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High Resolution Miniaturized CMOS Camera Module for Medical Electronic Endoscope

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Abstract: A novel miniaturized camera module with 1.3 megapixels for electronic endoscope is developed and presented. This module realizes long-distance and high-fidelity transmission of image data adopting Low-Voltage Differential Signaling technology. It includes a 1/5.5 inch CMOS image sensor with a resolution of 1 280×1 024 $pixel^2$, a small integrated lens with field of view of 140° and two electric circuit boards. The lens fixed with inner screw thread is cemented directly onto the non-optical part of the image sensor′s surface. Two printed circuit boards are assembled vertically, which reduces the size of the module down to 5.5 mm in width, 5.2 mm in height and 15.0 mm in length. The 10-bit parallel digital signals are encoded into low-voltage differential signals before they are output through a twisted pair. A demonstration system is developed to evaluate the performance of the camera module. Experimental results show that the module′s resolution reaches to 136 lp · mm^{-1}, and the image transmission length is over 2 meters. The compact size, high resolution image, wide field of view and long-distance transmission enable the camera module to be used in video endoscopy, especially for HDTV gastroscopes and colonoscopes.

Key words: CMOS Camera module; Miniaturization; HDTV endoscopy

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0 Introduction

Visualization of the health status of organs is a vital task in medical diagnosis and therapy. Medical electronic endoscopes (MEE) are modern devices for this purpose. High definition television (HDTV) endoscopy[1-3] enhances the quality of visualization and has brought doctors′ view onto the mucosa. Its better resolution provides essential indications for doctors to be aware of patients′ health status and diagnose their health problems accurately and quickly. On the other hand, endoscopic inspection needs an endoscope to be inserted into the human body through a natural orifice, which is a painful procedure. In order to diagnose in a safe and well-tolerated manner, narrow diameter is very important in endoscopic imaging. With the development of microelectronics and other techniques, several miniaturized camera devices have been demonstrated under the trade-off between the resolution and the dimensions.

D. Covi et al.[4] designed a CMOS based camera module for disposable endoscopic application and minimally invasive surgery. The device with the size of 5.0×8.2×7.0 mm^3 and VGA resolution had been tested on a porcine model. A consortium in the project IVP[5] developed a video probe whose diameter equals to 3.5 mm. The camera utilized a size reduced color image sensor with outer dimensions of 1.7×1.3 mm^2 and a resolution of 36,000 pixels. WANG Li-qiang et al.[6] presented an image pick-up module for an endoscope using a 1/18 inch CMOS image sensor (CIS); its resolution is only 76,800 pixels. YE Bin et al.[7] designed an image acquisition system for electronic endoscope basing on a CIS camera module of 1.3 megapixels. But the system was 10 mm in diameter and 85 mm in length. Researchers are making great efforts in optimizing CMOS imaging module for MEE and other miniature instruments.

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Although the CISs are reported in above situations, all of the HDTV endoscopes currently available are based on CCD image sensors[8-10]. The available CMOS image modules for HDTV endoscopy suffer from two major problems. Firstly, the typical size with 1.3 megapixels is above 6.5×6.5 mm^2 without related circuit boards and connectors, which makes it difficult to be integrated in an endoscope with distal end diameter under 13 mm. Secondly, the video transmission distance is shorter than 30 cm, which makes it impossible to be used in an endoscope with more than 1 meter working length.

In order to address the two problems above and design new HDTV endoscopes employing CMOS sensors, a new miniaturized camera module, especially for gastroscope and colonoscope applications, is developed. Its working length increases to 2 meters through Low-Voltage Differential Signaling (LVDS) codec method[11]. It includes a 1/5.5 inch CIS (1.3 megapixels), a small integrated lens with field of view (FOV) of 140° and two electric circuit boards. Size of the module is reduced to 5.5 mm in width, 5.2 mm in height and 15.0 mm in length, 33% thinner than current camera modules with the same CIS. A prototype of the module has been built up to evaluate the preliminary performance.

1 Camera module

Compared to the well known CCDs, CISs have advantages in on-chip functionality, power reduction, low cost and miniaturization[12]. This camera module is based on OV9660 (Omnivision), with 1 280×1 024 effective pixels and 4.5×5.0 mm^2 package size. It needs clock signal and 2.45-V to 3.0-V DC power supply to drive the image signal out. The serial camera control bus (SCCB) interface provides flexibility in image processing functions, such as exposure control, gamma correction, color saturation and defect pixel canceling. The features above make it an ideal solution for low-cost applications requiring high-resolution image and a small package.

An integrated objective lens is designed to focus the light reflected from mucosa onto the CIS. Small size, wide FOV and low aberrations should be satisfied in endoscopic imaging. Six pieces of elements are incorporated for objective lens to measure up to the requirements mentioned, as shown in Fig. 1. The lens is 6.5 mm in depth and 4.0 mm in diameter. The FOV is 140°.

