Development of a wireless electrogastrography measurement system*

Alonso Ochoa [1], Juan Carlos Herrera-Lozada[1], David Cruz-Ortiz[2], *Member, IEEE*

***Abstract*— This paper presents the development of an electrogastrography system used to measure the myoelectrical activity of the stomach through surface electrodes. The proposed system considers an electronic circuit that comprises five main stages. In the first stage, a pre-amplification array coupled to a driven right leg circuit provides a gain equal to 1000 to collect the Electrogastrogram (EGG). A filtering and amplification stages are considered, where a band-pass filter with a cutoff range from 0.015 Hz 3. 12 Hz was implemented. As part of she amplification stage, provide a gain equal to 10 to obtain a total amplification gain of 10000 finally. In the subsequent stage, an analog-digital converter was implemented to digitalize the signal, considering a 16-bit resolution. The last stage comprises an ESP32 microcontroller, which sends the collected signal through WiFi to a graphical user interface in a Personal Computer (PC), where the signals are displayed and stored. The proposed system was tested with 10 healthy subjects (eight males and three females, ages 18 to 23 years). Then, the collected data were analyzed to validate the EGG frequency signature.**

***Index Terms*— Wireless system, Electrogastrography, Electrogastrogram**

I. INTRODUCTION

Nowadays, gastrointestinal diseases characterized by affecting the stomach and intestinal tract [1], contribute to approximately 1.4 million deaths annually, with low and middle-income countries being the most affected [2]. Particularly, in Mexico, these diseases are among the most common health problems, accounting for approximately 20% of outpatient consultations in public health institutions [3]. Previous facts have favored the development of digestive diagnostic techniques, which can be classified as invasive or non-invasive. The invasive procedures include endoscopic studies, esophageal manometry, and pH monitoring. On the other hand, non-invasive techniques include laboratory analysis.

Electrogastrography is a non-invasive and cost-effective technique used to assess gastric myoelectrical activity via cutaneous surface electrodes. Due to its simplicity and minimal interference with physiological function, EGG has emerged as a valuable diagnostic tool for identifying motility-related disorders such as gastroparesis and functional dyspepsia. Recent studies have demonstrated its ability to detect abnormalities in gastric slow waves, thereby enabling clinicians to distinguish between various gastrointestinal conditions and tailor more targeted treatment approaches [4].

As a result of an electrogastrography study, electrical signals, also known as Electrogastrogram (EGG), are generated by the combination of the electrical Gastric Rhythm (GR), originated in the stomach wall, and the muscle activity that produces gastric peristaltic contractions. Then, from the EGG, information about the gastric myoelectric frequency and amplitude can be obtained. Power of the EGG in the normal or abnormal frequency ranges can be computed.

In humans, the GR defines the frequency of muscle contractions and controls their propagation, and its normal frequency in healthy subjects is 0.05 Hz or three Cycles Per Minute (CPM), corresponding to one cycle every 20 s. The normal frequency range of the GR in humans, known as normogastric, varies depending on the authors since some consider 2-4 CPM [5], but others suggest 2.5 to 3.6 CPM [6]. Nevertheless, most of them converge in ranges closer to the definition adopted in this work. On the other hand, if some abnormalities in the frequency of the GR are present in the EGG, conditions such as bradygastria (less than 2 CPM) and tachygastria (greater than 4 CPM) can be defined [7].

As an example of a typical raw EGG signal collected from cutaneous abdominal electrodes, Figure 1 shows the Gastric and Respiratory Cycles (RC) as well as the Heartbeat (HB).

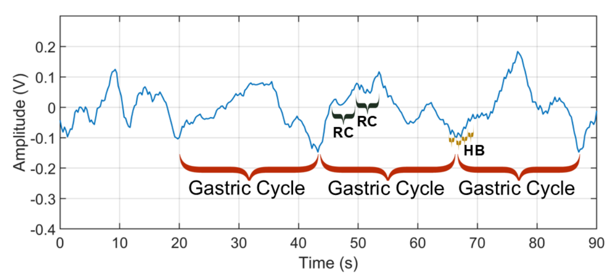

Fig. 1. Example of a raw EGG signal.

