ELECTRICAL STIMULI CAPSULE FOR CONTROL MOVING DIRECTION
AT THE SMALL INTESTINE


*School of Electronic Engineering and Computer Science, Kyungpook National University,
**College of Veterinary Medicine Dept. of physiology, Kynugpook National University,
***Department of Computer Control & Electrical Engineering, Kyungil University,
****Advanced Research Center for Recovery of Human Sensibility, Kyungpook National University.

Room 512, Engineering building 10, Kyungpook National University,
1370 Sankyuk-dong, Buk-gu, Daegu 702-701, Korea
jhcho@ee.knu.ac.kr

ABSTRACT
Recently, a capsule endoscope has been developed to observe images from the inside of intestine. Such a capsule endoscope does not have locomotion or hold method. To get proper diagnosis and medication, it is necessary to control the capsule from outside to guide locomotion. The designed and implemented capsule has feasibility to contract the small intestine by electrical stimuli through the electrodes. When the small intestine is contracted by electrical stimuli, the capsule can move to opposite direction, which means the capsule can go up and down in the small intestine. The implemented stimuli capsule always monitors excessive energy transmission and automatically shuts down the electrical stimuli to make it more secure. Additionally, the stimuli capsule goes on standby mode to save the battery, and it can be reset by comparator circuit which is connected to stimulus electrodes. To verify the design and implement the stimuli capsule, in-vitro experiments were performed with pig’s small intestine.

KEY WORDS
Capsule endoscope, Locomotion, Change moving direction, Improve moving speed, Electrical stimuli.

1. Introduction
Recently the capsule endoscope has been developed to observe the small intestine to reduce the pain that occurs when using a normal endoscope. The capsule at the forefront of this development is the M2A (Given Imaging, Israel), which can transmit two frames of CIF (352*288) resolution images from inside the intestine[1,2].

Although the capsule endoscope has some benefit, the capsule does not have the ability to stop or the locomotive faculty which is essential for diagnosis and remedy. Many researchers have tried to make locomotive capsule which can travel through the intestine and find a tumor or bleeding in the intestine.

Montesi et al. developed the shape memory alloy (SMA) based the locomotive capsule to travel the intestine[3]. But the movement of SMA is too slow to move fast in the intestine, and the high power consumption for the small battery application.

Attanasio et al. developed an inchworm-like capsule to move through the intestine[4,5]. It has an inlet valve to suck up on the intestinal wall, and doing stretches and contracts to travel in the intestine. However, it also has problems about the capsule size due to inlet valve. In addition, the power consumption is too much for a small battery application.

On the other hand, an electrical stimuli capsule stimulates the intestine to improve the moving speed of the capsule. Moreover, the power consumption is much lower than mentioned methods. The electrical stimuli capsule not only improves the moving speed, it can go backward which is essential to diagnosis and dosage. Several experiments have been conducted about electrical stimuli to improve moving speed.

Mosse et al. has reported that electrical stimuli can propel the capsule endoscopes. However, the diameters of capsules are over 2cm, which is too large to swallow. In addition, the surge current for only electrical stimuli was over 30mA that is too large for small batteries. Moreover, the experiments were carried out in wired condition that can effect moving speed of capsule.

Park et al. has reported that electrical stimuli can move faster from the in-vivo experiment without any wires. However, the implemented capsule has no feasibility to go backward, and the size of capsule was still large. Also the capsule needs 6~9V batteries, which are impractical for the commercial capsule endoscope[7].

In this paper, the electrical stimuli capsule is designed and implemented for low power consumption. The capsule needs the small 3V batteries, which are currently using at capsule endoscope. In addition, the size of capsule is small enough to swallow. The implemented capsule can generate electrical stimuli, which can cause contraction in the small intestine to propel moving speed,
and can go forward and backward. To find the proper electrical stimuli parameters, the capsule can generate various stimuli, which can be controlled by an external wireless controller. Also, the capsule checks excessive energy transmission, and automatically shuts down the electrical stimuli. To verify the design and implement the stimuli capsule, in-vitro experiments were performed with the pig’s small intestine.

