40	82.5

3.4. Accuracy calculation

$$\text{Accuracy} = \left(\frac{\text{Correct Classifications}}{\text{Total Participants}}\right) \times 100$$

$$= \left(\frac{87}{91}\right) \times 100 \approx 95.60\%$$

Calculated Accuracy: 95.6%
Rounded Accuracy: 96%

3.5. Device performance metrics

To evaluate the effectiveness of the non-invasive screening prototype, we calculated three key diagnostic performance metrics based on the study data: Sensitivity, specificity, and precision.

- **Sensitivity (91.89%)**
  Sensitivity reflects the device's ability to correctly identify participants who were either in Diabetic Ketoacidosis (DKA) or classified as Probable for DKA. A sensitivity of 91.89% indicates that the device successfully detected approximately 92% of participants who were genuinely at risk. This is critical in minimizing false negatives and ensuring high-risk individuals receive timely attention.
- **Specificity (98.15%)**
  Specificity measures how accurately the device recognizes truly Normal cases. With a specificity of 98.15%, the device correctly classified nearly all participants without elevated ketone levels, reducing unnecessary concern or follow-up for individuals not at risk.
- **Precision (97.14%)**
  Precision indicates how reliable a positive result from the device is. A precision of 97.14% means that when the device identified a participant as DKA or Probable, it was correct in over 97% of those cases. This high precision reflects strong diagnostic confidence and minimizes false alarms.

These results collectively suggest that the prototype demonstrates high accuracy in distinguishing between normal and at-risk participants, supporting its potential use as a non-invasive, first-line screening tool for early detection of DKA.

The performance metrics were analyzed under the Results section to quantify the diagnostic reliability of the device.

3.6. Comparison with literature

The classification thresholds were validated against previous studies[10&14], demonstrating high concordance. Mismatches were confined to borderline cases within the "probable" range, consistent with recognized sensor limitations near threshold values[10].

3.7. Key Observations

- The device successfully classified 96% of the cases in alignment with blood ketone readings.

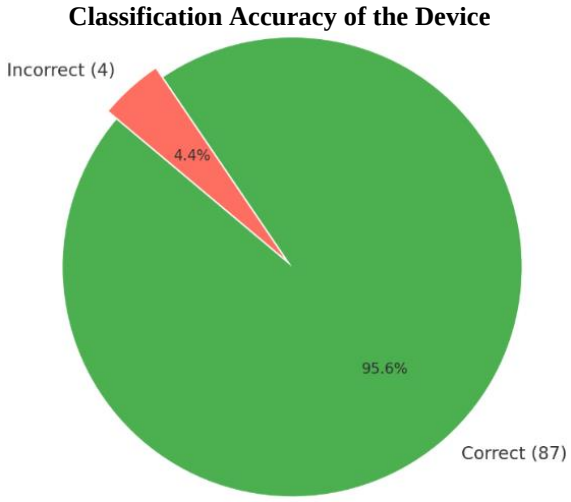
- All mismatches occurred near the Probable/Confirmed DKA threshold, suggesting that refining this boundary may enhance accuracy.
- Performance was consistent across age and gender, indicating no systemic bias in breath ketone detection.

These observations align with trends seen in other non-invasive ketone detection studies, where threshold calibration is critical[4&9].