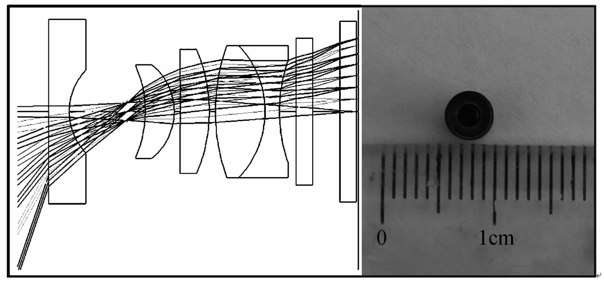

Fig. 1 Optical layout and picture of the integrated lens

Because the video output format is 8-bit digital parallel data, the transmission distance is under 30 cm. In order to increase this distance to 2 meters, LVDS codec is used in the camera module, which guarantees the long-range signal integrity for the image data stream. A point-to-point LVDS topology shown in Fig. 2 is the manner adopted in our system. The driver contained in the serializer has a nominal 3.5 mA current source which flows through the 100Ω termination resistor and produces a nominal 350 mV voltage across the resistor at the receiver end. Changing the current direction results in the same amplitude but opposite polarity at the receiver, in which logic ones and zeros are generated. And the appropriate receiver threshold provides excellent noise margins and tolerance to common-mode shifts between the driver and receiver[11]. The original 8-bit digital signals and sync timing outputs from the CIS are transformed into serial signal firstly and then encoded into differential pairs signal by the LVDS serializer. At the remote end, the deserializer chip recovers the parallel signals from the LVDS with excellent noise immunity. In order to reduce the noise further, transmission lines for differential signal should be a twisted pair.

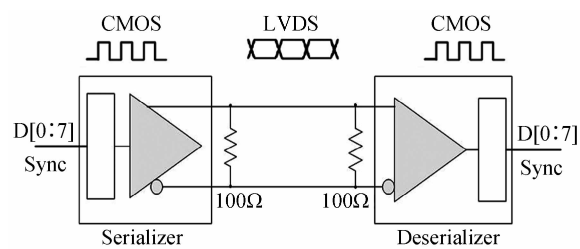

Fig. 2 Point-to-point LVDS topology

The whole camera module (Fig. 3) consists of two printed circuit board (PCB) substrates. The dies of the CIS are attached directly on one side of the first PCB substrate with the LVDS encoder chip on the other side of the same PCB. The clock oscillator attached on the second PCB outputs 24 MHz clock signal for the required timing of CIS. Two PCBs are fixed together vertically to reduce the cross size of the module. A lens seat with inner screw thread is cemented onto the non-optical part of the CIS surface. Then the lens is assembled by the thread to realize focusing. The first prototype has the dimensions of $5.5\times5.2\times15.0\ mm^3$, including the lens and two PCBs with electronic components. The entire module has a cable bundled by nine wires of LVDS pairs, power, and SCCB pairs. This enables 33% thinner camera module and 2 meters longer working length, meeting the requirements of HDTV endoscopy designs.

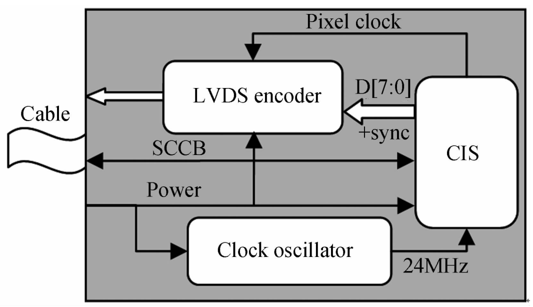

Fig. 3 Block diagram of the camera module

2 Demonstration system

A demonstration system shown in Fig. 4 has developed to evaluate the performance of the camera module in practice, which contains a receiver board, a data acquisition card and a computer. Data stream from the camera module is decoded into 8-bit digital signals and sync signals by an LVDS decoder. Then the raw data are transferred into the acquisition card on the computer and displayed on a monitor. The clock oscillator outputs 24 MHz clock signal, which is as the same as that of the camera module, for the LVDS decoder. The microcontroller provides SCCB to set registers of the CIS including exposure control, gamma correction, color saturation, defect pixel canceling, etc. The power module

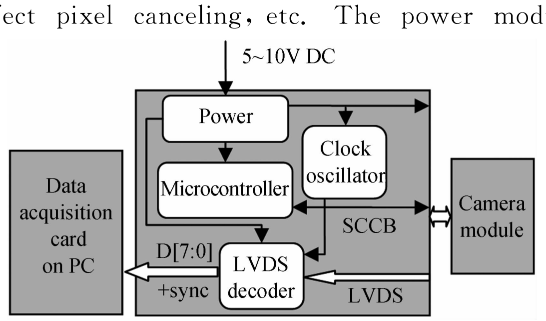

Fig. 4 Hardware structure of the demonstration system

composed of three low-dropout linear regulators converts any voltages between 5-V and 10-V input to 2.5-V, 2.85-V and 3.3-V fixed output respectively. The camera module is powered by 2.5-V and 2.85-V voltages and other components are powered by 3.3-V output.

