Design and Development of a Low Cost Video Bronchoscope

Submitted by:

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College of Engineering, Guindy

Anna University, Chennai

Our Team for TI Analog Design contest

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Acknowledgement

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We express our thanks to **Mr. N. Kumaravel, Head of the Department** for providing us infrastructure and other sophisticated equipments needed for testing the system.

We hereby take the opportunity to thank **Mr. Senthil Kumar , Researcher** in the Integrated Systems Laboratory for providing time to time suggestions and critical reviews .

We also take this opportunity to thank all the doctors of Stanley Medical College for their support and their wisdom imparted to us throughout the contest.

We thank **Mr. Shankar , Professor , Department of Physics** for giving us this opportunity to work with.

We thank our parents, friends, and family for bearing with us throughout the course of our project.

M. Aravind Krishnan **S. Ganapathy** **N. Hari Prasad**

Abstract

The aim of this project was to build a complete video bronchoscope system without the use of fibre optic cables, thereby trying to make it both low-cost and portable in nature. During the course of the project, the distal and the frontal electronic modules were successfully built and tested. The primary idea of the project is to build the electronics of a bronchoscope conforming to constraints of size as required by commercial bronchoscopes while reducing the cost of the unit device. The device also is needed to provide a real time clear video of the insides of the human airways under conditions of very low illumination. The system should also have the provision to record and store videos of the invasive procedure for future diagnosis. For these purposes a very small video sensor (about 2 mm in diameter) was accompanied by a small (1.5 mm) LED that formed the distal tip of the bronchoscope, and the output video was compressed to an mpeg4 format for efficient categorization. The bronchoscope was able to provide a clear image of objects placed within a close range of the bronchoscope. Image processing algorithms such as periodic noise reduction were implemented to improve the quality of the video obtained from the distal end of the bronchoscope.

Introduction:

A bronchoscope is a non-invasive device used to provide a clear image of the internal respiratory system. The bronchoscope can be used for both diagnostic purposes such as detection of pulmonary tumors and other diseases or for surgical purposes like administration of general anesthesia and for endoscopic surgeries. Bronchoscopes are of primarily two types viz. The fiber-optic bronchoscope and the video bronchoscope. The former uses a fiber-optic cable while the latter uses an electronic image sensor like CCD or CMOS camera. The major disadvantage with the fiber-optic bronchoscope is that the fiber-optic cable bundle used is extremely fragile and its cost is also high. Video bronchoscopes, on the other hand provide a less-expensive but equally efficient solution for imaging the airways. So, it was decided to build a low-cost video bronchoscope which efficient and portable. A general schematic of the conventional fibre optic bronchoscope is shown in Fig 1.

Fig 1 A Fibre Optic Bronchoscope

They are mainly used for administering anesthesia, picking cancerous cells for biopsy, and seeing the inside of trachea for other clinical analyses.

Motivation:

In the year 2009, Mr. Shankar, a Professor from the Physics Department of College of Engineering, Guindy had a chance to meet a professor from the department of anaesthesia from the Stanley Medical College, Chennai. The doctor from Stanley had a brief discussion about the existing bronchoscopes and their demerits. The doctor has told that there is a need for a device that is long standing. So, Mr. Shankar brought this to the notice of Dr. P.V. Ramakrishna, Professor Dept of Electronics and Communication Engineering at the College of Engineering, Guindy. So, myself (Hari Prasad) and Aravind Krishnan, who were working in the Integrated Systems Laboratory were asked to make a brief presentation at the Stanley Medical College before the team of doctors. We were shown demonstrations on how does an actual bronchoscope used. The doctor there told us that there were 5 bronchoscopes, of which only two were working properly and had to be used for the entire hospital. The other three bronchoscopes were useless because of the reason that the fibre inside was broken. So the doctors told it would be good if the fibre were eliminated. Also the doctors found it difficult with the existing system having only two degrees of freedom. If the doctors wanted to navigate in the other two directions he must turn it 90 degree. So, the doctors suggested a system with four degrees of freedom rather than two. Also, they said that the Phlegm accumulates at the tip and hampers the doctor's vision so they said there is a need for a Wiper arrangement. We were also shown some videos on the way doctors actually navigate the device.