2. Designed System

2.1 Concept of System

In fig. 1 shows the concept of the electrical stimuli capsule. The external controlling device use amplitude shift keying (ASK) modulation to control the electrical stimuli parameters in the stimulus capsule. The capsule can stimulate the small intestine by electrical stimuli, which can induce contraction, then it can be propelling to opposite direction of the contraction. By using an external controller, the doctor can improve moving speed of endoscope to reach a target or go backward to get detail image.

![Fig. 1. The concept of the electrical stimuli capsule.](image)

2.2 Implement Small RF Receiver and External Controller

To measure exact moving speed of the capsule, and to control its direction of movement, a wireless control is necessary. The brief structure of the external controller is shown in Fig. 3. A microcontroller checks keypad input, and then displays the LCD and transmits stimulus parameter by a transmitter MAX1472 (MAXIM, USA). To transmit the parameter, 433 MHz industrial, scientific and medical (ISM) band is chosen regarding attenuation RF transmit power from inside the human body. To receive the parameter, a 9mm diameter 433MHz receiver MAX1473 (MAXIM, USA) is implemented.

![Fig. 3. Brief structure of an external controller.](image)

2.3 Electrical Stimulus Circuit and Bi-directional Output

To cause contractions in the small intestine, the strength duration (SD) curve is necessary to determine the proper stimulus parameters. Referring to the SD curve, the duration of stimulus has to be more than 2msec, but still the intensity is unknown. To find the best the stimulus parameters, the smallest boost converter is used, and...
shown in fig 3. The value of the tank capacitor C3 is determined to hold voltage more than 2msec.

To save power consumption, we did not use pulse width modulation to control the boost voltage, which cause periodic power consumption. To prevent periodic power consumption, an analog to digital converter (ADC) is connected to the tank capacitor and the voltage is checked to determine whether to activate the boost converter or not.

Fig. 4. Modified the boost converter.

After charging the electrical energy at the tank capacitor, the capsule transmits the energy to one side of stimulus electrodes to control the direction of movement. To transmit the stimulus to each side of electrodes, an H-bridge circuit is used.

2.4 Controller for Electrical Stimulus

Implemented the stimuli capsule is working following flowchart, which is shown in fig. 5. To save the battery after the capsule was sealed; the capsule goes on standby mode that consumes only 500nA, and waits for the reset signal from the stimulus electrodes. After the user resets the controller, it checks the start signal from the RF receiver.

If the capsule received a start signal, then the controller activates the boost converter until the target voltage is charged at the tank capacitor. Then the capsule transmits the charged energy to the small intestine with various stimuli parameters, as shown in fig. 6.

2.5 Communication Protocol and Decoder Algorithm

To make stable communication for on off keying (OOK) receiver, the Manchester code is chosen to prevent inter symbol interface, also the address and the modified CRC-3 are chosen, and as shown in fig 7.

Fig 8 shows the flowchart of the decoder. First, to save the battery, the controller turns on the RF receiver periodically, and synchronizes itself by tracking null code, and then determines whether address data is received. After all data are received, the microcontroller compares the electrical parameters and CRC-3 to determine whether the received data are correct. If the received data are correct, the microcontroller disables the receiver and enables it at the next stimulus rest period to save the battery.

There are several methods to porting CRC-3 to the microcontroller, but making a look-up table is the most appropriate method for save the battery and reducing CPU utilization. However, a look-up table for the 13 bits data signal is 8192 bytes which is impossible to put in the small microcontroller due to limited memory size. Therefore, it is necessary to make 256 bytes look-up table for 8 bits data, and then calculate CRC-3 twice, and then decide modified CRC-3. The modified CRC-3 is shown at fig. 9.

Fig. 5. The flowchart of the microcontroller.

Fig. 6. Controllable electrical stimuli parameters.