In some cases, GR may be visible to the naked eye in a high-quality raw EGG signal. However, faster rhythms associated with respiration can also be observed in the 0.2 to 0.4 Hz range, and the Heartbeat (HB) typically appears between 1 and 1.7 Hz [8]. Consequently, the EGG is usually analyzed in the frequency domain, where a sharp peak around 0.05 Hz highlights that the EGG spectral signature is notably distinct from those of respiration and heart rate, as the GR peak is significantly higher.

Despite the EGG signal analysis advantages for diagnosing gastric diseases, clinical applications of the EGG are still

*This work was partly supported by the Instituto Politécnico Nacional under the Grant: SIP-20250223. Alonso Ochoa is sponsored by a Mexican scholarship from the SECIHTI, CVU: 1347201.

[1] CIDETEC-Instituto Politécnico Nacional, Av.Juan de Dios Bátiz S/N, Nueva Industrial Vallejo, 07700, Mexico City, Mexico. `email: cochoal1500@alumno.ipn.mx.`

[2] Medical Robotics and Biosignals Lab, UPIBI-Instituto Politécnico Nacional, Av. Acueducto S/N, La Laguna Ticoman, Gustavo A. Madero, 07340, Mexico City, Mexico. `email: dcruzo@ipn.mx.`

limited. The reason is mainly that the amplitude of the signal is weak, around 40-500 μV [9], but also that its frequency band is very low (around 0.008 to 0.15 Hz or 0.5 - 9.0 cpm). Another limitation regarding the EGG usability is the time needed to collect the signals, since according to the conventional method of the EGG analysis , the EGG study generally takes about 2 hours to collect the signals [10].

In that sense, some commercially platforms support the EGG signal acquisition. However, the majority are multi-purpose systems not specifically optimized for the characteristics of gastric electrical activity. A representative case is the biosignalsplux® sensor [11], which offers a voltage gain of 6114, an input range of ±0.25 mV at a 3V supply, and an ultra-low bandwidth of 0.01591–0.15910 Hz, making it suitable for detecting slow-wave gastric signals. It also provides a high input impedance exceeding 100 $G\Omega$, minimizing signal attenuation, and a common-mode rejection ratio (CMRR) of 100 dB, ensuring effective noise suppression. The base price of the sensor is 150 USD, but its operation requires an additional Data Acquisition System costing at least 559 USD, which make it unafordable for most of the patients.

Another commercial system is the MP200 with AMI100D Biopotential Amplifier developed by BIOPAC Systems, Inc. This advanced amplifier is designed specifically for research applications and provides a complete solution for recording biopotential signals, including electrogastrography. The system utilizes wired electrodes attached to the subject, transmitting the signals to the MP200 unit, which interfaces via Ethernet with a computer running AcqKnowledge software for signal visualization and analysis. This modular configuration allows for high-fidelity recordings and extensive signal processing capabilities, making it suitable for clinical-grade and laboratory research. Although the MP200 offers superior performance and flexibility, its high cost and non-portable setup represent limitations for EGG monitoring [12].

The above conditions make it difficult to acquire commercial systems capable of acquiring the EGG signals. Consequently, an absence of reliable EGG databases notably limits the research in the electrogastrography field [13]. Therefore, developing new technologies that allow the acquisition of EGG signals is an open research field.

This work presents the development of a non-invasive, wireless EGG monitoring system, which comprises an acquisition circuit, composed of an instrumentation amplifier as a pre-amplification stage. Then, analogical filters were designed to collect the signal with a low noise level. After that, a signal conditioning stage comprised of a dedicated Analog-Digital Converter (ADC) aside from an ESP32 microcontroller was used to adjust the signals and send them to a Graphical User Interface (GUI) in a personal computer. The main contributions of this study are the design and implementation of a low-cost, portable EGG device, and the validation of its performance through experimental testing with healthy subjects. This development offers an alternative tool for non-invasive gastric monitoring and provides a foundation for future research in electrogastrography signal acquisition and analysis.

