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# Development of an Affordable Internet of Things-Based Bowel Sound Monitoring System for Analysing Gut Health

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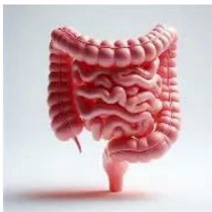
*Abstract*— **Traditional approaches are frequently intrusive or subjective, making the objective evaluation of gastrointestinal (GI) health a major clinical challenge. In this work, a low-cost, non-invasive Internet of Things (IoT)-based system for the real-time monitoring of bowel sound frequencies is developed and validated. The system uses an Arduino-based microcontroller to condition and process the abdominal acoustic signals that are recorded by a high-sensitivity Knowles condenser microphone. Twenty male subjects (ages 18 to 24) with a range of Body Mass Index (BMI) classifications were used to gather data on various meal types (solid, semi-solid, and liquid) and timings. Significant pre-meal frequency peaks that indicate the cephalic phase of digestion and a distinctive post-meal "dip-and-rise" pattern that reflects acoustic muffling followed by the reflex of gastrocolic. Especially in subjects who were overweight, solid meals produced greater frequency spikes than liquid meals. There was a lot of variation between people, which suggested that there were different acoustic signatures; however, these patterns were affected by BMI. The results suggest that a person's acoustic signature could be a valuable biomarker for digestive function and reveal that the system could be a viable tool for long-term monitoring of gut health in a personalized way.**

**Keywords: gastrointestinal monitoring, bowel sound analysis, intestinal motility, IoT health, Diagnostics, Signal Conditioning, Bowel Sound Monitoring**

## I. INTRODUCTION (*GASTROINTESTINAL SYSTEM*)

The gastrointestinal tract is a vital component of human physiology, orchestrating the intricate processes of nutrient absorption, metabolic regulation, and immune surveillance, which collectively determine individual physiological health. Changes in digestive activity can be observed in numerous pathologies, including functional disorders such as irritable bowel syndrome and organic diseases that require preventive diagnosis for optimal outcomes.

*Fig 1:* Gastrointestinal System



General health depends on a healthy gut microbiota, and disruption of this microbiota can have systemic effects. Based on the sounds that the gut gives, one can have an impression of the role the gut plays. These noises are governed by two important reflexes. The cephalic phase is the pre-emptive neurological reaction that is caused by the sight or smell of food, and hastens the gastrointestinal motility.

### *A. Developments in Bowel Sound Auscultation Technology*

Bowel sounds are non-stationary events, low-frequency, and hard to describe, which are generally characterized as low-frequency events the predominant frequencies of which occur between 100 Hz and 1000 Hz [2]. Manual monitoring has not been found reliable, and this is why electronic monitoring systems, which are objective, have been adopted [5]. The development of this technological progress began as electronic stethoscopes but has been availed through the development of special wearable acoustic sensors [8]. Scholars have come up with small, cheap, and highly sensitive sensors such as MEMS microphones, accelerators, piezoelectric transducers (3) that are able to record continuous abdominal very small vibrations. The introduction of these sensors equipped with Internet of Things (IoT) that will make them potent tools of constant and remote health control is one of the most significant aspects of such development [4, 6, 7]. This allows recording the long-term digestive trends and also the clinical snapshots and this paves the way to advanced methodologies of diagnostics like predictive modelling [5]. Moreover, without the application of such techniques as the

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Wavelet Transform, noise reduction, signal conditioning, and accurate classification of such complex sounds are not possible [1, 10, 12].

### *B. Research Gaps and Moderating Factors*

The gut's acoustic signature is influenced by dietary and systemic variables. Body mass index (BMI) is a crucial determinant since being overweight (having a high BMI) is linked to changes in GI motility, like delayed stomach emptying and more cases of GERD [7, 11]. Hormonal abnormalities and a complex dysregulation of the gut-brain axis are the primary culprits.

The content of a meal affects the subsequent auditory patterns because solid, semi-solid, and liquid foods need differing amounts of work to digest [2]. Nonetheless, there is limited study on the unique acoustic signatures generated by different meal kinds, especially among young adults (18–24 years old), a demographic increasingly impacted by gastrointestinal issues associated with lifestyle [7].

