Optik 126 (2015) 1277–1281

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Development of an electronic endoscope for the diagnosis of uterine diseases without anesthetics

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ARTICLE INFO

Article history:
Received 20 October 2013
Accepted 31 May 2014

Keywords:
Medical electronic endoscope
Extreme wide-angle optical imaging system
Diagnosis of uterine diseases

ABSTRACT

A medical electronic endoscope with an outside diameter of 4.5 mm was developed for uterine cavity lesions examination without anesthetics. The electronic endoscope, with a flexible head of 270° turning angle and an optical imaging system of 100° field angle, realizes non-blind spot diagnosis. The effective focus length of the optical imaging system is 1.2 mm, the depth of field 10–100 mm, the maximum field curvature 0.1 mm, and the resolution capability of image system 145 cycles/mm. CCD image sensor is with a diagonal dimension of 1/10 in. and SVGA display model of 500 × 580 pixels. The illumination system uses the crescent-shaped optical fiber bundle as light transmission and metal halide lamps, high illuminance and high color temperature, as light source. Filter denoise, image enhancement and distortion correction are performed on video image to get a clear, distortionless and high resolution image where blood vessels and tissue morphology of uterine are displayed in real time. The medical electronic endoscope can offer doctors an effective means and reliable bases to early diagnose uterine diseases, especially early-stage malignant tumors.

1. Introduction

Medical electronic endoscope plays an important role in clinic. When medical electronic endoscope is inserted into human body doctors can directly observe the tissue morphology and pathological changes of the body cavity and internal organs. Therefore the disease can be easily and accurately diagnosed with endoscope [1,2]. In addition, compared with the traditional open surgery, minimally invasive surgery with medical electronic endoscope possesses the advantages of little damage, light pain and quick recovery [3,4]. The diagnosis and treatment advantages of medical electronic endoscope have become the general consensus of the medical profession.

The development history of medical endoscope experiences three periods: rigid endoscope, fiber endoscope and electronic endoscope. Rigid endoscope transmits image with lens group and fiber endoscope with optical fiber bundle, which belong to optical endoscope. In 1983, the optical fiber and rigid tube of endoscope image transmission were replaced by the image sensors of charge couple device (CCD) researched and produced by Welchallyn Company of American, which declared the birth of electronic endoscope and realized the historic breakthrough of endoscope. The principle of electronic endoscope is that object is imaged on the photosensitive surface of CCD by the objective lens and CCD converts light signals into electrical ones which are transmitted into the video processor by cable and displayed on the monitor, and then high definition and vivid image is reconstructed from electrical signals by digital image processor (DSP). The image quality directly influences the application of endoscope and also marks the development process of the endoscope technology. Generally, fiber endoscope resolution is 20,000 pixels, but the resolution of the electronic endoscope is 20 times of fiber endoscope so that image quality of electronic endoscope is greatly improved. Electronic endoscope image is more clear, bright, vivid, and has higher resolution and signal-to-noise ratio than fiber endoscope. By means of electronic endoscope doctors can find the pathological changes undetected with fiber endoscope, which improves detectable rate of diseases, especially of early stage tumor [5–8]. Moreover, the suffering of the patients can be relieved because of small outside diameter of electronic endoscope. Hence, electronic endoscope is being applied more and more widely in the clinical medicine [9].

One of the most important application fields of electronic endoscope is the early diagnosis of various malignant tumours in womb, including cervical cancer, ovarian cancer, endometrium cancer and

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http://dx.doi.org/10.1016/j.ijleo.2014.07.035
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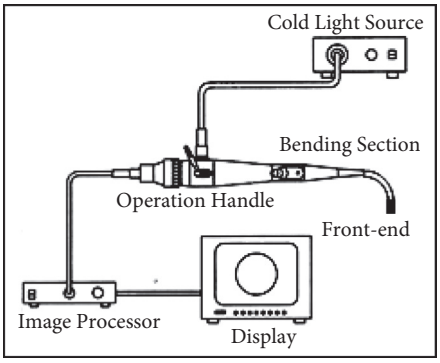

Fig. 1. Overall structure schematic drawing of electronic endoscope.

