2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

A High-Precision, Low-Cost, Wireless, Multi-Channel Electrogastrography System

Xiaoyi Guo, Zhongpeng Wang, Feng He, Hongzhi Qi, Long Chen, Chunyu Li, Yanchen Wang, Dong Ming, *Member, IEEE*

Abstract—**Electrogastrography (EGG), a method of recording gastric electrical activity, is attractive in both research and clinical applications because of its noninvasive nature. However, the commercially available wireless EGG acquisition system is relatively expensive and the portability is poor. The internal circuit design is unknown, making it difficult to further adjust the system. To overcome these limitations, we have developed a multi-channel EGG acquisition system based on the idea of "low magnification and wide dynamic range". In the system, an analog front end (AFE) including preamplifier, right leg drive (RLD) and low-pass anti-aliasing filter is designed according to the characteristics of the EGG signal, and the high-precision analog-to-digital converter (ADC) is selected for EGG signal collection. The system has the advantages of high precision, low noise, low power consumption, low cost, and high portability. The wireless multi-channel EGG acquisition system can achieve the characteristics of portability and device miniaturization. We provide multiple differential channels for acquisition, which will be helpful to obtain more information about gastric slow wave propagation and coupling.**

I. Introduction

Electrogastrography (EGG) is an electrophysiological technique of recording the gastric electrical activity by placing cutaneous electrodes on the abdominal skin over the stomach. Electrogastrogram refers to the recording obtained from the surface by using EGG [1]. EGG is an accurate measurement method of gastric slow waves, which can provide meaningful information in physiology, pathophysiology and clinical application. EGG has so far been used to study a variety of diseases related to gastric function and gastric motility, such as Functional dyspepsia (FD), gastroparesis [2-5], but it has not been widely used in clinical practice.

The EGG signal has three characteristics. One is that the EGG signal is weak, and the amplitude of EGG signal is in the range of 50-500μV. The second is that the frequency of the EGG signal is low. The frequency of the gastric slow wave in humans is in the range of 0.5-9.0 cycles per minute (cpm) or 0.0083-0.15 Hz, and the dominant frequency of EGG in healthy humans is 0.05 Hz or 3 cpm. Gastric dysrhythmias can be divided into tachygastria and bradygastria. Tachygastria is defined as a regular activity in which the dominant frequency of gastric myoelectric activity increases from 3 cpm to 4-9 cpm, and bradygastria is defined as the regular activity of gastric myoelectric activity with a dominant frequency of 0.5-2 cpm [6]. The third is that the artifacts of EGG signal are strong. The EGG signal is a mixture of gastric myoelectric activity, respiration artifact, bioelectric signals from other organs and motion artifacts due to body movement and breathing [7]. The interferences are stronger than gastric slow wave signal and distort it, which will make data processing more difficult. However, the frequency of most interference signals does not overlap with the frequency of EGG signal, so spectral analysis can be performed to distinguish them.

In the clinical environment, the artifacts in the EGG signal are abundant, resulting in poor quality of the collected EGG signal. The limited and effective information extracted from the collected data will make it difficult to interpret the EGG signals. In the early stage of the EGG study, the experiment of EGG used a single channel for measurement, which would face the problem of inconsistent measurement results caused by different electrode positions. Moreover, due to the different equipment and processing methods, previous studies had many contradictory conclusions, which reduced the credibility of the analysis results. Therefore, EGG was rarely studied for a long period of time, and some researchers even claimed that the acquisition method was ineffective. They thought that it might only be a method to measure stomach movement artifacts or contractile artifacts, but their conclusion was derived from the electrical activity analysis of gastric muscle samples taken during gastric cancer surgery using physiological methods such as intracellular microelectrodes, and the actual collection of EGG was not been carried out, so the reliability of the conclusions of the study needs to be verified [8].

The assessment of gastric function requires long-term monitoring and the existing commercially available EGG acquisition systems are too large to be portable, which cannot be met with existing systems. In addition, there are few commercial EGG acquisition equipment and their software and hardware designs and detection methods lack uniform standards, which will affect the accuracy of EGG collection. And we are unable to check and modify the internal system design. In order to overcome the above limitations, we have developed a wireless miniature multi-channel EGG acquisition system based on the characteristics of the EGG

This work was supported by National Natural Science Foundation of China (No. 81630051, 81925020, 62006171, 61976152), Tianjin Key Technology R&D Program (No. 17ZXRGGX00020) and Natural Science Foundation of Tianjin (No. 20JCYBJC00930).