II. EGG System design

The proposed EGG system comprises an electronic circuit with a gain amplification of ten thousand $G = 10000$ and an acquisition bandwith from 15.92 mHz to 3.121 Hz. Here, a delta-sigma ADC compatible with the Inter Integrated Circuits (I2C) interface was used to collect the signal. In addition, a WiFi transmission, considering the User Datagram Protocol (UDP) was also implemented to send the data to a personal computer. Each of the mentioned characteristics is explained in detail in the subsequent sections.

A. Electronic design

The proposed electronic design considers six stages as part of its electronic instrumentation, which are 1) Preamplification, 2) Filtering, 3) Amplification, 5) Signal conditioning, 6) Acquisition, and wireless transmission. Figure 2 shows a general diagram representing each of the mentioned stages, where A_1 and A_2 denote the negative and positive electrodes, R describes the reference electrode and Vout is the EGG with positive and negative values.

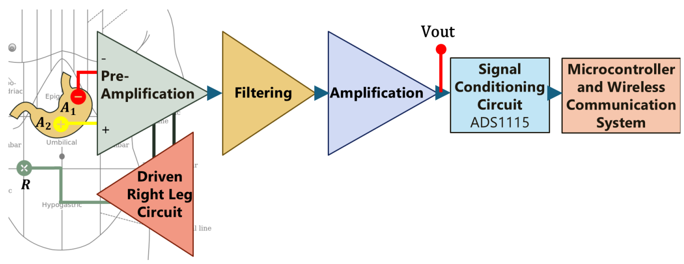

Fig. 2. Electronic instrumentation of the EGG system.

1) Preamplification stage: The preamplification circuit considers as a main element an INA122 as instrumentation amplifier coupled with an operational amplifier OPA2241 in a Driven Right Leg (DRL) circuit configuration to reduce common-mode interference. The INA122 was selected due to its high input impedance, low noise, and single-supply operation. Its differential architecture effectively rejects common-mode noise, an special feature for capturing weak bioelectrical signals in noisy environments. Additionally, the adjustable gain via a single external resistor provides flexibility to optimize signal amplification without complex circuit modifications.

Here, the gain of the instrumentation amplifier was selected as $G_1 = 1000$, as can be seen in Figure 3, where the electrical circuit considered in this stage aside from the selected values for the electrical elements are shown. In the circuit, the power supplies for the amplifiers were selected as $V+ = 5$ Volts Direct Current (VDC) and $V- = 5$ VDC.

2) Filtering stage: This stage consists of a band-pass filter composed of two filters: a high-pass filter with a cutoff frequency of 0.0159 Hz and a low-pass filter with a cutoff frequency of 3.121 Hz. Both are active second-order Butterworth configurations, considering as operational amplifiers the OPA2241. Figure 4, shows the considered

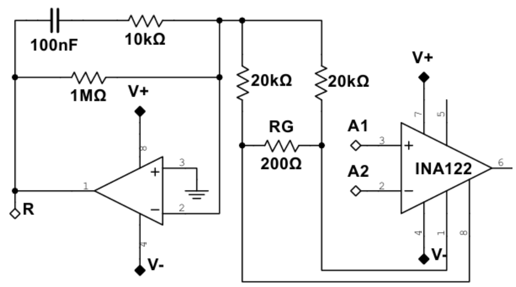

Fig. 3. Electrical diagram of the preamplification and DRL circuit.

electronic circuits and the selected valuces for this stage.

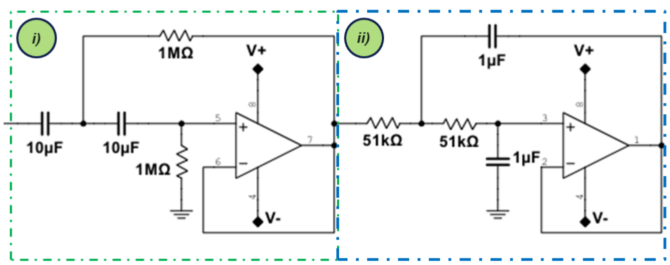

Fig. 4. Band-pass filter comprised by high-pass (i) and low-pass filters (ii).

