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Original research

Application of wireless electrical non-fiberoptic endoscope: Potential benefit and limitation in endoscopic surgery



Chih-Hao Chen ^{a, b, c, d, *}, Ho Chang ^{b, *}, Tsang-Pai Liu ^{a, d}, Tun-Sung Huang ^d,
Chao-Hung Chen ^{a, c}

^a Department of Medicine, Mackay Medical College, Taipei City, Taiwan

^b Graduate Institute of Mechanical and Electrical Engineering, National Taipei University of Technology, Taipei City, Taiwan

^c Department of Thoracic Surgery, Mackay Memorial Hospital, Taipei City, Taiwan

^d Department of General Surgery, Mackay Memorial Hospital, Taipei City, Taiwan

HIGHLIGHTS

- Initial application of wireless device into endoscope.
- Durability, feasibility and stability were tested and results were excellent.
- The device will extend the endoscope in regions other than the operative room.

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ABSTRACT

Introduction: Conventional rigid endoscope requires a bundle of optic fibers for illumination and a set of camera for viewing body cavity. The design is bulky in the hand-held part and the laterally positioned optic fibers may hinder manipulation of instruments, especially in single port surgery. We designed a simplified unit to replace conventional endoscope.

Materials and methods: We used an independent front image sensor along with six light emitting diode crystals. A wireless module working in 2.4 GHz and its antenna were integrated into the hand-help part. Two 800 mA batteries were used for power supply. The study was tested in two 35 kg pigs. Some simple thoracoscopic and laparoscopic operations were simulated to test the reliability and surgeon's acceptability.

Results: Signal Noise ratio can be controlled well in the setting of the operative room. Signal transmission was influenced significantly when covered by damped gauze or drape. The best quality of wireless transmission is through line-of-sight. Dropping frame is less than 1 frame per second in 99% time period during the test.

Conclusion: Wireless modules in the design of rigid endoscope may be a plausible option with good acceptability.

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1. Introduction

Endoscopic surgery is a popular approach in many fields of surgery in the present time. Therefore, the endoscope plays a major role in performing any endoscopic procedure. Currently, rigid endoscope that is composing of rod lens is the most common form

used in clinical practice. Conventional design of the rigid endoscope consists of long rod lens in the shaft and there are two connections in the hand-held part. One connection is for a camera and the other connection is for a bundle of optic fibers. The benefits of the conventional design are reliable lightening, clear field-of-view and good orientation. However, the design also limits some forms of single incision endoscopic surgery because the bulky size and laterally positioned optic fibers can interfere with other instruments. Camera and connecting cables as well as the video system are considered limitation for portability. In addition, optic fibers can be broken and causing efficiency of lightening declined

* Corresponding authors. No. 92, Section 2, Chung Shan North Road, Taipei City, Taiwan.

E-mail addresses: musclenet2003@yahoo.com.tw (C.-H. Chen), f10381@ntut.edu.tw (H. Chang).

with time. The effect is more prominently seen when surgery performed with a smaller rigid endoscope, such as 5 mm and 3 mm endoscope.

Connection with wires and cables greatly limits the use of endoscope in environments outside the operative room. In some simple procedures or inspection, such as pleural effusion or pleural biopsy, bedside procedure is an option. However, we can't perform simple procedure without endoscope and its whole set. Therefore, portability of rigid endoscope and video system is limited for bedside use.

Current study is an extension of our previous design of electrical non-fiberoptic endoscope [1,2]. In the study, we simplify the design by integrating the wireless module, antenna and the battery into the hand-help part of the endoscope. The feasibility and influencing environmental factors in the operative room were evaluated.

2. Material and method

The basic components of the electrical non-fiberoptic endoscope consist of four parts, including an independent image sensor module, light-emitting diode (LED) crystals, rigid body and a hand-held part (Fig. 1A). The overall design is straightforward and can be used as a conventional rigid endoscope. The basic circuits were assigned as in Fig. 1B.

The image sensor is a complementary metal-oxide semiconductor (CMOS) sensor with a resolution of 720 pixels vertically and 480 pixels horizontally. The refreshing rate is 30 frames per second under the working voltage of 5 V. The field of view is 60° in both vertical and horizontal axis. We placed six LED crystals in the tip of the image sensor for lightening purpose. The current to each LED crystal was set to be 18 mA. The body of the rigid part is made of aluminum material in order to improve heat dissipation.