The work was started in March 2009 with some reference papers and designs keeping in mind the doctor's suggestions. By May 2009, we came to know about the TI Analog Design Contest for Indian Universities. So we submitted our design and our abstract got selected and we started working on it

System Requirements :

The system requirements are those issues which need to be addressed for the effective functioning of the basic system. Some issues of primary concern are the replacement of fibre with electrical cables, real time output and low cost. Some of the basic requirements are shown in table 1.

S No.	System Requirement	Degree of Importance from user view point on a scale of 5
1.	Detect tissues of almost similar colour distinctly i.e clarity	5
2.	Bio compatibility	4
3.	Cost	3
4.	Size	2
5.	Additional features	1

Table 1: System Requirements

Constraints:

The various constraints in achieving these above mentioned system requirements are mentioned below:

1)Clarity of Image i.e. better resolution cameras which increases the cost of the image sensor

Image sensor, being the heart of the system, any increase in its cost produces a significant increase in the cost of the system.

2)Choice of Bio-compatible materials are to be made with careful examination and suggestions from the medical people

3)Cost is the primary factor and increased demands in quality increases the cost significantly

Size of the system should be small so that the doctors find it handy to use. So, the electronics should be carefully located.

4)Additional features like wiper arrangement for reducing the red effect, giving the distal tip four degrees of freedom, etc increase the cost.

Design Concept:

The basic design concept of the system includes the camera chip or the image sensor and an LED or light source only at the distal tip with a diameter of 3mm. So that the device can penetrate upto the second level of bronchi. The essential idea of our design is to minimize the electronics at the distal tip. Thus the system consists of the CMOS Image sensor OV6920 and White SMT LED for illumination. The video captured are sent via very fine coax after preliminary processing. The output image appears to have periodic noise along the x-axis and green colouration. Thus the video obtained is made noise free with the help of DM355 processor programmed with iPIPE. The final image obtained is viewed in a hand held LCD.

The design concept must address the following factors:

S.No	Parameter
1.	High Video Clarity
2.	Less Complexity
3.	Comfort for the patient
4.	Aesthetics
5.	Less Cost
6.	Adaptable for future improvements

Table 2 : Design Parameters

Designs Considered:

When the problem was defined, we considered some designs that were similar to the existing ones. We tried to bring down the cost by actually not replacing the fibres. But after meeting a team of doctors at the Department of Anaesthesia, Stanley Medical College, Chennai, we found that fibres were posing serious maintenance problems such as breakage. So , we decided to replace it with electrical cables. The design consists of the tip with a CMOS Image sensor for capturing real time video , an LED to illuminate the inside of the trachea. Essentially we thought of placing the electronics at the tip, but later we realised that it would increase the complexity of the system. So, we decided to keep the electronics externally. So, this is indicated by the diagram shown below.

Proposed Solution:

The proposed bronchoscope can be divided broadly into the following two ends:

a. ***Distal End***: The distal end is the tip which is inserted into the patient to get the actual
image of the inner airways. The distal end comprises the following parts:

i) ***Light Source***: The primary function of the light source is to illuminate the interior respiratory system so as to obtain a clear image. This is achieved using a white SMT LED. Here care was taken that the power dissipation due to the LED should not increase the temperature of the lungs and cause discomfort to the patients.

ii) ***Imaging Sensor with Lens Apparatus***: The imaging sensor is responsible for the actual imaging of the respiratory system. The chip utilized for this purpose was Omnivision's OV6920. The main reason for choosing this chip was that it had a very small imaging aperture (1/18th of an inch) but a good resolution (320 x 250 pixels) and viewing angle(around 120º). The sensor was controlled using a PIC microcontroller using SPI interface. The output of the sensor was in the NTSC format. However the video directly obtained from the sensor was not of a very good quality and hence certain image processing algorithms like periodic noise reduction had to be implemented.

b. ***Proximal End***: The proximal end is located near the doctor. The main function of the proximal end is to process the images obtained from the sensor at the distal end. The proximal end comprises the following things:

(i) ***Video Decoder:*** The main function of the video decoder is to extract the video information from the incoming video signal and convert them into digital data. The video decoder also uses the framing and synchronization signals from the composite video signal so as to synchronize the chunks of video data available from its output. The video decoder used here is TI's TVP5146 which can be programmed easily.

(ii) ***Video Processor***: The main function of the video processor in the development of the low-cost bronchoscope was to perform an efficient video coding so as to serve three purposes:
• Storage of the video.
• Transfer of Video through IP so as to perform image processing.
• View the image from the image sensor on a 5" TFT LCD Screen.

