Pressure Monitoring System in Gastro-Intestinal Tract

Byungkyu kim*, Yongin Kim*, Sukho Park*, Jinho Jo**, and Gwitae Park***

* Korea Institute of Science and Technology, Seoul, Korea
(Tel : +82-2-958-6730; E-mail: bkim, kuciewsza, shpark@kist.re.kr)
** Kyungbook National University, Seoul, Korea
(Tel : +82-53-950-5538; E-mail: jhcho@ee.knu.ac.kr)
*** Korea University, Seoul, Korea
(Tel : +82-2-3290-3218; E-mail: gtpark@korea.ac.kr)

Abstract: Diseases in the gastro-intestinal tract are on an increasing trend. In order to diagnose a patient, various signals of the digestive organ, such as temperature, pH, and pressure, can offer the helpful information. Among the above mentioned signals, we choose the pressure variation as a monitoring signal. The variation of a pressure signal of the gastro-intestinal tract can offer the information of a digestive trouble or some clues of the diseases. In this paper, a pressure monitoring system for the digestive organs of a living pig is presented. This is why a pig's gastro-intestinal tract is very similar as human's. This system concept is to transmit the measured biomedical signals from a transmitter in a living pig to a wireless receiver that is positioned out of body. The integrated solution includes the swallow type pressure capsule and the receiving set consisting of a receiver, decoder circuit. The merit of the proposed system is that the monitoring system can supply the precise and a durable characteristic to measure and to transmit a signal in the gastro-intestinal tract. We achieved the pressure tracings in digestive organs and verified the validity of system after several in-vivo tests using the pressure monitoring system. Through various experiments, we found each organ has its own characterized pressure fluctuation.

Keywords: **Pressure monitoring system; pressure capsule; gastro-intestinal tract; in-vivo test**

1. INTRODUCTION

Recently, the endoscopy has been developed since diseases in the gastro-intestinal tract have gradually increased. Among the endoscopic technologies, a capsule type endoscope is highlighted for the convenience of a patient. While the capsule endoscope moves along the gastro-intestinal tract, it transmits the various visual images of in the digestive organs [1] [2]. The device, known as the M2A Imaging System (Given Imaging), can supply reliable images of the gastro-intestinal tract [1].

Except the visual images of the digestive organs, we can know that the various signals in the organs, such as temperature, pH, and pressure, can offer the useful information for the diagnosis of a patient. In addition, we have an interest in the miniaturized wireless telemetry modules in order to realize the functional endoscopes of temperature, pressure, pH, and so on.

For in-vivo telemetric studies of the gastro-intestinal tract, Johannessen [3] suggests an analytical microsystem, which incorporates a four sensing channel. The measuring signals are temperature, pH, conductivity and oxygen. However, they did not deal with a pressure signal in the body.

Especially, because the pressures in the human body or a living body is necessary as a part of clinical examinations and for physiological studies, a new inspection and new devices have been developed for a monitoring of a gastro-intestinal tract. Firstly, the intra gastric and intra intestinal pressures are measured in the gastro-intestinal tract [4]. These pressure signals are considered as the sum of the pressures developed by the peristaltic motions of the stomach or the intestine and the pressure in the peritoneal cavity. Recently, there are many endeavor and attempts for an increasing accuracy of the diagnosis in a bio-medical field for this environment. For the long-term monitoring of the pressure in the digestive system, it is preferable to use a pressure transducer that is separated from external instruments. Therefore, the pressure sensor module can be either surgically implanted (as in the case of the intracranial pressure measurements) or swallowed (for pressure measurements in the gastrointestinal tract) [4].

The swallowable capsule including gastro-intestinal pressure telemetry has been studied by many researchers [5-9]. In addition, Mackey has suggested the pressure sensor, which was enclosed in a rubber balloon and measured the pressure signal from a human stomach, a small intestine, and a colon [10]. However, the above mentioned results are insufficient to differentiate each digestive organ.