X. Guo and Z. Wang contributed equally to this work. Corresponding author: Feng He (heaven@tju.edu.cn)

Xiaoyi Guo, Feng He, Long Chen, Chunyu Li, Dong Ming are with Academy of Medical Engineering and Translational Medicine, Tianjin University, Tianjin, 300072, China.

Zhongpeng Wang, Feng He, Hongzhi Qi, Dong Ming are with Department of Biomedical Engineering, College of Precision Instruments and Optoelectronics Engineering, Tianjin University, Tianjin, 300072, China.

Yanchen Wang is with Tianjin International Engineering Institute, Tianjin 300072, China.

signal to ensure the reliability of the data and increase the use of the EGG.

II. EGG SYSTEM DESIGN

The EGG acquisition system is developed based on the idea of "low magnification and wide dynamic range". The common design idea of biomedical electrical signal acquisition system is to use band-pass filter and multi-stage amplification to collect the signal. However, due to the low-frequency characteristics of EGG signal, it is difficult to implement band-pass filtering in hardware, and it will also complicate the circuit. Therefore, DC amplification and anti-aliasing low-pass filtering are used to preprocess the signal. In order to collect EGG signals with lower amplitude without the signal drift caused by the polarization voltage generated on the abdominal skin not exceeding the collected dynamic range, a 32-bit high-resolution and high-precision analog-to-digital converter (ADC) was selected. The accuracy and wide dynamic range of the collected signal can be ensured by one-stage low power amplification of the collected signal. In order to achieve high performance, low power consumption and wireless communication, the Bluetooth low-energy (BLE) module is selected.

Fig. 1 shows the wireless portable multi-channel EGG acquisition hardware. The system is mainly composed of the analog front end (AFE), the high-precision ADC module, the BLE module and a power supply module and the voltage regulator module. The overall block diagram of the EGG signal acquisition system is shown in Fig. 2. The EGG signal is collected by Ag/AgCl electrode. After EGG signal is

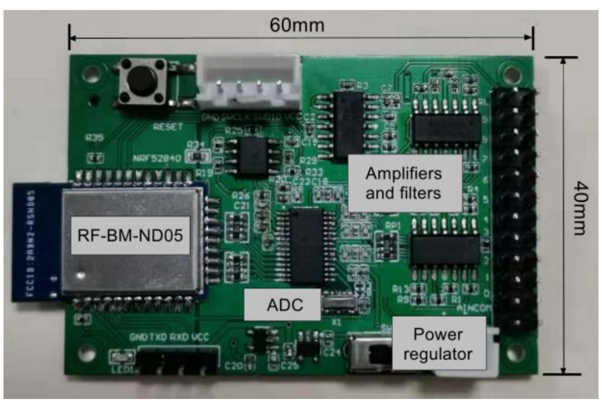

Figure 1. Five differential channels of EGG signal acquisition hardware, length 60mm, width 40mm.

amplified and filtered, the ADC performs analog-to-digital conversion and transmits it to the NRF52840. There are two ways to receive the data. One is to use the mobile phone APP NRF Connect which is officially developed by Nordic, which can receive and store data packets sent by Bluetooth slaves. The other way is to perform wireless data transmission through Bluetooth master-slave pairing connection, and then transmit the data to Matlab through the UART serial port for receiving and data analysis.

A. Design of analog front end

According to the characteristics of EGG signal, the AFE including a preamplifier, a right leg drive (RLD) and a low-pass anti-aliasing filter is designed. In order to increase the input impedance and improve the common-mode rejection ratio, a preamplifier is designed for low magnification. The preamplifier part has a high common-mode rejection ratio of 140 dB. The circuit of the RLD is improved with reference to the design of Enrique Mario Spinelli et al. [9] to reduce the common mode interference of the system. Because the EGG frequency is in the range of 0.5-9.0cpm or 0.0083-0.15Hz, an anti-aliasing low-pass filter is designed.