The video processor we found best for this use was Texas Instruments' DaVinci Media Processor (TMS320DM355). The TMS320DM355 was mounted onto a Linux host workstation through NFS mount using the NAND flash memory of the processor. The processor was programmed to perform MPEG4 encoding and the resulting video stream obtained was transmitted to the workstation using an Ethernet cable over IP. The video processor also performed digital to analog conversion of the encoded video data to drive a composite video player.

(iii) ***Video Amplifier:*** The video amplifier was used for amplifying the analog video signal obtained from the video processor and provided matching for driving an LCD Screen. Here the Video Amplifier used is OPA360 from Texas Instruments.

(iv***) LCD Screen***: The LCD Screen was used for displaying the encoded video from the
processor itself.

(v) ***Image Processing***: The encoded video from the processor is then processed using MATLAB. The major need of the Image Processing was that the video obtained from the image sensor had a high amount of periodic noise along the y-axis. The periodic noise had a period frequency of about 0.1 times the sampling frequency and this was eliminated using a simple image notch filter. The filtering is yet to be made real-time using the processor.

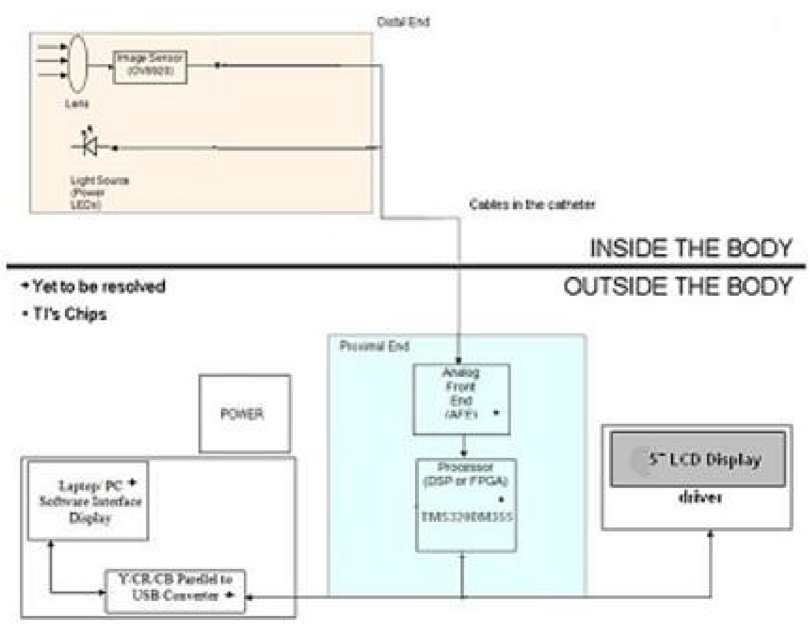


Fig 2 : General Block Diagram of the Video Bronchoscope

System Description:

The bronchoscope, we built comprises the following parts:

(i)Light Source*:* The light source is used for illuminating the interior of the trachea. It is composed primarily of 2-3 bright LEDs which do not dissipate a large amount of heat (< 3W) into the surroundings as this will result in the patient feeling uncomfortable.

(ii)The image sensor and lens*:* A CMOS single chip image sensor, OV6920 from Omnivision is the most suited for this purpose. The highlighting feature of this chip is its extremely small size (2.1mm x 2.3 mm). The image sensor also has an inbuilt lens and a resolution of 328 x 250 pixels