In this paper, we report the concept of the telemetry system about the proposed pressure monitoring system as shown in Figure1. This concept is to transmit the measured biomedical signals from the transmitter in the body to the wireless receiver out of the body. The RF carrier frequency is 433 MHz (Frequency Shift Keying) for the transmission of the signals from inside the living body. The pressure monitoring system comprises: (1) the swallowable type pressure capsule and (2) the receiving set including the receiver, the decoder circuit. The developed pressure monitoring system has several advantages of the following. Firstly, the monitoring system has the capability to measure precise pressure in the gastro-intestinal tract. Secondly, low power consumption of the pressure capsule enables to keep stable power while the pressure capsule is working over 20 hours. Finally, from the measured signal, we can analyze that the pressure signals are caused by the movements of the organ, such as the breathing in the lungs and the beating in the heart.

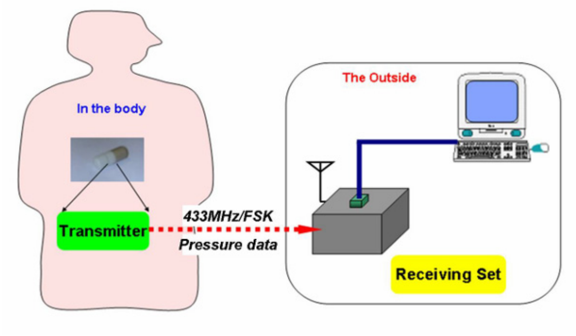


Fig. 1 Concept of Pressure monitoring system.

The rest of the paper is organized as follows: In the following chapter, the conceptual design and the prototype of the pressure monitoring system are presented. And the design of the pressure capsule and the design of the wireless transmitter module are described. Chapter3 will present the experimental verification for the proposed pressure monitoring system. In Chapter4 it is confirmed that the experimental results verify the reliability and the validity of the monitoring system through an in-vivo test using a living pig. In addition, some analytic results of the measured pressures will be presented. Finally, concluding remarks will be drawn in Chapter5.

2. CONSTRUCTION OF SYSTEM

The pressure monitoring system embodies a kind of functional endoscope in order to measure pressure in the digestive tract of a living body. Pressure monitoring system is classified into the pressure capsule and the receiving set.

2.1 Pressure Capsule

The pressure capsule has to be small for inserting through a mouth and an esophagus. External shape and rigidity have to be optimized to fix in the alimentary canal. Figure3 shows a photograph of shape for the pressure capsule. The dimensions of this capsule included all components are 30 mm in length and 13 mm in diameter. For the manufacture process of the pressure capsule, a commercial pressure sensor, electronic circuits with an antenna, and a commercial battery were integrated into the capsule as three multistage. After the integration, the capsule was sealed with a water-proof agent. Figure2 shows an electronic circuit block diagram of the inside of the pressure capsule.

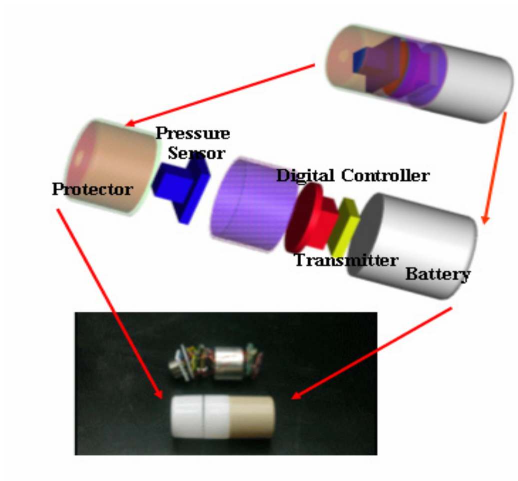


Fig. 2 Layout of pressure capsule

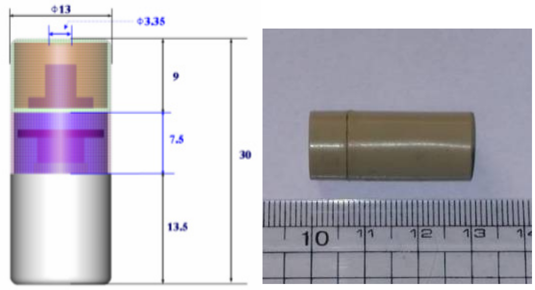


Fig. 3 Shape of pressure capsule

This capsule consists of a pressure sensor, a digital controller by Verilog HDL, a transmitter, and a battery as shown in Figure5. The dimension of this controller with an oscillator is 4.5 mm in thickness and 10 mm in diameter. The pressure sensor and electronic circuits are connected to a 3 V Li-battery. The Li- battery uses lithium metal alloy in its negative electrode (anode) and manganese dioxide in its positive electrode (cathode) [8]. The consumable power from the battery is an average level of 48 ㎽. The energy output rating for the Li- battery used is typically 160 ㎃ *Hours indicating. The pressure capsule can work more over 20 hours sufficient for measuring in an alimentary canal because the operating voltage of each module is 2.2 V at the minimum.