In the hand-held part of the rigid endoscope, we used plastic materials to enclose all the required units, including the battery, wireless chip, circuits and the antenna. The signal transmission chip is analogue and working through 2.4 GHz. The transmission chip consumes minimal current around 50 mA under 12 dB output. The size was quite small measuring around 27.8 mm × 28.5 mm. The signal receiver was placed within 5 m and was consistently kept in line-of-sight. In order to keep stable working status, we used a fixed-output regulator to reinforce stable voltage and current output in more than 95% period. The transmission and receiver chips can negotiate quickly to establish connection using a certain channel.

The animal study was performed in the animal study center in our institution. The study protocol was reviewed and approved by the ethical committee of animal center. The tested pigs weighted around 35 kg. They were given intramuscular muscle relaxant followed by oral endotracheal intubation and adequate fixation on the operative table. The tested environment was in the peritoneal cavity and in the pleural cavity. In the end of the procedures, the tested animal would be sacrificed by a bolus intra-cardiac injection of potassium chloride. The tested procedures included simple thoracoscopic exploration and laparoscopic exploration and for simple dissection of the diaphragm, peritoneum and some visceral

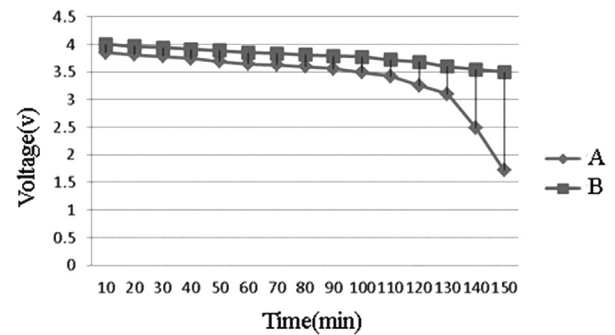


Fig. 2. The curve showed that if there is no fixed output regulator (curved A), the working voltage would decline more quickly. Stable working voltage is seen in curved B because there is a fixed output regulator, which can support stable wireless signal transmission.

organs. Electrical cautery would also be used to check for any influence on signal transmission. All the procedures were performed by a single surgeon.

The end points of the animal study were the feasibility of using wireless endoscope, the benefits compared to conventional rigid endoscope, and stability of image transmission during operation.

3. Results

The tested parameters and variables were evaluated before animal study. When there was no fixed output regulator in wireless transmission, the working voltage would become unstable after working for a certain period of time (Fig. 2). After adding a fixed output regulator, the working voltage would be more stable before the battery is depleted. A single 800 mA battery could provide at least 2-hr working time. In the study prototype, we used two batteries. Therefore, the durability supported by the system can sustain for at least 4–4.5 h, which is enough for most endoscopic procedures.

The lightening efficiency and temperature exerted in the tip of endoscope are major issues for safety as emphasized in Food and Drug Administration 510 K guidance for conventional endoscope. According to the guidance, the tip of the endoscope should be kept less than 50 Celsius degrees. The wireless ENFE prototype could provide 1200 Lux at a distance of 5 cm (Fig. 3A). The temperature in the tip of wireless ENFE fluctuated from 40 to 47 Celsius degree (Fig. 3B). The measurement was recorded outside the body cavity. The measurement of the tip of the wireless ENFE was performed by non-contact method.

In order to evaluate the commonly encountered factors that may have influences on the stability of signal transmission. We used dry drape and damped drape to cover the signal transmission chip and antenna to simulate the conditions in the operative room because water or high water content barrier is the most powerful shielding effect in wireless transmission. Fig. 4 showed the path loss in each scenario. Among the different scenarios, transmission chip without any drape had least path loss and the chip covered by damped

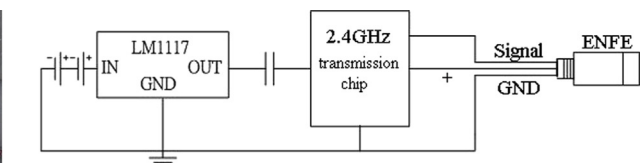


Fig. 1. The overall appearance of wireless ENFE showed that there is no additional connection (A) The circuits design is very straightforward (B).

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