3) Post-amplification: The post-amplification stage considers an OPA2241 in a non-inverting configuration [14]. The selected gain was set as $G_2 = 10$. Then, the complete gain in the proposed EGG circuit was defined as $G = G_1 \times G_2$, equivalent to $G = 10,000$, which according to the reported voltage range for the EGG, provides signals in the interval of ± 5 V.

4) Signal conditioning: As previously shown in Figure 1, the raw EGG signal has negative and positive components. Then, a particular ADC must be used to collect the complete signal. In this case, the proposed design considers an ADS1115, a 16-bit, delta-sigma ADC compatible with the I2C interface. The ADS1115, compared to the ESP32's ADC, has a higher resolution and allows measuring both positive and negative voltages in differential mode. Figure 5, depicts in a general form the connections between the signal conditioning circuit and the microcontroller.

5) Microcontroller and wireless communication system: The data transmission was carried out using an ESP32 wirelessly via WiFi/UDP to a computer, where the data can be visualized and saved for further processing.

B. Printed circuit board

Once the design had been completed, a printed circuit board (PCB) containing the preamplification, filtering, and amplification circuits, aside from the signal conditioning stage, was designed using Altium®. Figure 6 depicts the PCB render, where (a) denotes the electrode connection, and

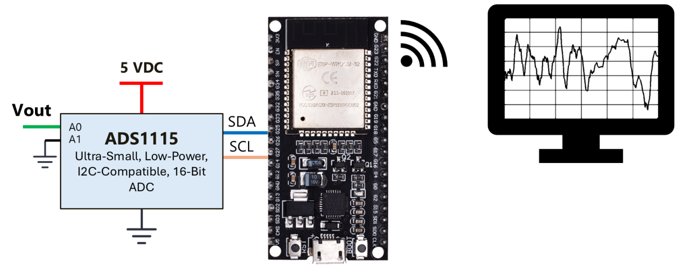

Fig. 5. Scheme of the signal conditioning circuit.

(b) is the DRL circuit, whereas the rest of the stages are preamplification (c), filtering (d), and amplification (e). The signal conditioning circuit is denoted as (f), whereas the connections for the power supplies are in section (g) of the PCB. The PCB has a dimension of 6.2 cm $\times$ 2.8 cm.

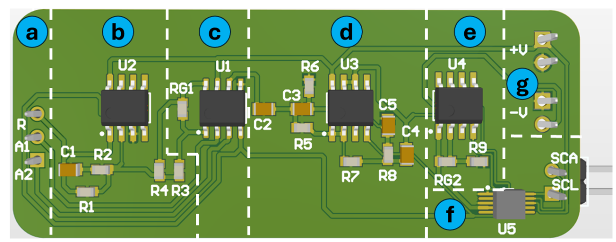

Fig. 6. EGG system PCB.

C. Graphical User Interface

The electrogastogram GUI collects, displays, and stores the EGG signals. It was developed in App Designer, from MATLAB®, using App Designer as can be seen in Figure 7.

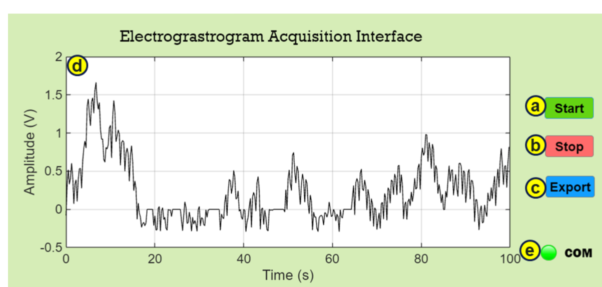

Fig. 7. EGG GUI. a: Starts the acquisition. b: Stops the acquisition. c: Exports the data to an .xlsx archive. d: Signal plotting area. e: Success communication indicator; red: no communication, green: communication

III. Experimental Results

In order to validate the proposed device, a test with healthy volunteers was performed. The description of the participants, and the obtained results are discussed below.