The wireless transmitter is realized a VCO (Voltage Controlled Oscillator) with the resonant component like a type of a microstrip line and a buffer Amp (Amplifier) in order to stabilize the output and the characteristic. The buffer Amp plays a role in amplifying output power and restraining the oscillation frequency of the VCO due to the change of impedance at the output stage. The transmitter PCB has the dimension of 10 ㎜ in diameter and 2.3 ㎜ in thickness. Then, the operating point is Vce=2 V, Ic=7mA. It is shown that The fabricated transmitter had -19 dBm of power spectrum and 434MHz of frequency displacement in Figure4.

In addition, the manufactured antenna is illustrated in Figure5. The antenna for transmission has the dimension of 10 ㎜ in diameter and 2.2 ㎜ in thickness.

The radiation pattern of an antenna for pressure capsule has to have an omnidirectional antenna characteristic in order to transmit measured signals continuously in Figure6. Although acquired patterns are not an ideally omnidirectional characteristic, radiation patterns are similar to a microwave radiation theory at the tested result. The consuming current of wireless transmitter module is 3 ㎃.

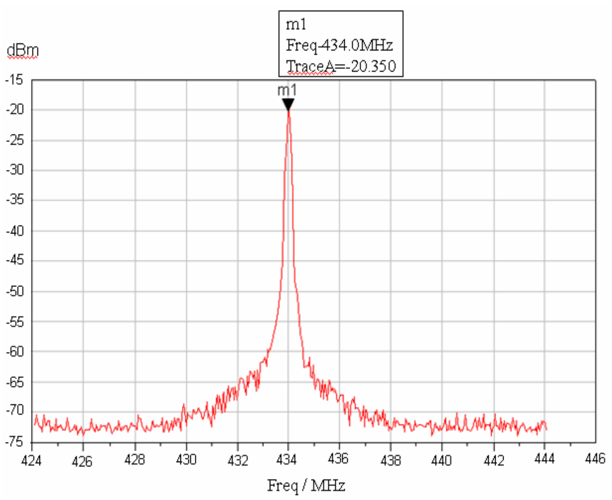


Fig. 4 Radiation Characteristic of transmitter module

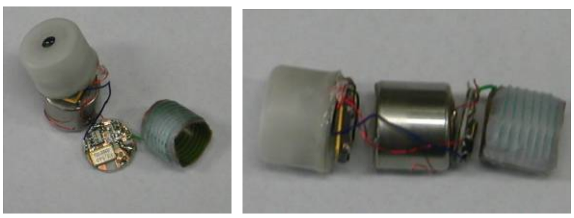
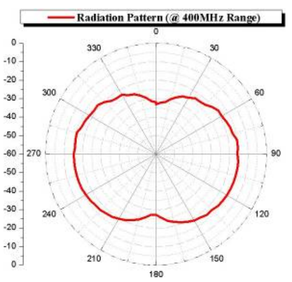
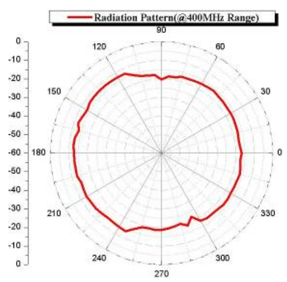


Fig. 5 Transmitter module, battery and antenna.



(a) Theta - direction



(b) Phi - direction

Fig. 6 Radiation pattern of antenna.