### *C. Justification and Objectives of the Current Study*

While automated gut acoustic monitoring shows promise, there is a need for studies that use affordable and accessible IoT infrastructure for at-home use. Key knowledge gaps exist regarding the specific acoustic signatures of different meal types and their relationship to BMI in young adults. Therefore, this project seeks to close these gaps with the following goals:

To design and validate a low-cost, IoT-based bowel sound monitoring system using commercially available components like Arduino microcontrollers [13, 14].To examine the acoustic frequency patterns of bowel sounds in connection to meal type (liquid, semi-solid, or solid) and timing (pre- and post-prandial).To investigate the connection between the subjects' BMI and these detected acoustic patterns in a cohort of young adults, using real-time data visualization techniques [16, 18].

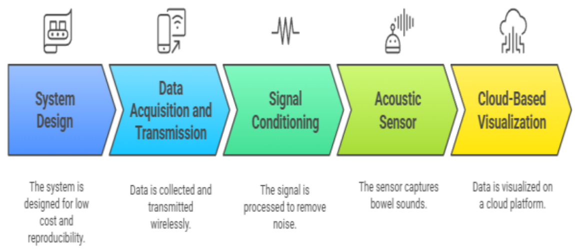
## II. Materials and Methods

### *A. System architecture*

To provide low cost and reproducibility, a real-time, non-invasive bowel sound monitoring system was designed and assembled using off-the-shelf electronics. The system has four primary modules; a data acquisition and transmission unit, signal conditioning circuit, acoustic sensor, and cloud-based visualization platform.[14]

*Fig 2. Bowel Sound Monitoring system*

*Fig 3. Bowel Sound Monitoring system architecture*




- The Knowles Condenser Microphone is a high-sensitivity microphone designed to record the low-frequency vibrations of the abdomen's bowel sounds. Capturing low-frequency biomedical sounds, particularly the 100 Hz to 1000 Hz range typical of bowel sounds.[5] For data collection, the sensor was placed externally on the subject's abdomen.

- A signal conditioning circuit was put in place to address this. To boost the signal's amplitude, this circuit makes use of an operational amplifier (such as the LM386). Gain control was achieved with resistors (1 kΩ–10 kΩ), and filters were provided by capacitors (10 µF–100 µF) owner background noise. The circuit also contained IN4007 diodes for protection against incorrect polarity and an LM7805 5V voltage regulator to power all of the components from the same stable supply. Including also a step-down transformer to keep the amplified signal voltage within the microcontroller's analog to digital converter's (ADC) acceptable input range of 0–5V.

- Platform for IoT Visualization The frequency data that had been processed was sent to a specially designed web platform that was housed on a cloud server and used Java.[10] This platform included a graphical user interface that allowed users to view the frequency of bowel sounds plotted against time in real time.[18] The website is available to the general at https://iotcloud22.in/3913_bowel/index.php.

*Fig 4. IoT Visualization*

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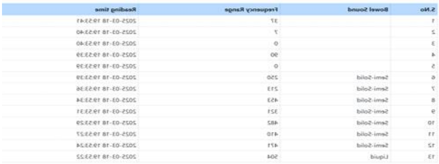

A summary of the key hardware components is provided in Table 1.

*TABLE 1. Hardware Component Specifications*

| Component | Specification/Details |
|---|---|
| Microphone Sensor | Knowles Condenser, 100–1000 Hz range |
| Operational Amplifier | LM386 |
| Resistors | 1 kΩ–10 kΩ |
| Capacitors | 10 µF–100 µF |
| Diodes | IN4007 |
| Voltage Regulator | LM7805 – 5V |
| Step-down Transformer | Used to scale down signal voltage |
| Arduino Microcontroller | Inbuilt Wi-Fi, 10-bit ADC |

Participants: The study involved twenty male individuals aged between 18 and 24 years. The study divided participants into three BMI categories which included Underweight, Normal, and Overweight to analyse their digestive patterns [13].