B. Analog-to-digital converter

In order to distinguish the EGG signal clearly, the ADC chip was selected to perform analog-to-digital conversion of the signal. The ADC has 32-bit high resolution, 27-bit effective number of bits (ENOB) and the sampling rate can be as high as 38400 sample per second (SPS). With a data rate of 2.5SPS and a gain of 32, there is 7 nVrms noise, indicating that it can accurately measure weak bioelectric signals. The single-cycle settling digital filter can maximize the multi-input conversion throughput, while providing 130-dB rejection of 50Hz and 60Hz line cycle interference. The ADC has excellent performance of high precision, low drift and low noise. There is no AFE designed for bioelectric signals in this chip, which greatly improves the flexibility of system design. Because the frequency of the EGG signal is low, a lower sampling rate is selected. The sampling rate of 5SPS and 5 differential channels are set by software programming and the internal finite impulse response (FIR) filter is used. Based on the aforementioned performance and software programming settings, ADC can record multi-channel EGG signals clearly and accurately, and can achieve a wide dynamic range. Therefore, ADC can well meet the design requirements.

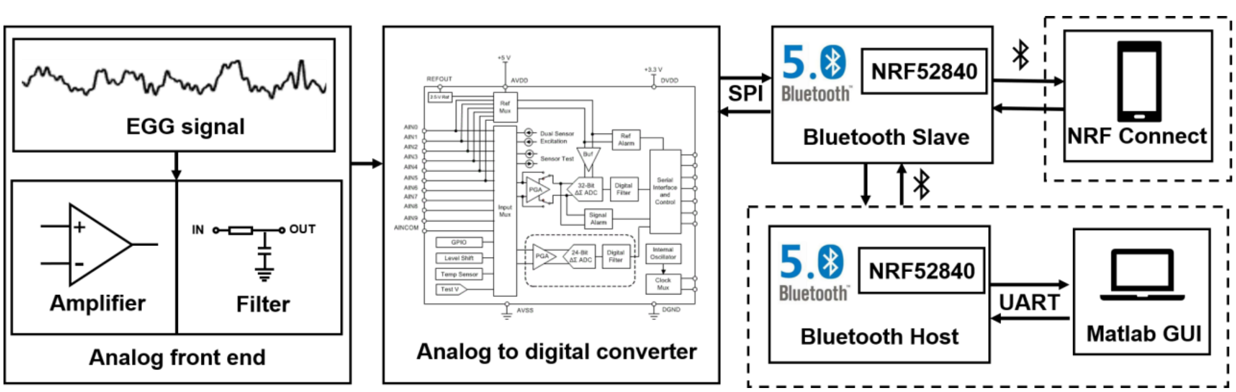

Figure 2. The wireless multi-channel EGG acquisition system overall block diagram

C. Bluetooth Low Energy module

In the system, the BLE module with high performance and low power consumption is selected for wireless communication. The Bluetooth slave selects the RF-BM-ND05 module (RF-STAR China), which includes the BLE 5.0 NRF52840 system on a chip (SoC) [10] and PCB antenna. This module is suitable for short-distance wireless communication. It has the characteristics of long transmission distance, and strong anti-interference ability. Compared with other Bluetooth modules, it has more powerful computing power and floating-point computing technology, and can realize higher throughput applications. The Bluetooth slave receives the data through serial peripheral interface (SPI), and packs the data through software programming. The data packet contains the data of a certain channel and the information of the channel serial number, which is convenient for subsequent processing and analysis of the data of each channel. Finally, the data packet is sent to the mobile phone or the Bluetooth host module via Bluetooth.

The Bluetooth host selects the integrated BLE 5.0 module with NRF52832 SoC as the core. The NRF52832 is also a powerful, ultra-low power chip, with powerful processing capabilities, multi-protocol support and other advantages. The module can be paired and connected with a Bluetooth slave for wireless transmission of data packets. The data can be directly transmitted to the upper computer software such as Matlab through the miniature Bluetooth host module to process and analyze the data. This design has good flexibility, strong portability, and the upper computer program can be modified according to different needs.

III. RESULTS

Our system has been assembled. The power consumption of the circuit was tested when the system was in working condition and the peak-to-peak current of the system was 19mA. The micro lithium battery (35mm×12mm×10mm) can be used for about 10 hours, meeting the needs of long-term gastric electricity monitoring or 4 typical experiments, and has the functions of low power consumption and strong endurance. Longer monitoring can be achieved by using 2 lithium batteries in turn.