The pressure sensor, in Figure7, commercialized pressure sensor (MS5534A, Intersema of Switzerland) was used. The pressure sensor module [7], MS5535A, is a SMD-hybrid device including a piezoresistive pressure sensor and an ADC-interface IC. This resolution of this sensor is typically 1.2 mbar and 0.005~ 0.015℃ provides a 16 bit data word from a pressure and temperature dependent voltage. A four-wire interface is used for all communication between the sensor and the digital controller unit by Verilog HDL. The SCLK (Serial Clock =125 kHz) signal initiates and synchronizes the data transference. Moreover, the data signal is the ADC conversion result for measured data by pressure sensor. The selection of the output data is dependent on the control signal. The signal MCLK (Master Clock) indicates the AD-converter clock (32.768 kHz frequency), that is also supplied in the digital controller unit.

The digital controller is designed using Verilog HDL in ISE-WebPACK (Xilinx). The selected chip, In Figure7, is XCR3064-10CP56C (Xilinx) for the digital control unit when operating frequency is 4 MHz. Its standard operating voltage is 3.3V and consumable current is 8mA. This unit generates MCLK signal, SCLK signal, and control signal in order to operate the pressure sensor and transmit measured pressure data to the encoder. The output of the digital controller is encoded to suit wireless transmission and reconstruction of pressure measurement data.

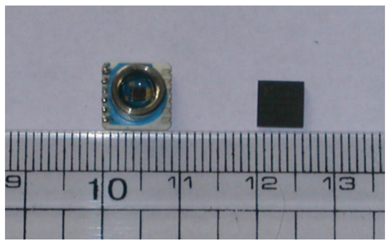


Fig. 7 Pressure sensor (left) and controller (right)

2.2 Receiving Set

Figure8 shows the receiving set. And it is shown RF receiver module in Figure9. The wireless receiver is realized a microstrip line. The signal of transferred is decoded and saved NandFlash memory. The CPLD (Complex Programmable Logic Device) decoder, XCR3064XL-10CP44C (Xilinx, USA), separates these signals to pressure data and the sync control signal. The sync signals need to synchronize with measured pressure data from capsule. These data are parallel and valid only at the positive edge of the sync signals. The data stream of the decoder signal is illustrated in Figure10. The separated signals are transferred to the PC by RS-232C. Finally, the interface program displays pressure measurement results.

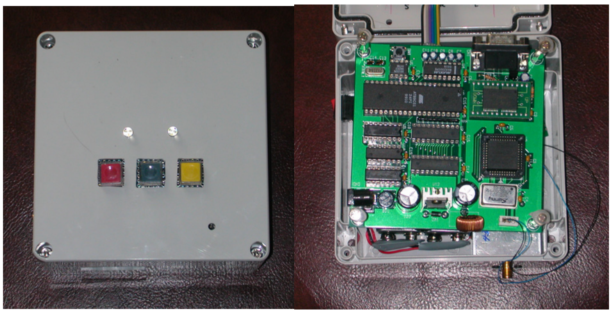


Fig. 8 Shape of receiving set.

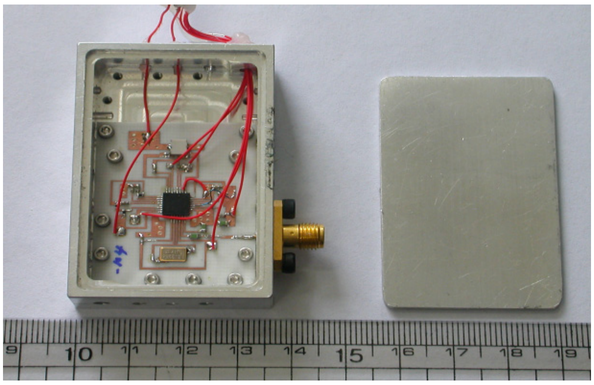


Fig. 9 Shape of RF receiver.