A. Data collection

The device developed to collect the EGG signal was tested with 10 healthy human volunteers (without diagnosed gastric pathologies), performing 10-minutes recordings. Then, the obtained dataset was collected from eight males and three females, ages 18 to 23 years, with a mean age of 21.5 years). Each volunteer previously signed the informed consent as part of this research project. The study protocol SIP-20250223 underwent review and approval by the Secretaria de Investigación y Posgrado del IPN, which is in charge of approving the research protocols according to the ethical standards defined in the declaration of Helsinki.

As part of the methodology to collect the signals, the study start with a set of questions to gather information that might be of interest to the research, including the participant's age and gender.

After that, the volunteer is asked to lie down on a stretcher. Then, the skin of the abdomen was disinfected using alcohol and cotton to place the three wet electrodes. During the signal recording process, the standard electrode configuration was applied as seen in Figure 8, where the green electrode denotes the reference, yellow is A_2, whereas red A_1. Once the wet electrodes were placed, a 10-minute EGG signal was recorded, with an additional 20 s for further analysis.

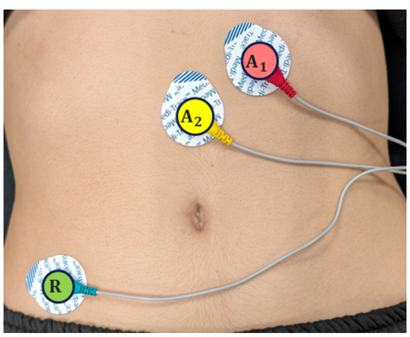

Fig. 8. Example of the collocation of the wet electrodes.

As a result of data collection, Figure 9, shows the average value of the raw EGG signals collected from all participants. From this figure, it can be corroborated that all the collected signals considered have a similar voltage range; also, the standard deviation (STD) is shown in the figure.

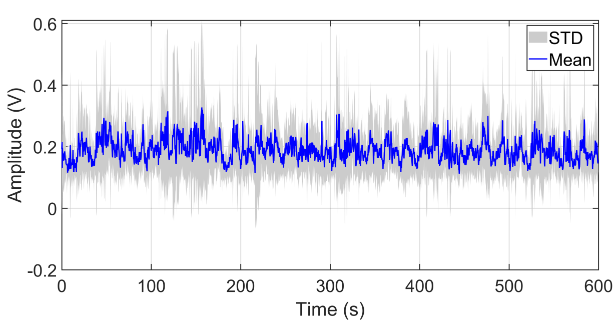

Fig. 9. Mean and STD of the collected raw EGG signals.

TABLE I

MAIN COMPONENTS IN FFT OF THE AVERAGE RAW EGG SIGNALS

Windows	W_1	W_2	W_3
Magnitude	1274.773	138.392	21.950
Frequency [Hz]	0.055	0.232	1.138

B. Signal Processing

Starting with analyzing the EGG signals, the fast Fourier transform (FFT) was computed for the average value of the raw EGG signals. As a result, three main frequency components were identified, which according to the literature [15], one matches the EGG signal's spectral signature, and, the other two match with the frequency ranges where the rhythms of respiration aside from the HB are usually found. Table I, shows the three main frequency components.

As illustrated in Figure 10, the signal processing methodology applied to the raw EGG recordings consisted of three main steps.