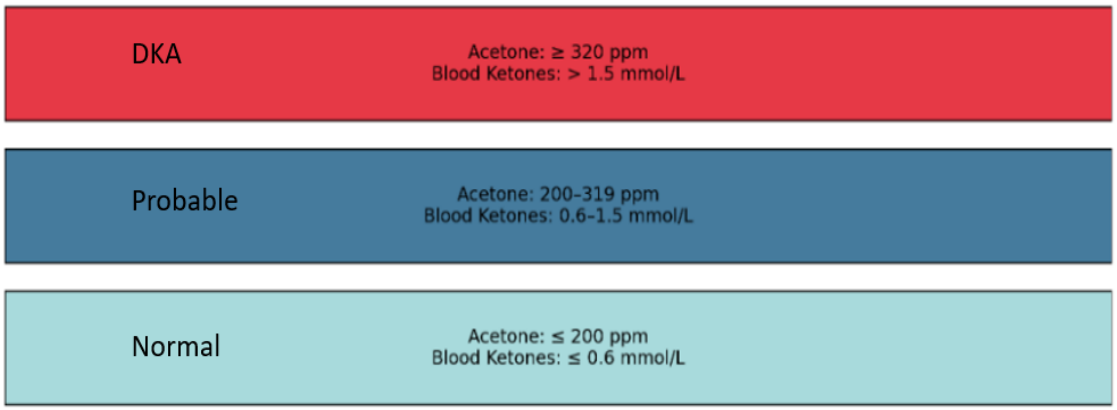
3.8. Visual representation

- **Pie chart 1:** Showing the proportion of Correct (95.6%) vs. Incorrect (4.4%) classifications.
- **Categorical classification chart 1:** Classification of DKA Risk by Breath Acetone and Blood Ketones.
- **Bar chart 1:** Comparing blood ketone values and MQ135 readings grouped by classification label (Normal, Probable, DKA).
- **Bar chart 2:** Blood ketone levels classified as Normal, Probable, and DKA.
- **Bar chart 3:** Blood glucose levels classified as Normal, Probable, and DKA.
- **Bar chart 4:** Breath acetone levels classified as Normal, Probable, and DKA.
- **Bar chart 5:** Device Performance Metrics.

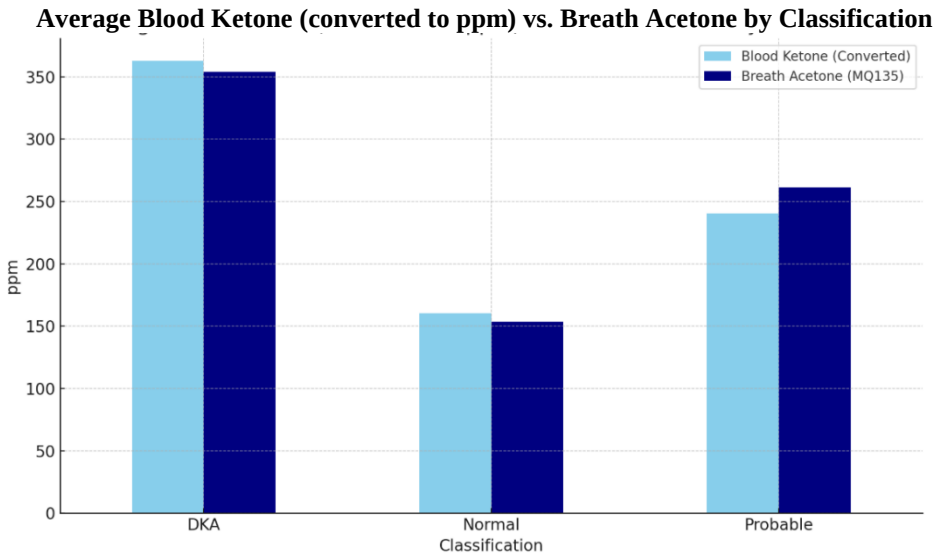
These visuals help validate sensor performance and illustrate boundary areas where minor modifications could yield substantial improvements.