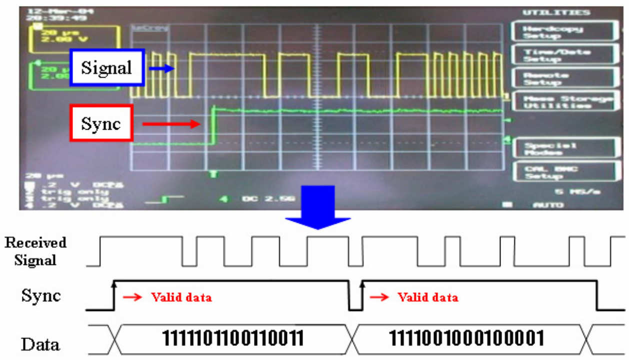


Fig. 10 Data stream of decoder set

3. EXPERIMENT VERIFICATION

3.1 Experiment while anesthetized

While anesthetized the procedure of the in-vivo testing for the pressure monitoring system was as follows. Before putting the swallowable pressure capsule in a living pig in Figure11-(a) & (b), we measured for atmospheric pressure. The capsule was inserted through an over-tube and started monitoring pressure data at the esophagus (Figure11-(c)). Next, the pressure capsule reached at the stomach and transmitted pressure data in the stomach. (Figure11-(c)). When the pressure capsule was situated at the stomach, we pressed the region of the stomach with hands and acquired the pressure data for the living pig. Finally, the capsule was deeply put in the large intestine through the anus and then received the pressure measurement data of the large intestine (Figure11-(d)).

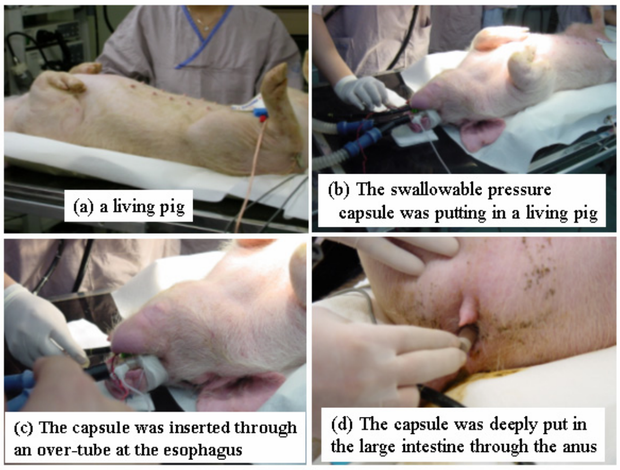


Fig. 11 In-Vivo test while anesthetized

3.2 Experiment while non-anesthetized

Fig. 12 In-Vivo test while non-anesthetized

While non-anesthetized the procedure of the in-vivo testing for the pressure monitoring system was as follows. First, we put the swallowable pressure capsule in a living pig. The capsule was inserted through an over-tube and started monitoring pressure data at the stomach and transmitted pressure data in the stomach. And the measured power of transmitter antenna is enough to receiver is working. Then pig was in cage and receiver box with receiver antenna was set. It is shown in Figure12. And monitoring of pressure data was started for 20 hours.

4. RESULTS

4.1 Experiment while anesthetized

While anesthetized the pressure measuring results of in-vivo test are shown in Figure13. First, the pressure capsule measures the atmospheric pressure of about 100 kPa. From these data, we can know that the pressure capsule works well. Second, when the capsule is located in esophagus, the average pressure is measured as 99.22 kPa and the signal is fluctuated between 98.91 kPa and 99.52 kPa. Third, the pressure in the stomach is about 99.78 ~ 99.93 kPa. Finally, when the pressure capsule is situated at the colon, the measured pressure is about 101.16 ~ 101.85 kPa.

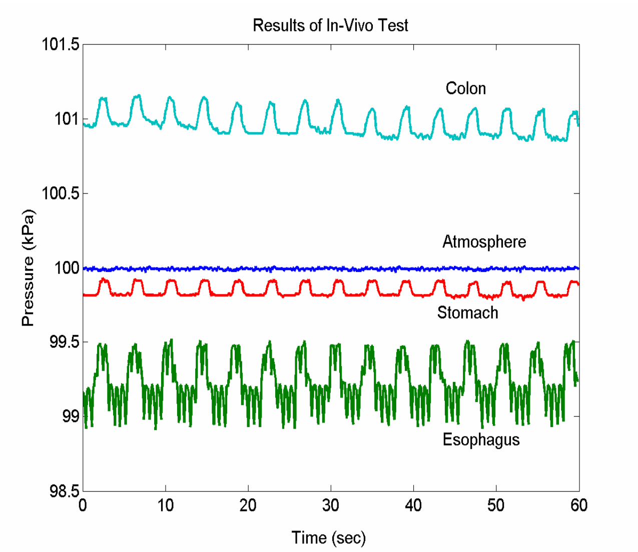


Fig. 13 In-Vivo result while anesthetized.