*TABLE 2. BMI Categorization of subjects*

| Subject ID | Age (Years) | BMI Category |
|---|---|---|
| Subject 1 | 20 | Underweight |
| Subject 2 | 22 | Underweight |
| Subject 3 | 20 | Underweight |
| Subject 4 | 24 | Underweight |
| Subject 5 | 22 | Underweight |
| Subject 6 | 22 | Normal |
| Subject 7 | 24 | Normal |
| Subject 8 | 24 | Normal |
| Subject 9 | 20 | Underweight |
| Subject 10 | 19 | Normal |
| Subject 11 | 21 | Overweight |
| Subject 12 | 22 | Underweight |
| Subject 13 | 18 | Underweight |
| Subject 14 | 21 | Underweight |
| Subject 15 | 20 | Overweight |
| Subject 16 | 18 | Normal |
| Subject 17 | 23 | Normal |
| Subject 18 | 22 | Underweight |
| Subject 19 | 18 | Normal |
| Subject 20 | 20 | Normal |

### *B. Meal protocol*

All subjects received standardized meals which ensured measurement consistency throughout the research. The meals were classified into three categories which were: liquid (e.g. oat smoothie, white sauce pasta), semi-solid (e.g. apple juice, pineapple juice), and solid (e.g. paneer fried rice, chicken biriyani, idly chutney).

*TABLE. 3. Meal type administered*

| Meal Type | Food Items |
|---|---|
| Solid | Idly chutney, Bread jam, Chicken biriyani, Paneer fried rice |
| Semi-Solid | Oats smoothie, White sauce pasta |
| Liquid | Apple juice, Pineapple juice, Watermelon juice |

### *C. Data collection method*

Bowel sounds were collected in a systematic fashion at nine-time intervals relative to three primary daily meals (breakfast, lunch, and dinner).[16] The nine intervals were: immediately after the meal (post-meal digestive activity), 15 minutes before the meal (pre-meal baseline), right after the meal (post-meal digestive activity) and two hours after the meal (post-absorption phase).[15] The protocol was

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specifically created to monitor the complete digestive sound pattern between the cephalic and gastric and intestinal stages. The subject received microphone placement on their abdominal area for recording purposes.

*Table 4. Data collection protocol*

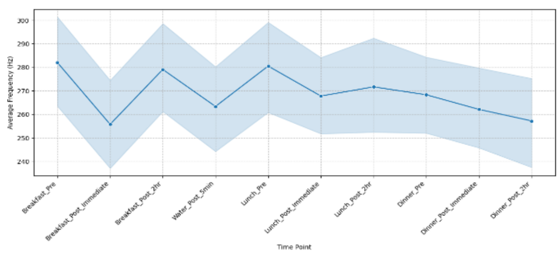
| Time Interval | Description |
|---|---|
| 15 min before breakfast | Pre-meal baseline reading |
| Immediately after breakfast | Post-meal digestive activity |
| 2 hours after breakfast | Post-absorption phase |
| 15 min before lunch | Pre-lunch baseline reading |
| 15 min after lunch | Post-lunch digestive activity |
| 2 hours after lunch | Post-absorption phase |
| 15 min before dinner | Pre-dinner baseline reading |
| 15 min after dinner | Post-dinner digestive activity |
| 2 hours after dinner | Final post-absorption phase |

## III. RESULTS AND DISCUSSION:

Several subjects showed higher pre-meal rates that may imply anticipatory motility or borborygmi but in response to the post-meal intervals showed in opposite directions that might imply intricate physiologic mechanism other than the activation of simple gastrocolic reflexes. Subject 7 recorded the highest peak and one of the lowest trough values with one of the highest values whereas Subject 15 maintained his frequencies all through the day. The acoustic behaviour of the gut to water intake (5 min post) also exhibited a great individual variation which also indicates the variety of patterns of the gut acoustic behaviour.