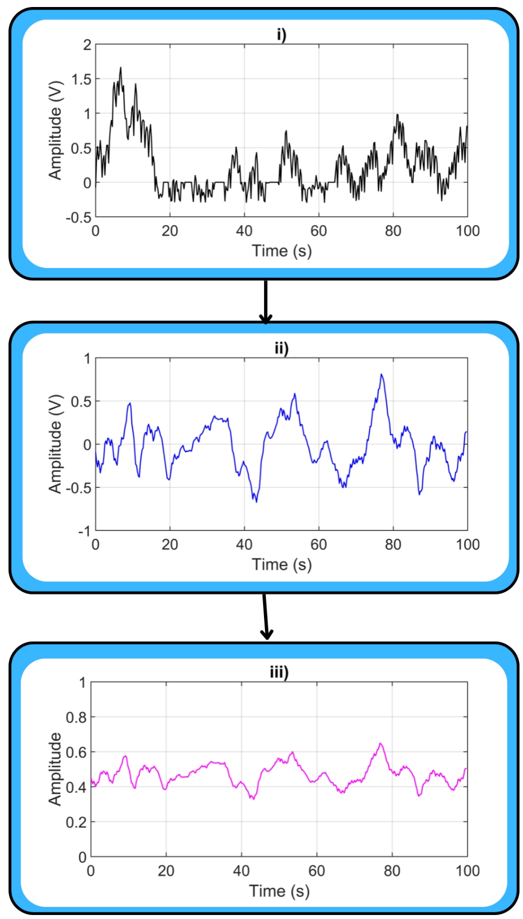

Fig. 10. Signal Processing Methodology.

First, the raw signal in Figure 10 (i) was subjected to a digital band-pass filtering stage, combining a low-pass and a high-pass filter to isolate the frequency components of interest while removing baseline drift and high-frequency noise. Then, the filtered signal, Figure 10 (ii), was normalized using a min-max normalization strategy, in which the global minimum and maximum values across all collected signals were considered. This process scaled each signal in amplitude into a uniform range between 0 and 1 [16], Figure 10 (iii). This normalization was performed to standardize the amplitude across different recordings and to facilitate a comparative analysis. As a result, the analyzed signals and their corresponding spectral components became dimensionless, which is reflected in the reported magnitudes shown in Table I and Table II.

C. Data Analysis

After that, each signal was analyzed individually. Then, the methodology proposed in Figure 11 has been implemented, where from each normalized EGG raw signal, its Power Spectrum (PS) was computed. Then, three frequency windows were defined in the PS to analyze the dataset. The first window (W_1) considers 0.03-0.06 Hz (red), the second one (W_2), 0.2-0.4 Hz (green), and the last one (W_3) 1-1.7 Hz (cyan).

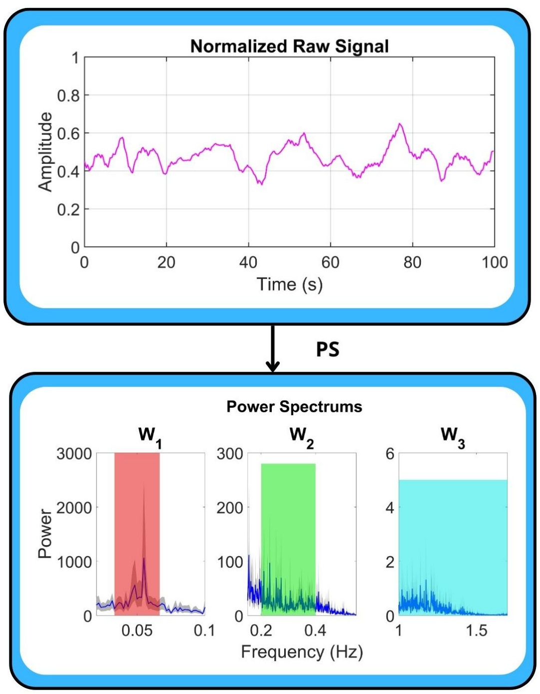

Fig. 11. Signal processing methodology.

After that, the average of the power spectrum is obtained. From Figure 12, it can be seen that the characteristic sharp peak of the EGG is present since the maximum power (yellow dot) of the average EGG raw signals evidenced the characteristic GR in 0.055 Hz.

On the other hand, Figure 13 and Figure 14 correspond to the characteristic frequencies of the faster respiratory rhythms aside from the HB, respectively. Notice that in Figure 13, the maximum magnitude (yellow dot) is obtained in 0.232 Hz, whereas in Figure 14 is equivalent to 1.309 Hz (yellow dot).