From result of In-vivo test we can know as follow.

- The pressure signal of the colon is higher than the atmospheric pressure and those of the esophagus and the stomach are below the atmospheric pressure;

- The fluctuating signal is caused by the movements of the organs such as the breathing in the lungs and the beating in the heart. This result can be well explained by the FFT (Fast Fourier Transform) of the esophagus signal (Figure15). The peak frequencies in the FFT are about 0.258 Hz and 1.425 Hz. It is estimated that the frequency of 0.258 Hz (=15.5 cycle/minute) is caused by the breathing in the lungs. In addition, the peak of 1.425 Hz (=85.5 cycle/minute) can be explained by the beating of the heart.

- The fluctuation by the breathing is well shown in the all organs. However, the beating fluctuation is well shown in the esophagus only. The reason can be interpreted that the esophagus is very closer to the heart than other organs.

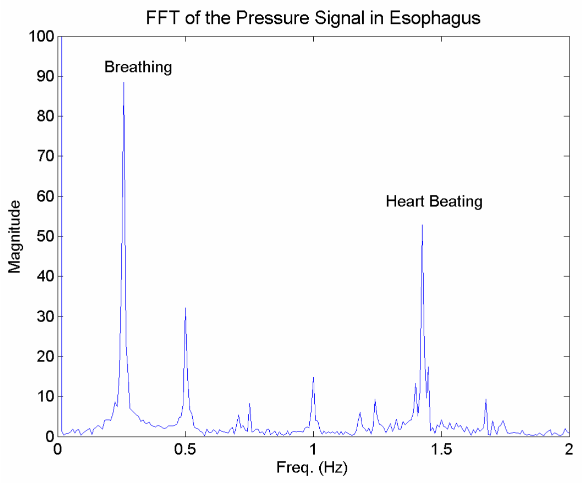


Fig. 14 FFT of the pressure signal in esophagus

4.2 Experiment while non-anesthetized

While non-anethetized the pressure measuring results of in-vivo test are shown in Figure15. Total signal contains some noise like movement and howl of pig. So some of total signal is cannot analysis. We remove noise signal using filtering technique as moving average, threshold technique, and so on.

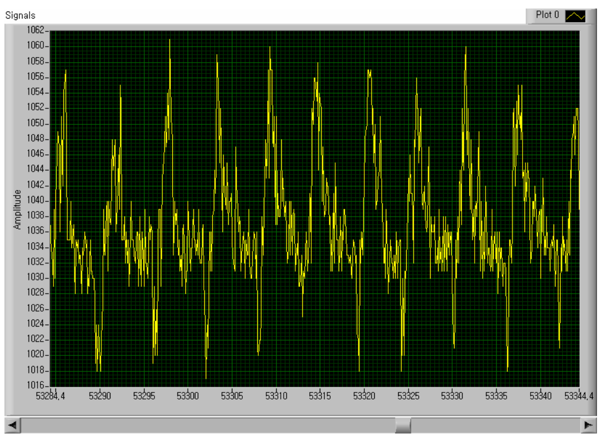


Fig. 15 In-Vivo result while non-anesthetized.

From result of In-vivo test we can know as follow.

- While non-anesthetized the pressure signal was captured over 20 hours. The pressure pattern is not a fixed set like experiment in anesthetized condition. It verified pressure monitoring system is reliable. So I think it can use variety of animal without movement and howl.

- The fluctuating signal is caused by the movements of the organs such as the breathing in the lungs and the beating in the heart. But most of signals was effected movement and howl of pig. This result is shown in figure 16 by the FFT (Fast Fourier Transform) of the Fine signal. The peak frequencies in the FFT are about 0.213Hz. It is estimated that the frequency of 0.213 Hz (=15.4 cycle/minute) is caused by the breathing in the lungs. In the contrary around of peak is clean while anesthetized, in non-anesthetized not clean of peak. It caused between artificial breathing and natural breathing. There is no peak signal about 1.4Hz as heart beating too.

- The signal was captured over 20 hours. Since amount of noise exist, we cannot find fence of each organ. If another animal that is lower noise than pig is test successful signal will be captured to recognize fence of each organ.