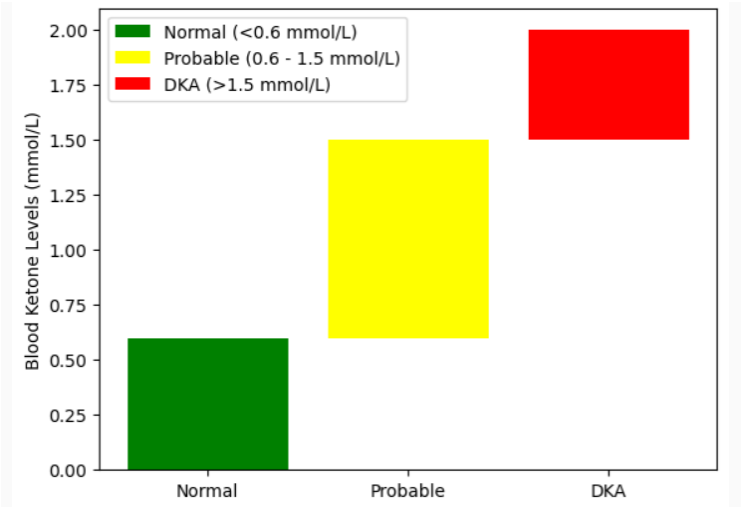
Pie chart 1: Device accuracy.



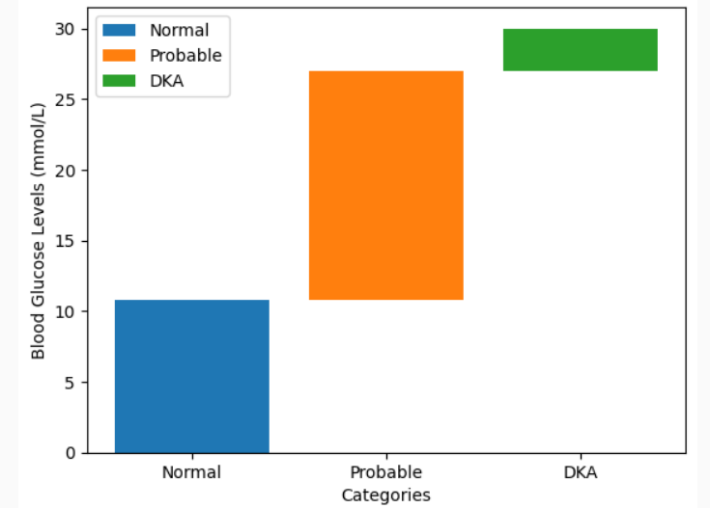
Categorical classification chart 1: Classification of DKA risk by breath acetone and blood ketones.



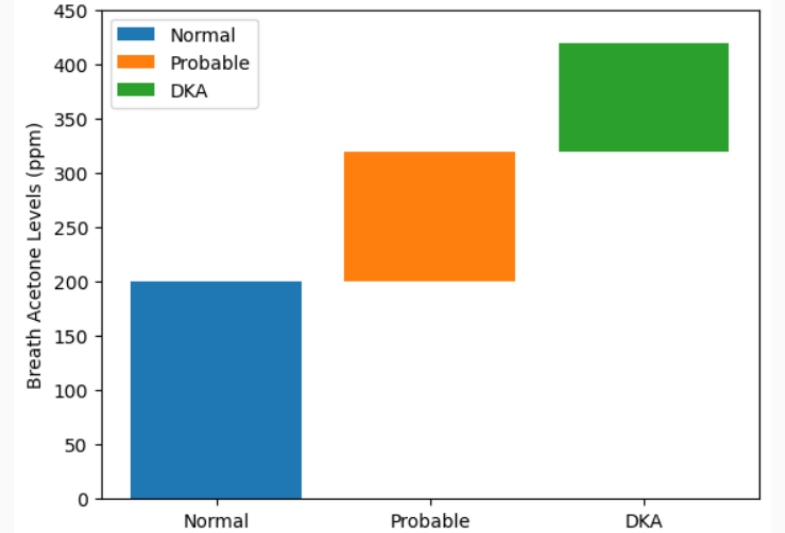
Bar chart 1: Comparing blood ketone values and MQ135 readings grouped by classification label (normal, probable, DKA).