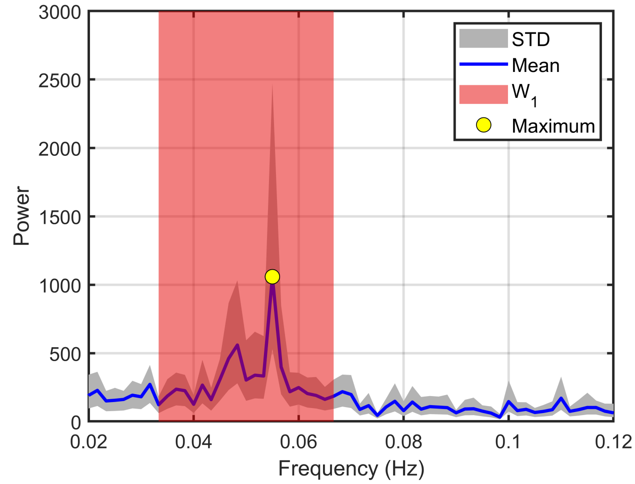

Fig. 12. Power spectrum of the collected EGG signals in the window W_1.

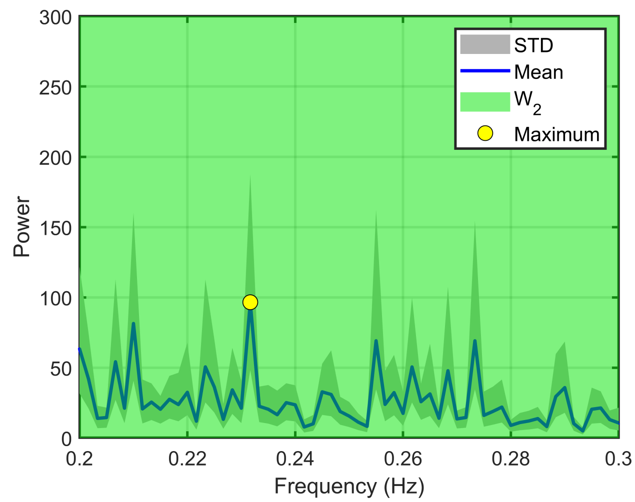

Fig. 13. Spectrum of the collected EGG signals in W_2.

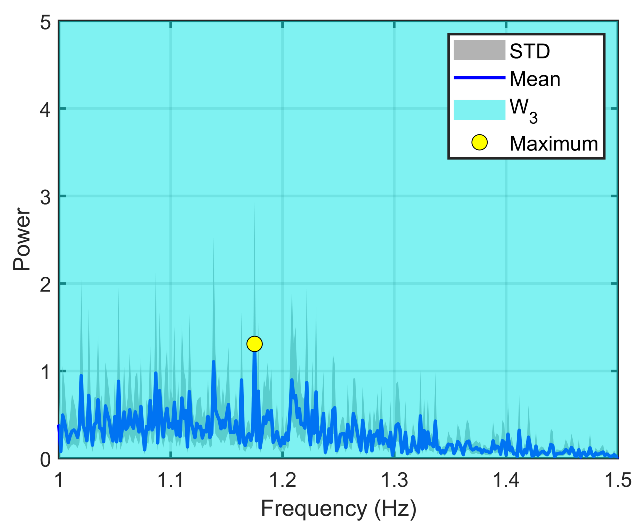

Fig. 14. Spectrum of the collected EGG signals in W_3.

Table II shows the principal frequency components in each of the three defined windows for each of the collected signals to sum up the obtained results. The mean and the STD in the table were calculated with every maximum of each signal.

TABLE II
MAXIMUMS. F: FREQUENCY [HZ], M: MAGNITUDE.

	W_1		W_2		W_3	
	F	M	F	M	F	M
S1	0.047	4.990	0.295	2.838	0.966	2.838
S2	0.053	20.433	0.340	21.232	1.014	21.232
S3	0.052	42.166	0.200	21.276	0.874	21.276
S4	0.055	102.988	0.399	10.420	1.209	10.420
S5	0.055	30.058	0.205	7.248	1.470	7.248
S6	0.050	49.358	0.232	16.442	0.866	16.442
S7	0.047	56.279	0.255	30.376	0.847	30.376
S8	0.048	58.270	0.264	9.876	1.443	9.876
S9	0.060	25.537	0.209	7.054	1.189	7.054
S10	0.058	35.223	0.204	8.767	0.991	8.767
Mean	0.053	42.530	0.260	13.553	1.087	13.553
STD	0.004	25.561	0.063	8.081	0.219	8.081