### A. Diurnal Bowel Sound Pattern Analysis

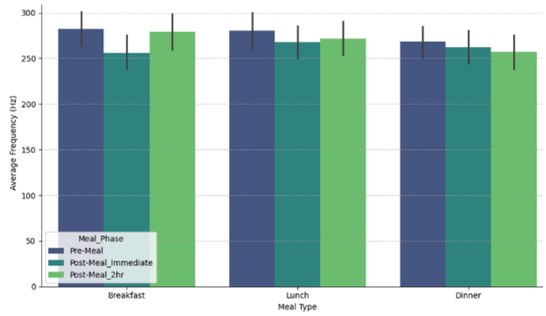
*Fig 5. Average diurnal bowel frequency pattern*




The independent variable of water intake showed a predictable rise of the motility to about 270 Hz which proved that it is an easy stimulus of motility. The gut activity was seen to decrease progressively between Dinner Pré (approximately 265Hz) and PostDinner2hr (approximately 180Hz) which validates the daily rhythm of reduced autonomic control and release of melatonin. The variations in the frequency between the meal periods were noted to be 3035 percent and night and day innovations were noted to be 40 percent which is a quantitative measure of the healthy gastrointestinal period dynamics.

### B. Meal-Based Response Analysis

*Fig 6. Average bowel sound frequency by meal type and phase*

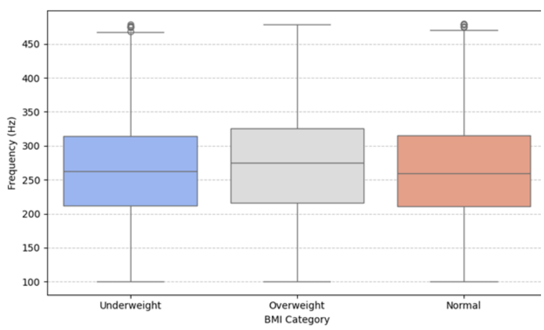



The frequency data of the bowel sounds analysis at the breakfast, lunch, and dinner revealed a regular, physiologically important gastrointestinal (GI) motility pattern. The pre meal frequencies were the highest in history and the highest frequencies pre breakfast (~278 Hz) and pre-lunch (~281 Hz). The bowel sound is significantly active, which is the evidence of the readiness of the digestive apparatus to process the food due to the stimulation of the processes of processing the food by the cephalic-phase and circadian preparedness.

The frequency in the immediate after meals is considerably lower than that of the immediate before meals with a difference average of 20-30. The decrease was probably due to the gastric accommodation since the stomach is expanded to accommodate the swallowed food, and at the later age has low bowel motility. These frequencies show transient recovery at 2 hrs after the mealtime which show that the small intestine and the colon have already recovered their mobility and utilised food via the digestive system with the assistance of regular gastrointestinal emptying and nutrient-receptive motility reflexes. Nevertheless, the 2-hour readings are not habitually hit to the close to maximum before eating that proposes that the motility process is observed to shift to the normal functioning; in phases.

### C. Group-wise Comparison (BMI-wise)

*Fig 7. Overall bowel sound frequency distribution by BMI category*



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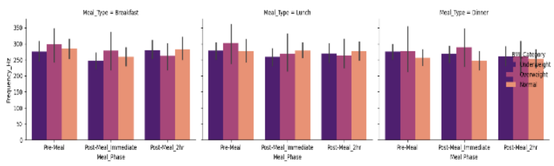
The evaluation of bowel sound frequencies across BMI groups —Underweight, Normal, and Overweight—showed similar median values near 265–278 Hz which indicates that overall gastrointestinal (GI) motility stays constant across body compositions. The analysis showed that the Overweight group had the highest median frequency (~278 Hz) combined with lower variability (IQR ~80 Hz) which suggests better regularity in bowel movements yet the Underweight group demonstrated the highest variability (IQR ~110 Hz) which could result from nutritional variations or gut motility changes. Observations from all groups included outliers that reached 450 Hz without any correlation to BMI. The collected data shows that body type does not influence average gut sound frequency but BMI affects the regularity of GI activity thus demonstrating acoustic bowel monitoring as a non-invasive digestive health and nutritional assessment method.