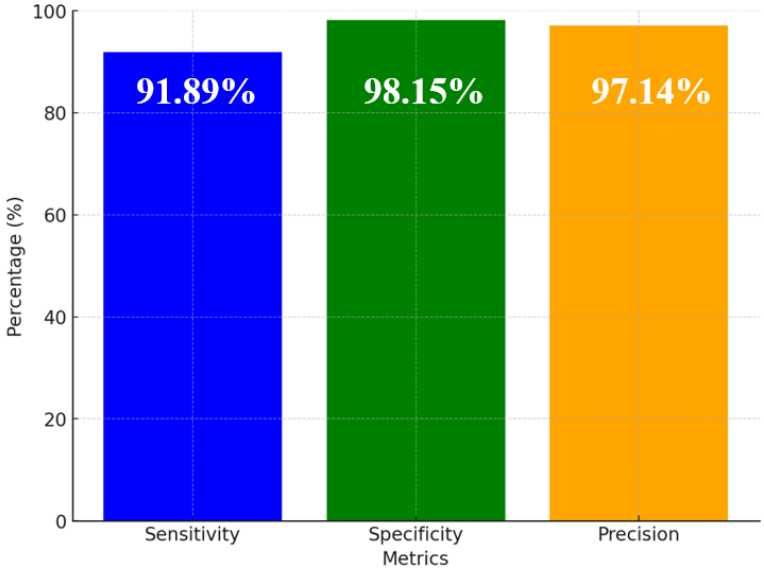
Bar chart 2: Blood ketone levels classification.



Bar chart 3: Blood glucose levels classification.



Bar chart 4: Breath acetone levels classification.



Bar chart 5: Device performance metrics.

4. DISCUSSION

4.1. Original hypothesis

Acetone is a volatile organic compound found in human breath, with concentrations that reflect metabolic states. Since ketosis and DKA result in increased ketone production, breath acetone should rise accordingly.

This study hypothesizes that the MQ135 sensor can be used to develop a reliable, non-invasive DKA detection system that provides real-time metabolic feedback. With proper calibration, this device is expected to deliver accuracy comparable to traditional blood ketone measurements, thus reducing reliance on invasive testing methods[7&10].

4.2. Interpretation of results

The analysis of data from 91 adolescent participants confirms that the non-invasive DKA detection prototype, based on the MQ135 gas sensor, achieved an accuracy of 96% when compared to standard blood ketone meter results. This validates the sensor's capability to estimate acetone concentrations in exhaled breath, which strongly correlate with elevated ketone body levels in individuals with type 1 diabetes mellitus (T1DM)[3].

The sensor showed excellent performance in detecting the "Normal" and "Probable DKA" categories. However, classification mismatches occurred near the critical threshold of 320 – the cutoff value for distinguishing between "Probable DKA" and "Confirmed DKA." This suggests that while the current classification logic is largely effective, further refinement through dynamic thresholding or calibration adjustments could improve sensitivity and reliability, especially near the DKA onset point[10].

4.3. Supporting the hypothesis

The outcomes support the study's original hypothesis:

"By using the MQ135 sensor, it is possible to develop a reliable, non-invasive DKA detection system that provides real-time feedback on a patient's metabolic state."

The device accurately captured differences in breath acetone concentrations, reinforcing the idea that volatile organic compounds (VOCs) like acetone serve as effective non-invasive biomarkers for metabolic imbalances in diabetes[1]. Although the breath-based approach cannot entirely replace clinical blood testing – especially in emergencies – it shows strong potential as a daily screening tool or early-warning system, particularly for young users managing diabetes outside of clinical settings.

4.4. Implications

This project presents a painless, accessible, and teen-friendly alternative to invasive ketone testing methods. Frequent finger-prick blood tests often lead to testing avoidance among adolescents due to discomfort, fear, or hygienic concerns[2]. The breath-based system eliminates these barriers and enables frequent self-monitoring with minimal effort.

The device is particularly suited for:

- Home monitoring by adolescents.
- School-based diabetes screenings.
- Remote or low-resource settings without access to blood testing kits.