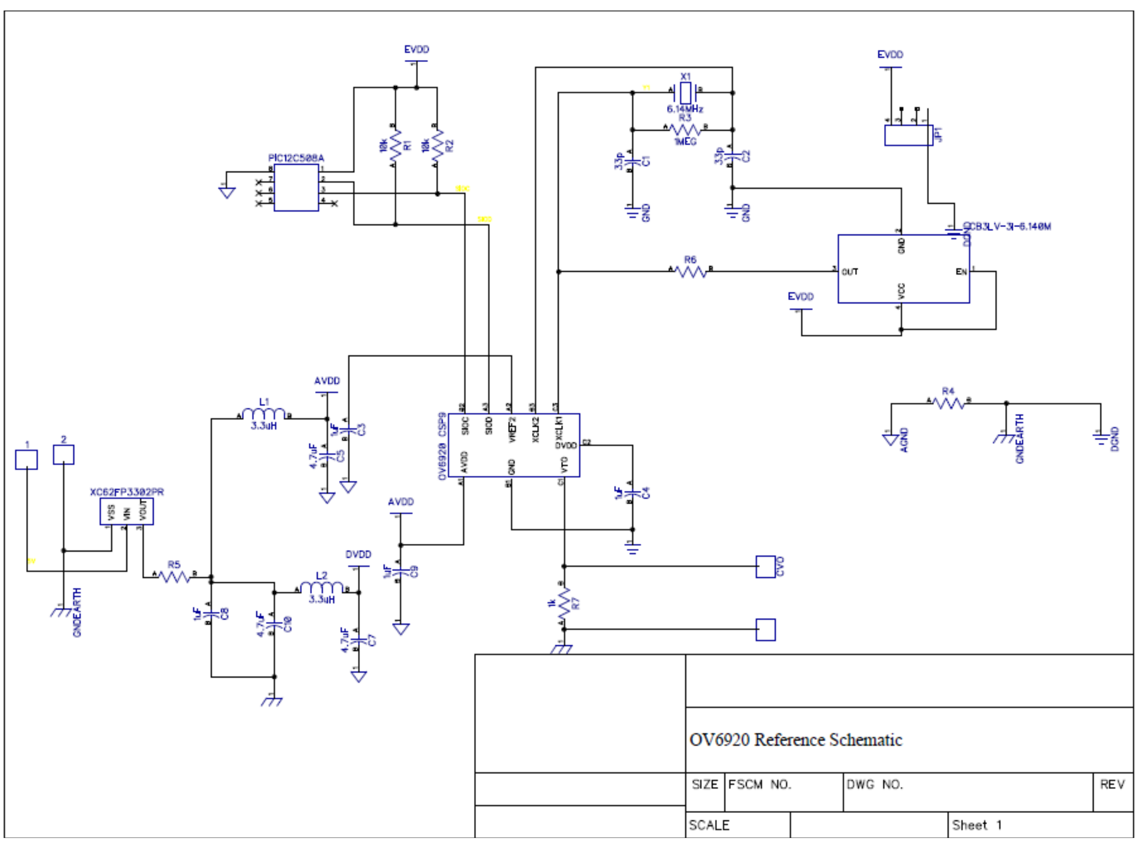


Fig 3 : OV6920 Schematic

(iii)Analog Line Drivers: An analog line driver is used at the output of the sensor. The chip appropriate for this function is TI's OPA360, a video amplifier with a gain of 6 db also having an inbuilt two-pole active reconstruction filter. Its dimensions are 2.3 x 2.1 mm.

***(iv)Analog Front End**:* The analog front end (AFE) is used for preliminary processing of the video signals obtained from the image sensor. The AFE which is proposed is TI's VSP2566. This chip is a mixed signal processing IC which processes the output from a CCD/CMOS camera.

***(v)Processor**:* The processor forms the core of the proximal end performs functions such as distortion removal, image enhancement, etc. The processor can be built around a digital media processor such as Texas Instruments' TMS320DM355 or a Field Programmable Gate Array (FPGA).

***(vi)Video DAC and Video Amplifier**:* The DAC proposed is THS8135 which has 3 10-bit DACs. It also has a very high speed of conversion (up to 240 MSPS). The device can be used for both the RGB video format and the YCrCb video format. The video amplifier can again be OPA360 because of its high amplification gain.

(vii) LCD Display: The output of the Video Amplifier is provided to the LCD display. Here a 5” TFT display is sufficient for providing a good image of reasonable resolution.

DM355 IPIPE

The Image Pipe (IPIPE) is a programmable hardware image processing module that generates image data in YCbCr-4:2:2 format from RAW CCD/CMOS data. The IPIPE can be used for a horde of image processing functions such as noise filtering, pseudo-colour elimination, etc. The IPIPE can also be configured to operate in a resize only mode, which allows YCbCr-4:2:2 to be resized without applying the processing of every other module in the IPIPE. The IPIPE can also be used for video compression and display

The IPIPE has several registers which can be used for employing the various image processing modules. The overall block diagram of the IPIPE is shown below:

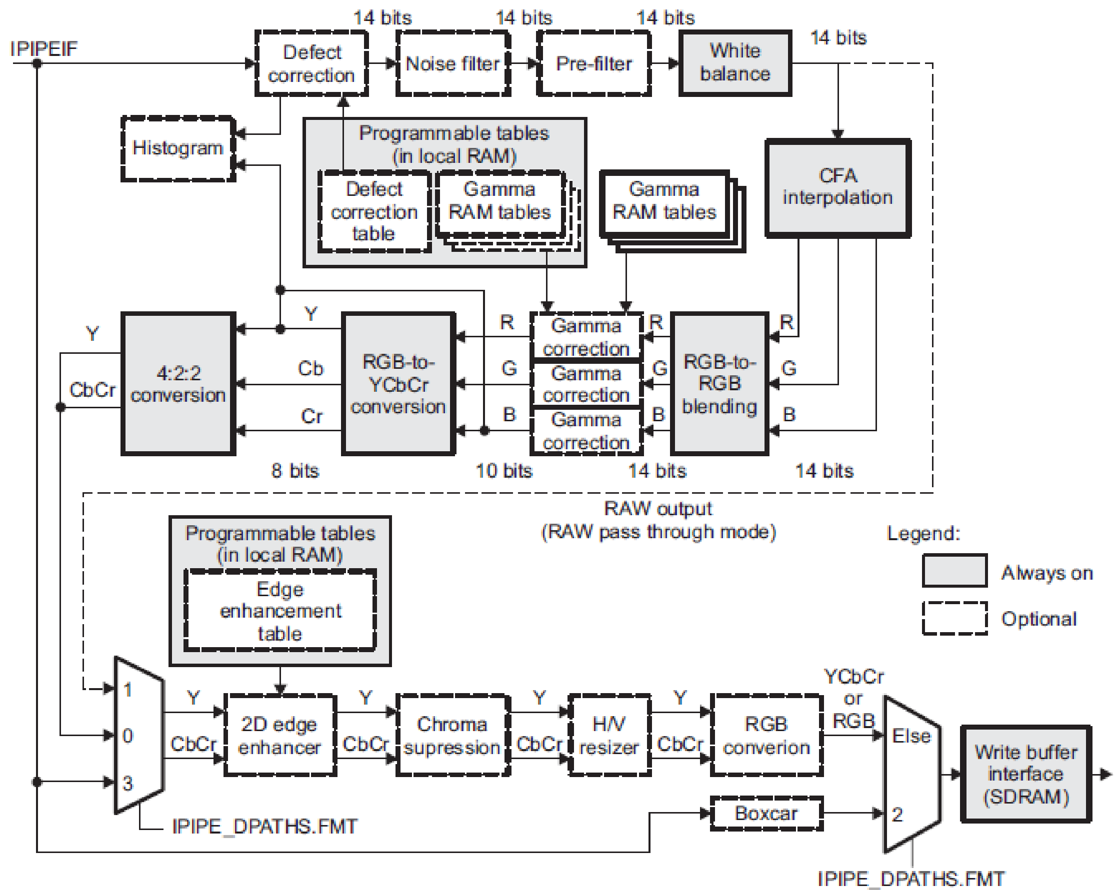


Fig 4- TMS320DM355 IPIPE Block Diagram

The output of the video from the OV6920 sensor had primarily two defects:

a. Green pseudo-colour as a background
b. Periodic noise along the x-axis

Initially MATLAB simulations were run to determine the frequency of the periodic noise and the specifications of the noise filter to be employed.

The noise filter module in the IPIPE can be employed by setting the following registers:

a. 2D- Noise Filter Enable Register (D2F_EN)- To enable the noise filter

15	1	0
Reserved		EN
R-0		R/W-0

Bit	Field	Value	Description
15-1	Reserved	0	Reserved.
0	SEL		Noise filter enable.
		0	Disable.
		1	Enable.

b. Noise Filter Configuration Register- To provide the specifications of the noise filter.

15	4	3	2	1	0
Reserved	TYP	SHF		SPR	
R-0	R/W-0	R/W-0		R/W-0	

Bit	Field	Value	Description
15-5	Reserved	0	Reserved.
4	TYP		Sampling method of green pixels.
		0	Box (same as R or B).
		1	Diamond mode.
3-2	SHF	0-3	Down shift value in LUT reference address.
1-0	SPR	0-3	Spread value in noise filter algorithm.

c. Noise Filter LUT Values(Threshold) Register- To set the threshold values of the LUT of filter coefficients obtained through a noise algorithm.