In order to test the performance of the system, firstly, the signal generator was used to input sinusoidal signal to the multi-channel EGG acquisition system to verify the reliability of the equipment. Then, four channels were used to collect the EGG signals for further verification. In a noninterference and temperature-appropriate experimental environment, the EGG signals of healthy subject in the awake state were collected for analysis. Ag/AgCl electrodes were used for collection during the experiment. Participants took a 45-degree supine position, tried to avoid movement and stayed still to avoid motion artifacts. The multi-channel EGG signals of participants in this state were recorded for 30 minutes. The data of a differential channel was selected for subsequent analysis. This study was approved by the ethical committee of Tianjin University.

The Butterworth digital band-pass filter is used for preliminary data processing of the EGG signal, and the waveform and frequency spectrum of the filtered data are preliminary analyzed. The upper part of Fig. 3 shows the Electrogastrogram within 20 minutes after digital bandpass filtering, and the lower part shows the changes in the waveform of the EGG signal within 5 minutes for waveform analysis. Fig. 4 shows the frequency spectrum of the collected signal. In the spectrogram, there is a higher position at about 0.05 Hz, which is consistent with the dominant frequency of gastric electricity of healthy subjects. Through the waveform and spectrogram, it can be preliminarily proved that the EGG signal is collected. In the follow-up research, further experiments and analysis will be carried out on the propagation and coupling of slow waves between multiple channels.

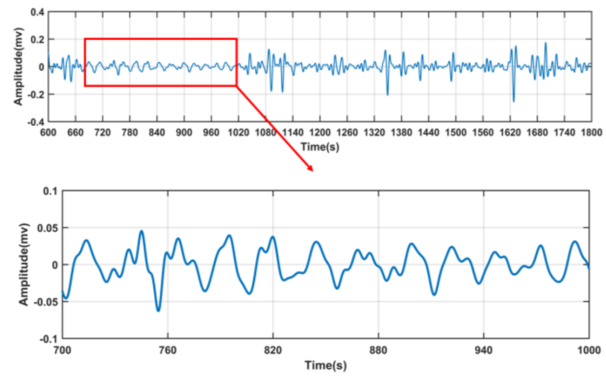

Figure 3. Signal waveform in five minutes

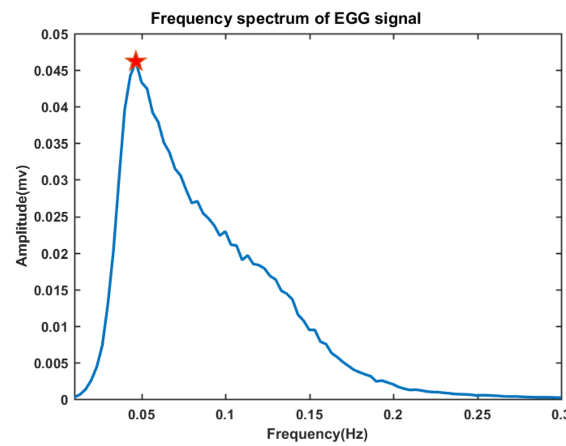

Figure 4. Frequency spectrum of the filtered signal

IV. CONCLUSION AND DISSCUSION

The paper introduces a hardware system for wireless portable multi-channel EGG acquisition, which can monitor EGG signal for a long time and complete data transmission and storage by Bluetooth connection with portable devices such as mobile phones and tablets. Compared with the wireless physiological systems currently on the market, our system has higher EGG acquisition performance and larger dynamic range due to the 32-bit ADC (Table 1), and the cost of this device is within \$80. The system receives and processes data on the PC side through Matlab software, so the subsequent data processing and analysis can be freely designed according to requirements, with high flexibility, strong portability, and high applicability. When using a single channel for acquisition, some low-frequency components in the spectrum are difficult to distinguish between artifacts and valid signals. The joint analysis of multi-channel data can make a more reasonable interpretation of the low-frequency components in the signal, which will be the direction of our next work. In future work, we will also optimize the hardware system and embedded software programs, and integrate the system into a wearable device after successful debugging. At the same time, we will design and optimize the upper computer programs of mobile phones and computers to realize the functions of data cloud storage and telemedicine.