Moreover, early detection of DKA using breath analysis may reduce hospital admissions**,** enable timely insulin interventions**,** and ultimately lower the healthcare burden associated with diabetes mismanagement.

With ongoing improvement and clinical validation, this system could become a vital tool in youth-centered diabetes care and preventative medicine**.**

4.5. Differentiation from previous MQ135 sensor applications

Unlike previous studies that have employed the MQ135 sensor primarily for general air quality monitoring or broad breath analysis applications, such as Sha *et al.*[14], this study specifically repurposes the sensor to detect breath acetone concentrations associated with diabetic ketoacidosis (DKA). While prior work generally used the MQ135 to measure total volatile organic compounds (VOCs) without targeting specific clinical thresholds, our approach involved calibrating the sensor output to match clinically relevant acetone ranges and classifying the results into three diagnostic categories: Normal, probable, and DKA. Furthermore, the sensor was embedded into a compact, non-invasive prototype designed for adolescent users, with a strong emphasis on accessibility and early screening. This tailored implementation addresses a critical gap in existing literature, where the MQ135 has not been systematically adapted or validated for DKA detection in this population.

5. RECOMMENDATIONS AND LIMITATIONS

5.1. Project limitations

Despite promising results, this study and its prototype encountered several limitations that should be addressed in future research and development:

- **Sensor Specificity Issues:** The MQ135 sensor used is a general-purpose gas sensor sensitive to multiple gases, not exclusively acetone. This cross-sensitivity can lead to inaccurate readings due to interference from substances such as alcohol, ammonia, or

other volatile organic compounds (VOCs) commonly found in the environment[6&11]. Although calibration with known acetone concentrations and controlled testing environments minimized these effects, real-world applications may still face variability. Advanced signal processing partially mitigated interference, but future work should explore more selective sensors or sensor arrays combined with machine learning algorithms to improve specificity and reduce false positives.

- **System Setup Limitations:** While the device operation requires only a simple breath into a disposable mouthpiece, initial assembly and microcontroller programming necessitate basic electronics knowledge. This technical barrier could limit accessibility for end-users without engineering backgrounds. Developing pre-assembled, plug-and-play devices or companion kits would help overcome this hurdle and promote wider adoption.

Addressing these limitations will be crucial to enhancing the device's robustness, user-friendliness, and practical utility in diverse settings.

5.2. Recommendations for improvement

Building on the successful prototype, several enhancements are recommended to boost device performance and user experience:

- **Expanded Participant Testing:** Future studies should include a larger and more diverse cohort, spanning various age groups, ethnicities, and health conditions – especially individuals with respiratory illnesses or metabolic comorbidities – to validate the sensor's accuracy and generalizability across populations.
- **Acetone-Specific Filtering:** Incorporating a chemical pre-filter that selectively isolates acetone from other VOCs such as ethanol or ammonia could significantly reduce cross-sensitivity and improve measurement precision[1&15].
- **Enhanced User Interface:** Multi-sensory feedback – including auditory cues, visual displays, and tactile signals (e.g., vibration) – would make the device more accessible and intuitive, particularly for adolescents or users with visual or cognitive impairments.

5.3. Recommendations for practical use

Given its non-invasive nature, portability, and simplicity, the device is well-suited for several practical applications:

- **Home-based monitoring:** Ideal for adolescents with Type 1 Diabetes, the device encourages frequent ketone screening without the discomfort of finger-prick blood tests, fostering better disease management.
- **Preliminary assessments in limited-resource settings:** The device can facilitate ketone monitoring in schools, remote clinics, or during travel, especially where laboratory infrastructure is limited or unavailable.
- **Routine monitoring during high-risk periods:** Use during illness, fasting, or intense exercise, when ketone levels are more prone to fluctuation, can help detect early signs of metabolic imbalance.

To maximize safe and effective use, comprehensive educational resources such as illustrated manuals, video tutorials, and clinician-led training sessions should accompany the device.