IV. CONCLUSION

According to the results, the developed methodology enables accurate acquisition of gastric myoelectrical activity and introduces a practical, low-cost, and portable solution that can facilitate future research in electrogastrography. The system was tested in ten healthy subjects; the collected signals were analyzed to evidence that the main frequency components, which correspond with the frequency signature of the EGG recordings, are present in the collected dataset, validating the usability of the proposed device and demonstrating the system's capability for gastric myoelectrical activity monitoring. Furthermore, the proposed device enables the systematic collection and storage of electrogastrographic recordings in a standardized format. This functionality opens the possibility of developing comprehensive EGG databases and addressing the current lack of publicly available datasets in this field. The availability of such databases could serve as a foundation for advanced data-driven approaches, including the application of artificial intelligence and machine learning algorithms, aimed at improving the classification, diagnosis, and understanding of gastric motility disorders. Future work will focus on developing a long-term multichannel EGG acquisition device and creating a public database.

REFERENCES

[1] Instituto Mexicano del Seguro Social, “Gastroenteritis, Tercera Causa de Urgencias Médicas en el IMSS,” 2019. Accessed: 2025-01-01.

[2] World Health Organization, “Global Health Estimates: Life expectancy and leading causes of death,” 2021. Accessed: 2025-01-01.

[3] Facultad de Medicina, “Principales enfermedades Gastroenterológicas en México.”

[4] A. Al Kafee, T. Cilacı, Y. Kayar, and A. Akan, “Electrogastrography in patients with functional dyspepsia, joint hypermobility, and diabetic gastroparesis,” *Turkish Journal of Gastroenterology*, vol. 33, no. 3, pp. 171–181, 2022.

[5] J. Yin and J. D. Chen, “Electrogastrography: methodology, validation and applications,” *Journal of neurogastroenterology and motility*, vol. 19, no. 1, p. 5, 2013.

[6] H. P. Parkman, W. L. Hasler, J. Barnett, and E. Eaker, “Electrogastrography: a document prepared by the gastric section of the american motility society clinical gi motility testing task force,” *Neurogastroenterology & Motility*, vol. 15, no. 2, pp. 89–102, 2003.

[7] Z. Wang, Z. He, and J. Chen, “Optimized overcomplete signal representation and its applications to time-frequency analysis of electrogastrogram,” *Annals of biomedical engineering*, vol. 26, pp. 859–869, 1998.

[8] H. Liang, Z. Lin, and R. W. McCallum, “Artifact reduction in electrogastrogram based on empirical mode decomposition method,” *Medical and Biological Engineering and Computing*, vol. 38, pp. 35–41, 2000.

[9] F.-Y. CHANG, “Electrogastrography: basic knowledge, recording, processing and its clinical applications,” *Journal of gastroenterology and hepatology*, vol. 20, no. 4, pp. 502–516, 2005.

[10] K. L. Koch and R. M. Stern, *Handbook of electrogastrography*. Oxford University Press, 2004.

[11] PLUX – Wireless Biosignals, “Electrogastrography (egg),” 2024. Accessed: 2025-05-09.

[12] BIOPAC Systems Inc., “Electrogastrogram amplifier (egg100c),” 2025. Accessed: 2025-05-12.

[13] D. J. Levinthal, “Slow Wave(s) of Enthusiasm: Electrogastrography as an Electrodiagnostic Tool in Clinical Gastroenterology,” *Digestive Diseases and Sciences*, vol. 67, p. 737–738, 2022.

[14] A. P. Malvino, *Principios de Electrónica*. Buenos Aires: McGraw-Hill, 1994. ISBN y otros detalles pueden variar según la edición.

[15] C. T.-B. Nicolai Wolpert, Ignacio Rebollo, “Electrogastrography for psychophysiological research: Practical considerations, analysis pipeline, and normative data in a large sample,” *Psychophysiology*, vol. 57, 2020.

[16] J. Han, M. Kamber, and J. Pei, *Data Mining: Concepts and Techniques*. Elsevier, 3rd ed., 2011.