*D. Individual Variability*

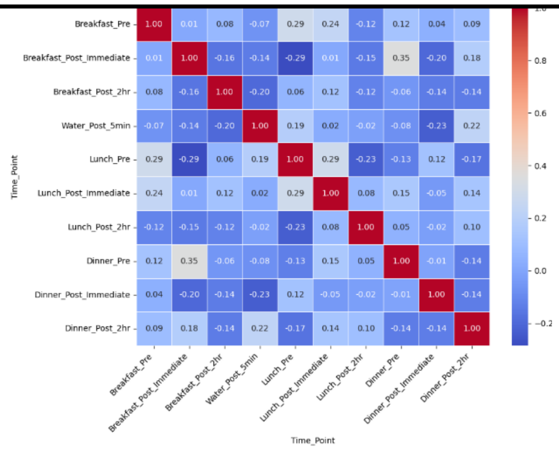
*Fig 8. Bowel sound frequency by meal type, phase and BMI category*




Analysis of bowel sound frequencies across BMI levels shows gastrointestinal motility patterns stay steady throughout Pre-Meal and Post-Meal phases with median frequencies between 260 and 280 Hz. The difference between lunch and dinner frequencies among Overweight and Normal BMI individuals was modest which demonstrates a slight effect of body composition on gut sounds. All participants showed typical digestive cycle performance because their post-meal recovery frequencies returned to baseline within two hours. The study found no significant variations between meal types which established that bowel sound frequency does not change depending on food consumption timing. The investigation shows that each individual maintains distinct gut motility patterns although BMI variations slightly affect bowel sounds thus validating wearable acoustic sensors for individualized digestive health monitoring.

*E. Correlation Analysis*

*Fig 9. correlation matrix of bowel sound frequency across time points*




Research into bowel sounds across various time frames and meal types and BMI groups reveals that frequencies increase after eating particularly following lunch and dinner which activates the gastrocolic reflex. Bowel sound frequencies decrease two hours following meals as part of normal digestive process. The data analysis reveals that BMI groups demonstrate little change in their sound signals because each participant maintained consistent gut sound patterns throughout all sessions which proves bowel sounds originate from individual physiology instead of body composition. The higher gut motility after lunch compared to breakfast probably exists because of food characteristics and timing patterns. The frequencies of the time-point determine weak connections that contribute to the formation of simple physiological patterns that allow the forecast. The studies prove the usefulness of wearable acoustic sensors in the context of the individualized monitoring of the digestive health providing the basic data on the early detection of the stomach disorders.

## IV. Related Work:

This study sought to develop and validate a cost-effective, non-invasive Internet of Things (IoT)-based system to better objectively assess gastrointestinal (GI) health, which remains a clinical challenge for the discerning healthcare provider. Using a high-sensitivity (Knowles) condenser microphone with an Arduino-based microcontroller, GI acoustic signals are analysed in real-time by the system to isolate specific sounds of interest. We collected data from 20 male subjects aged 19-24 years, and varying Body Mass Indexes (BMI), recording for 60 minutes in 3-meal conditions (solid, semi-solid, and liquid). The study found several significant diurnal patterns, including distinct high-frequency peaks preceding the meal recorded (cephalic phase of digestion), and a clear "dip-and-rise" pattern following each meal, demonstrating the gastrocolic reflex. The major findings: [1] solid meals resulted in higher frequency peaks than liquid meals, especially in the overweight subjects; [2] median frequencies were relatively equal between groups (underweight, normal weight, overweight), but the overweight had the least variability, suggesting the remaining three groups had more infrequent bowel movements; and [3]although all 20 subjects participated in the study, analysis of inter-individual variability was substantial, indicating that every subject had a unique acoustic signature, modulated by BMI, which may be a useful biomarker of digestive function.

## V. CONCLUSION:

The findings demonstrate that gastrointestinal (GI) acoustics follow strong circadian rhythms and respond to meals and show considerable differences between people while being minimally affected by BMI levels The analysis shows water consumption triggers an insignificant frequency decrease while confirming its operational impact on gastrointestinal movements. The stability of mean frequency values across different BMI ranges reveals that gut motility consistency proves more important than average frequency measurements because underweight groups show greater internal variation.

Individual bowel sound trajectories demonstrated distinct recurring patterns. The detection of frequency peaks before meals and their evening suppression indicates the combined effects of the cephalic phase of digestion together with circadian rhythm regulation

## VI. FUTURE WORK

The next phase of work is mainly based on a wearable system for monitoring gut health integrated with a multimodal sensor, the conduction of a study on a large population for better analysis, and interaction of AI for disease prediction.

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