Fig. 7. The protocol of wireless communication.
2.6 Standby Mode to Save the Battery and an External Case

Once the total circuit is sealed, the receiver consumes power periodically. To make the capsule in standby mode at await situation, and activate the capsule at experiment, the external stimulus electrodes are connected to a comparator circuit, as shown in Fig. 10. If RF signals are not received by the microcontroller, it goes on standby mode, which only consumes 0.5 μA. The two stimulus electrodes are connected to the comparator and reset the controller when the opposite voltage is induced. To prevent reset by power line interface, the external case provides 3.3V to the stimulus electrodes, to maintain standby mode, and -3.3V to activate the capsule.

3. The Implemented System

In this paper, an electrical stimuli capsule which can improve the moving speed of a capsule and control its moving direction was designed and implemented. Fig. 11 shows the implemented modules which are 9.5mm in diameter, and implemented the stimuli capsule’s diameter is 11mm and length is 21mm, as shown Fig. 12 (a). Also Fig. 12 (b) shows implemented the external controller and (c) shows the external case for preventing reset from the various noises. Fig. 13 shows an example of the stimuli pattern, which can cause contraction in the small intestine.

Fig. 8. Flowchart of the decoder.

Fig. 9. Modified CRC-3 block diagram.

Fig. 10. The circuit for the reset circuit.

Fig. 11. Implemented the modules; (a) the boost circuit and decoder, (b) the H-bridge, (c) the 433 MHz receiver, (d) the 433 MHz transmitter for external controller, (e) the assembled modules and battery.
The implemented capsule consumes only 4.6 mA (20 V, load resistor is 1 kΩ) at active time, and 0.7 mA for resting time while RF receiver is periodically active. Consequently, the capsule can active more than 15 hours, when using two silver-oxide button cells (60 mAh), which is sufficient time to pass the small intestine.

4. The In-vitro Experiment and Conclusion

To test the electrical stimuli capsule, a bath for in-vitro was prepared to reactivate the small intestine. Fig. 14 shows a bath for in-vitro experiment which contains Krebs’ solution. After several times waiting for stable the small intestine, we sorted out the bad sample, and then the stimuli capsule was inserted to the small intestine and test it for various stimulation patterns, including frequency, amplitude, and turn-on period.

Fig. 15 shows the dramatically improved moving speed of the capsule and can control the direction by electrical stimulus. The table 1 presents the result of the experiment. From the experiment, electrical stimulation can increase speed at normal direction, and it can go backward in the small intestine with a slower speed than normal direction.

From the in-vitro experiment, we deduce that an electrical stimulus can improve the moving speed, and can control the direction of the capsule. However, more experiments are needed to determine the exact relationship between the electrical stimulus and the moving speed of the capsule. To investigate this relation, not only in-vitro experiments but also in-vivo experiments are needed.
Table 1. Successful results of in-vitro experiments

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Sample condition</th>
<th>Stimulus Width</th>
<th>Stimulus frequency</th>
<th>Speed</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>30V</td>
<td>Excellent</td>
<td>25ms</td>
<td>300ms</td>
<td>12cm/min</td>
<td>Right</td>
</tr>
<tr>
<td>20V</td>
<td>Excellent</td>
<td>25ms</td>
<td>300ms</td>
<td>6cm/min</td>
<td>Right</td>
</tr>
<tr>
<td>30V</td>
<td>Good</td>
<td>25ms</td>
<td>300ms</td>
<td>7cm/min</td>
<td>Left</td>
</tr>
<tr>
<td>25V</td>
<td>Good</td>
<td>50ms</td>
<td>300ms</td>
<td>3cm/min</td>
<td>Left</td>
</tr>
<tr>
<td>30V</td>
<td>Not bad</td>
<td>50ms</td>
<td>300ms</td>
<td>4cm/min</td>
<td>Left</td>
</tr>
<tr>
<td>30V</td>
<td>Not bad</td>
<td>77ms</td>
<td>300ms</td>
<td>3cm/min</td>
<td>Right</td>
</tr>
</tbody>
</table>

Acknowledgements

This research has been supported by the Intelligent Microsystem Center(IMC; http://www.microsystem.re.kr), which carries out one of the 21st century's Frontier R&D Projects sponsored by the Korea Ministry Of Commerce, Industry and Energy.

References