REFERENCES

[1] J. Yin and J. D. Chen, "Electrogastrography: methodology, validation and applications," *J Neurogastroenterol Motil,* vol. 19, no. 1, pp. 5-17, Jan 2013.

[2] F. M. Vargas-Luna *et al.*, "Electrogastrographic and autonomic nervous system responses to solid and liquid meals in youth with functional dyspepsia," *Neurogastroenterol Motil,* vol. 32, no. 4, p. e13785, Apr 2020.

[3] A. A. Gharibans, T. P. Coleman, H. Mousa, and D. C. Kunkel, "Spatial Patterns From High-Resolution Electrogastrography Correlate With Severity of Symptoms in Patients With Functional Dyspepsia and Gastroparesis," (in eng), *Clinical Gastroenterology and Hepatology,* vol. 17, no. 13, pp. 2668-2677, Dec 2019.

[4] Y. Kayar, A. Danalioglu, A. A. Kafee, S. Okkesim, and H. Senturk, "Gastric myoelectrical activity abnormalities of electrogastrography in patients with functional dyspepsia," *Turk J Gastroenterol,* vol. 27, no. 5, pp. 415-420, Sep 2016.

[5] X. Xu, D. D. Chen, J. Yin, and J. D. Chen, "Altered postprandial responses in gastric myoelectrical activity and cardiac autonomic functions in healthy obese subjects," *Obesity Surgery,* vol. 24, no. 4, pp. 554-60, Apr 2014.

[6] S. Haddab and M. Laghrouche, "Microcontroller -Based System for Electrogastrography Monitoring Through Wireless Transmission," *Measurement Science Review,* vol. 9, no. 5, pp. 122-126, 2009 2009.

[7] A. A. Gharibans, B. L. Smarr, D. C. Kunkel, L. J. Kriegsfeld, H. M. Mousa, and T. P. Coleman, "Artifact Rejection Methodology Enables Continuous, Noninvasive Measurement of Gastric Myoelectric Activity in Ambulatory Subjects," *Sci Rep,* vol. 8, no. 1, p. 5019, Mar 22 2018.

[8] P. L. Rhee *et al.*, "Analysis of pacemaker activity in the human stomach," *The Journal of physiology,* vol. 589, no. Pt 24, pp. 6105-18, Dec 15 2011.

[9] E. M. Spinelli, R. Pallas-Areny, and M. A. Mayosky, "AC-coupled front-end for biopotential measurements," *IEEE transactions on biomedical engineering,* vol. 50, no. 3, pp. 391-5, Mar 2003.

[10] Nordic, "nRF52840 Advanced Bluetooth 5, Thread and Zigbee multiprotocol SoC," 2018.

[11] B. Systems, "MP Hardware Guide," 2013.

[12] D. Komorowski, S. Pietraszek, and D. Grzechca, *The wireless system for EGG signal acquisition* (IEEE International Conference on Electronics, Circuits and Systems). 2012, pp. 372-375.

TABLE I. PERFORMANCE COMPARISON OF GASTRIC ELECTRICAL ACQUISITION SYSTEM

Parameter	***Our System***	***BIOPAC Systems, MP150 BN-EGG2 [11]***	***Silesian University of Technology, wireless EGG system [12]***
Resolution	32-bit	16-bit	24-bit
Sampling Rate	2.5SPS – 38400SPS (programmable)	2000SPS	250 SPS – 32000 SPS (programmable)
Number of Differential Channels	5	2	4
CMRR (50/60 Hz)	130dB	110 dB	115 dB
Input Impedance	10MΩ	2 MΩ	1000 MΩ
Bandwidth	DC-0.5Hz	0.005Hz-1Hz	Adjustable (DC Coupled)
Gain	1-32 (programmable)	2000	1 – 12 (programmable)
Wireless Range	~100 m	~10 m	
Noise Voltage (shorted inputs):	7 nVrms (2.5 SPS, Gain = 32)	0.5 µV rms (bandwidth of 0.005 Hz to 1 Hz)	0.5 µVrms (at 500 SPS, gain=12)
Size & Weight:	70mm× 40 mm ×15mm, 27g	Transmitter :60mm×40mm×20mm, 54g; Receiver :4cm x 11cmx 19cm, 380g	
Power consumption (in operation)	19 mA	40 mA	90 mA
Cost	~ $80	$14000	~ $150