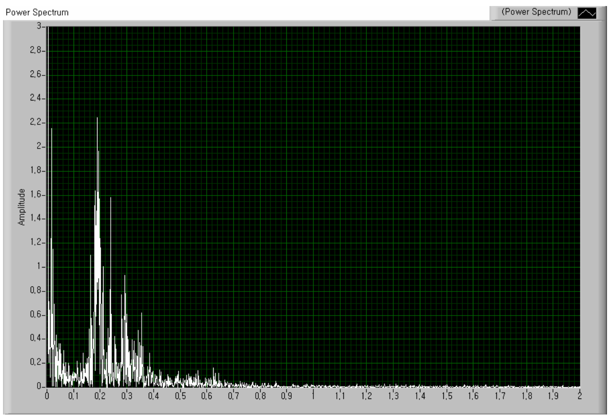


Fig. 16 FFT of the pressure signal in fine signal.

5. CONCLUSION

The pressure monitoring system for a digestive tract is presented. The system was consists of pressure capsule module and receiver box. The reliability and validity of the pressure monitoring system is verified experimentally.

Consequently, the proposed pressure monitoring system can supply precise and repeatable pressure in an alimentary canal. Based on design of low power consumption for pressure capsule, this capsule can keep sending reliable pressure data until it comes out through anus.

In anesthetized condition we could know each organ has it own characterized pressure fluctuation. And result of FFT was shown breathing and heart beating is exists. And while non-anesthetized the pressure capsule enables to last more over 20 hours sufficient for measuring in an alimentary canal because the operating voltage of the capsule is 2.2 V at the minimum. It make pressure monitoring system is reliable.

As result we could know difference between anesthetized and non-anesthetized. Because noise of movement and howl, the location of pressure capsule in digestive tract could not be obtained based on continuous monitoring of pressure while capsule is moving from mouth to anus. It successfully proves usefulness of the prototype system presented in this paper. Future work aims at measuring the pressure of the small intestine as well as in-vivo testing in another animal what lower noise than pig. And noise filtering technique must study too.

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REFERENCES

[1] G.A. Douglas and J. G. Christopher, “State of the Art - Wireless Capsule Endoscopy,” Hospital Physian, May, 2003, pp. 14-22.

[2] http://www.rfnorika.com/e_system/e_system_001.html

[3] E.A. Johannessen, L. Wang, L. Cui, T.B. Tang, M. Ahmadian, A. Astaras, S.W. Reld, P.S. Yam, A.F. Murray, B.W. Flynn, S.P. Beaumount, D.R. Cumming, and J.M. Cooper, “Implementation of Multichannel Sensors for Remote Biomedical Measurements in a Microsystems Format,” IEEE Tran. Biomedical Engineering, Vol. 51, No. 3, 2004, pp. 525-535.

[4] T. Togawa, T. Tamura, and P.A. Oberg , “Biomedical Transducers and Instruments,” CRC press, 1997, pp. 13-71

[5] J.T. Farrar, V.K. Zworykin, and J. Baum, “Pressure-sensitive telemetering capsule for study of gastrointestinal motility,” Science, Vol. 126, pp. 975~976, 1957.

[6] R.S. Mackay, “Radio telemetering from within the human body,” IRE Trans. Med. Electron., Vol. 6, pp. 100~105, 1959.

[7] J.T. Farrar, C. Berkley, and V.K. Zworykin, “Telemetering of inraenteric pressure in man by an externally energized wireless capsule,” Science, Vol. 131, pp. 1814, 1960.

[8] C.N. Smyth, and H.S. Wolff, “Application of endoradiosound or "wireless pill" to recording of uterine contractions and foetal heart sounds,” lancet, Vol. 2, pp. 412, 1960.

[9] M.B. Rappaport, E.H. Bloch, and J.W. Irwin, “A manometer for measuring dynamic pressures in the microvascular system,” J. Appl. Physiol., Vol. 14, pp. 651, 1959.

[10] R.S. Mackay, “Bio-medical telemetry,” IEEE press, 2nd Edition, 1993.

[11] http://www.intersema.ch/site/technical/ms5535.php

[12] http://www.sanyo.com/batteries/lithium_ind.cfm