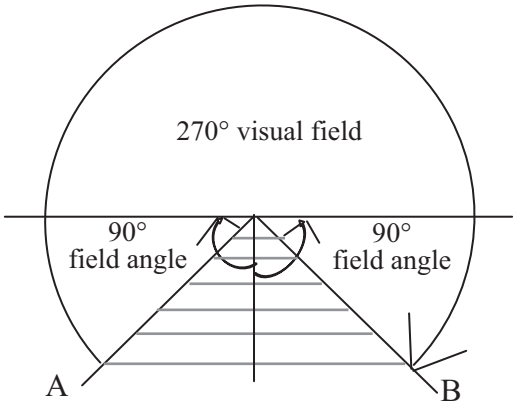

Fig. 2. The field of view of electronic endoscope.

so on [10–12]. The incidence of malignant tumour in womb is the second most common cancer in women worldwide. These malignancies in the uterus are diagnosed mainly with ultrasound and electronic endoscope. Ultrasonography cannot directly show the morphological changes but mainly depends on doctors' experience. The biopsy under electronic endoscope is more and more applied in early diagnosis of malignant tumour in womb, because the size, shape and extent of the tumor can be observed under direct vision [13–15]. However, if the outer diameter of the rigid part inserted into human exceeds the limit of 8 mm without anesthesia, electronic endoscope is not fitting to purely diagnose early cancer in womb. Rogerson compared the accuracy of hysterosonography with hysteroscopy in diagnosing uterus diseases [16]. The research result shows that the failure rate of hysterosonography is 17% while hysteroscopy only 0.85%. But due to large outside diameter, the hysteroscope examination requires cervical dilation which causing great pain. So hysteroscopy should be performed only when hysterosonography cannot definitely diagnose uterus lesions. In 2003, a celiac–thorax electronic endoscope with 80° field of view and rigid outer diameter of 10 mm was produced by Fujinon Company. Because of its bland area and the outer diameter larger than 8 mm, anesthesia is necessary when it is used in uterus examination, which only suitable for surgery. In 2004, a kind of flexible-head celiac-thorax electronic endoscope with 90° field angle was made by Olympus Company. Although non-blind spot can be get, the outer diameter of 9.2 mm restricts the application in early diagnosis for womb cancer. The ZJ-6000 type electronic endoscope with 6.4 mm outer diameter, but the field of view is 22° which has a big dead zone.

To satisfy the requirements of the diagnosis of uterine cavity lesions without anesthesia, this paper developed a low distortion, high-definition and non-blind medical electronic endoscope with an outside diameter of 4.5 mm, which included a high resolution, smaller-caliber and 100° extreme wide-angle optical imaging system, an illumination system with cold light source, an image processing system for image enhancement, edge sharpening and distortion correction.

2. Optical imaging system

The overall structure of electronic endoscope is shown in Fig. 1. It mainly includes the front end (composed of a CCD image sensor, an optical imaging system and an illumination system), the moving parts with a flexible head of 270° turning angle, an operating handle, an image processing system, a network transmission system.

The core part of electronic endoscope consists in optical imaging system, illumination system and CCD image sensor installed in the front end of the electronic endoscope. The images of tissues and organs are transmitted to displays outside human body in electrical signals. For this reason, the rigid outside diameter dimensions of the electronic endoscope are determined by that of optical imaging system and CCD image sensor. To obtain super-slender diameter and high definition electronic endoscope, the selected CCD should be with small size, high pixel and the designed optical imaging system with thin outer diameter, high resolution. At present the minimum diagonal size of CCD can reach 1/8 in., even 1/10 in., while its number of pixels is from hundreds of thousands to millions. Thus, the key part is the design and fabrication of the small outer diameter and high resolution optical imaging system.

2.1. Requirements for the optical imaging system

(1) Aperture size of the lens

Because the developed electronic endoscope is mainly used for the diagnosis of uterine lesions without anesthesia, its outer diameter should be no bigger than 8 mm and as small as possible, which is designated as 4.5 mm. The chosen CCD image sensor size is 1/10 in. along a diagonal and chip size 2.00 mm (H) × 2.00 mm (V). The diameter of the lens is 2–2.8 mm to match the chip size, that is 2 mm and 2.8 mm corresponding to maximum inscribed and minimum circumscribed around the chip, respectively.

(2) Field angle

Fig. 2 shows the field of view of electronic endoscope. The maximum bending angle of the endoscope flexible head is 270° and point A and point B are the two edges of the angle respectively. In order to realize non-blind spot diagnosis the field angle of the optical imaging system should be larger than 90°.

(3) Clear aperture

The larger the aperture, the brighter the image is, for getting high-brightness image the F-number of the optical imaging system is among 3.8–4.4.

(4) Spatial resolution

The 1/10 in. CCD image sensor is with SVGA display model of 580 (horizontal) × 500 (vertical) pixels and the unit cell size 2.90 μm (H) × 2.25 μm (V). Its spatial resolution is about 145 cycles/mm. To satisfy the requirement of CCD resolution, the spatial resolution of optical image system cannot less than 145 cycles/mm.

(5) Distortion of optical imaging system