With further clinical validation and regulatory approvals, this non-invasive breath ketone monitoring system has the potential to become an essential tool for youth-centered diabetes care and early intervention.

6. Conclusion

This project aimed to design and evaluate a non-invasive detection prototype for the early identification of Diabetic Ketoacidosis (DKA) using breath analysis, with a focus on accessibility and ease of use for adolescents with Type 1 Diabetes. By leveraging the MQ135 gas sensor and an Arduino-based platform, the prototype measured acetone concentrations in exhaled breath – an established proxy for blood ketone levels.

Evaluation was conducted with a sample of 91 participants aged 10–18 years. While the

prototype specifically measured acetone concentrations in breath (ppm), blood glucose levels were measured separately in mg/dL. The prototype successfully identified DKA-related cases with high reliability, showing only four mismatches between breath acetone and blood glucose readings. These results validate the core hypothesis of the project: That breath acetone can serve as a reliable, non-invasive biomarker for detecting DKA onset.

Beyond its technical performance, the prototype addresses a crucial real-world challenge by providing a painless, needle-free alternative to traditional ketone testing methods. This is particularly beneficial for adolescents who may avoid regular monitoring due to the discomfort or fear associated with finger-prick tests. By improving comfort and convenience, the prototype encourages better compliance and more consistent self-monitoring among young patients.

Although the prototype demonstrated promising results, several limitations remain, including potential environmental interference in real-world settings and the complexity of the initial setup. However, these challenges can be addressed through future improvements, such as acetone-specific filtering to enhance accuracy, pre-assembled or user-friendly kits to increase accessibility, and the integration of mobile applications for data tracking, real-time alerts, and seamless communication with healthcare providers.

In conclusion, this project confirms the technical feasibility and practical value of non-invasive DKA detection via breath analysis. It lays a strong foundation for future development and holds significant potential to revolutionize how young diabetic patients monitor and manage their condition – making routine care safer, more accessible, and proactive.

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الكشف غير الجراحي عن الحماض الكيتوني السكري لدى المراهقين باستخدام حساس MQ135 : بديل منخفض التكلفة لاختبار الكيتونات في الدم

مرح زيد سليمان العدوان

مؤسسة الملك الحسين ، معهد اليوبيل ، الأردن

الحماض الكيتوني السكري (DKA) هو مضاعفة تهدد الحياة لمرض السكري من النوع الأول ، لا سيما بين المراهقين الذين غالبًا ما يتجنبون المراقبة المتكررة للكيتونات بسبب الطبيعة الجراحية لاختبارات الدم. يقدم هذا البحث نظام كشف غير جراحي يعتمد على الزفير باستخدام حساس الغاز MQ135 لقياس الأسيتون المنبعث في النفس ، وهو مؤشر حيوي مرتبط بالكيتوزية. يقوم النموذج المحسن بدمج المتحكم الدقيق ESP32 وواجهة ويب ، ليحل محل الجهاز الذي كان يحتوي Arduino و LED السابق. يتيح هذا التطوير المعالجة في الوقت الحقيقي ، ونقل البيانات لاسلكيًا ، والمراقبة عن بعد ، مع الحفاظ على انخفاض التكلفة وقابلية النقل. أظهرت الاختبارات مع ٩١ مشاركًا تتراوح أعمارهم بين ١٠ و١٨ سنة دقة تصنيف بلغت ٩٦٪ ، مما يوضح توافقًا قويًا بين تركيز الأسيتون في الزفير ومستويات-β هيدروكسي بيوتيرات في الدم. وقعت بعض الاختلافات الطفيفة بالقرب من عتبة التشخيص للحماض الكيتوني السكري. تؤكد هذه النتائج أن النظام المطور القائم على ESP32 يوفر طريقة غير مؤلمة ، متصلة وموثوقة للفحص المبكر للحماض الكيتوني السكري ، مما يعزز سهولة الوصول والالتزام بين الشباب المصابين بالسكري.