Specially designed driver software for the acquisition card runs on the computer to read and display the raw image in the buffer. Because the CIS is covered by a Bayer pattern color filter array (CFA), the color information is restored by the software after extracting the valid raw data. Other procedures like lens distortion compensation, white balance, and other post-processing measurements are performed to obtain excellent image quality by the software too.

3 Camera module implementation and experimental results

The presented camera module is shown in Fig. 5. It is connected to the receiver board through a 2 m-long cable which is enough for a regular MEE. The acquisition card installed on the computer acquires decoded video data. The receiver board and the camera are powered by one single 5-V DC power source. Experiments have been carried out under the condition of incandescent lighting. The performance of the miniaturized camera module was evaluated utilizing the 1951 USAF resolution target.

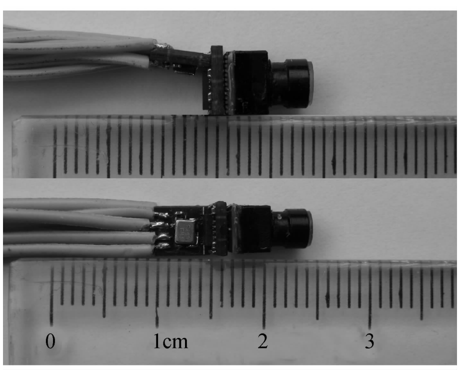

Fig. 5 The first prototype of the camera module

Fig. 6 is one frame of the acquired video of the resolution target. This image was acquired when the camera was located at a distance of 100 mm from the target. After testing three camera devices, the FOV is 135°~140° and the resolution of the system is 110 ~136 $lp\cdot mm^{-1}$. The low-noise and good focusing grayscale image in Fig. 6 is constructed by the raw data without any

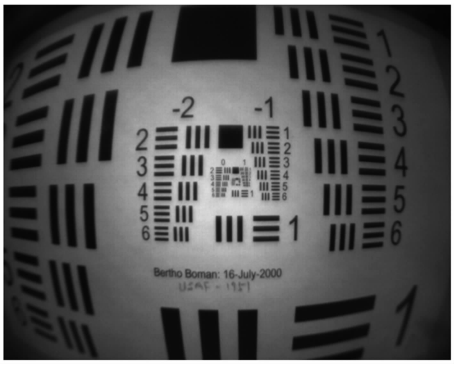

Fig. 6　Captured image of the 1951 USAF resolution target (at 100 mm distance)

processing. The experiments indicate that it is feasible to use the proposed camera module in an HDTV MEE.

4　Conclusion

A new miniaturized high-definition CMOS camera module has been presented in this paper. It is designed for the HDTV MEE and also suitable for many other applications, such as machine vision, security surveillance and industrial detection. The camera module is characterized by LVDS technology, a CIS with SXGA resolution, a small integrated lens and specially developed PCB substrates layout. Size of the camera tip is $5.5\times5.2\times15.0\ mm^3$ and the FOV is $140°$. We will embed the camera module into the distal tip of an electronic endoscope and do in-vivo tests first, then explore applications in other fields.

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高清医用电子内窥镜微型CMOS摄像模组

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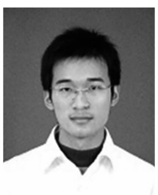
摘　要:研发并报道一个全新的130万像素电子内窥镜微型摄像模组.该模组采用低压差分信号技术实现图像数据的长距离高保真传输,它包括一个1/5.5英寸、分辨率为1 280×1 024像素的CMOS图像传感器,一个视场角为140°的小型镜头以及2个电路板.小型镜头座直接粘合到图像传感器的非光学窗口部分,两块印刷电路板垂直装配,使模组的尺寸缩小到长宽高分别为15.0 mm、5.5 mm、5.2 mm的空间.编码芯片将并行数字信号编码成低压差分信号经双绞线传出模组.搭建了实验系统并对摄像模组的实践性能进行评价.实验表明:模组分辨率达到136 lp·mm^{-1},图像传输距离达到2 m以上.紧凑的结构、高清分辨率图像、大视场和长传输距离使其适用于内窥镜诊治,特别是高清胃镜和结肠镜.

关键词:CMOS摄像模组;微型化;高清电子内窥镜



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