31–16
Reserved
R-0

15–12	11–0
Reserved	VAL
R-0	R/W-0

Bit	Field	Value	Description
31-12	Reserved	0	Reserved.
11-0	VAL	0-FFFh	Threshold value in noise filter algorithm.

d. Noise Filter LUT Values(Intensity) Register- To set the values of the LUT of filter coefficients obtained through a noise algorithm.

31–16
Reserved
R-0

15–5	4–0
Reserved	VAL
R-0	R/W-0

Bit	Field	Value	Description
31-5	Reserved	0	Reserved.
4-0	VAL	0-1Fh	Intensity value in noise filter algorithm. VAL needs to be equal to or less than 32.

Chroma Suppression Module:

This module is in-built in the IPIPE and suppresses the false colours caused due to mismatch between formats. This can be enabled by setting the Fault Colour Suppression Enable Register (FCS_EN).

15–1	0
Reserved	EN
R-0	R/W-0

Bit	Field	Value	Description
15-1	Reserved	0	Reserved.
0	EN		Fault color suppression enable.
		0	Disable.
		1	Enable.

Practical Challenges Faced:

• The illumination sensitivity of the image sensor was lower than required for the application.

• The video obtained from the image sensor had a periodic noise artifact making it necessary for us to employ image processing.

• The video from the processor in the encoded format, the video's green component was high making the video appear greenish.

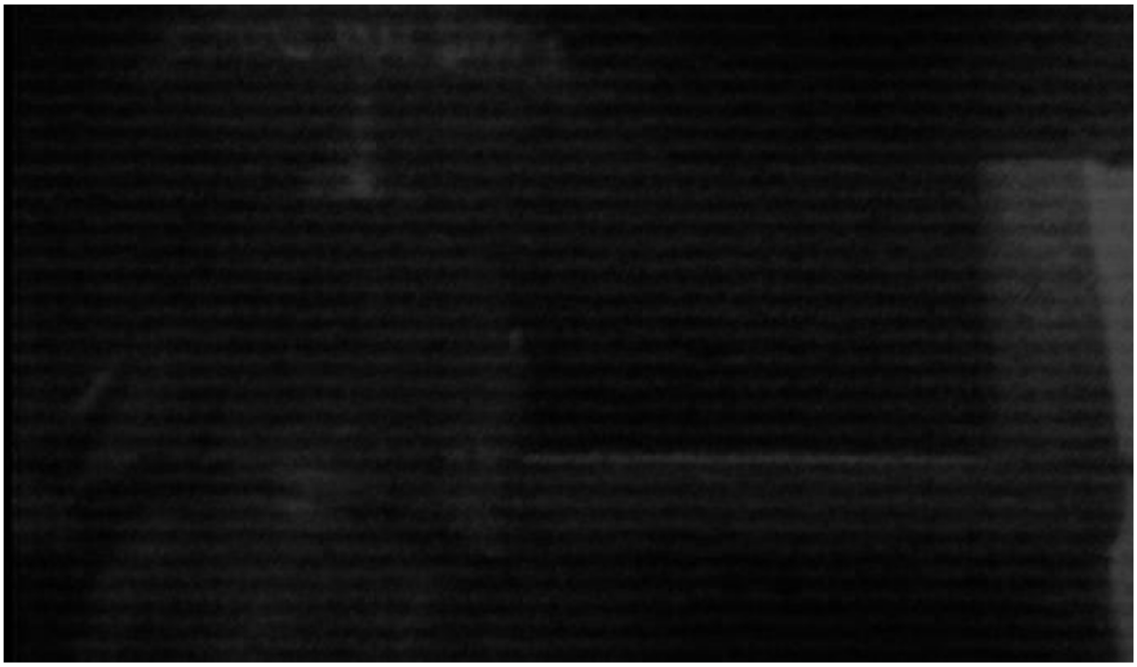
Shortcomings and defects of the device built:

• The camera chip module obtained from the manufacturer has to be soldered into a thin, flexible and cylindrical fashion with a total diameter not exceeding 3 mm (including the LED)

• The biocompatible mechanical casing of the bronchoscope forms the most crucial part of the system design and is yet to be devised.

Testing:

The real time video signal we obtained from the CMOS Image sensor has a periodic noise along the X- axis. We removed it using the MATLAB image processing toolbox initially and the results are shown below:



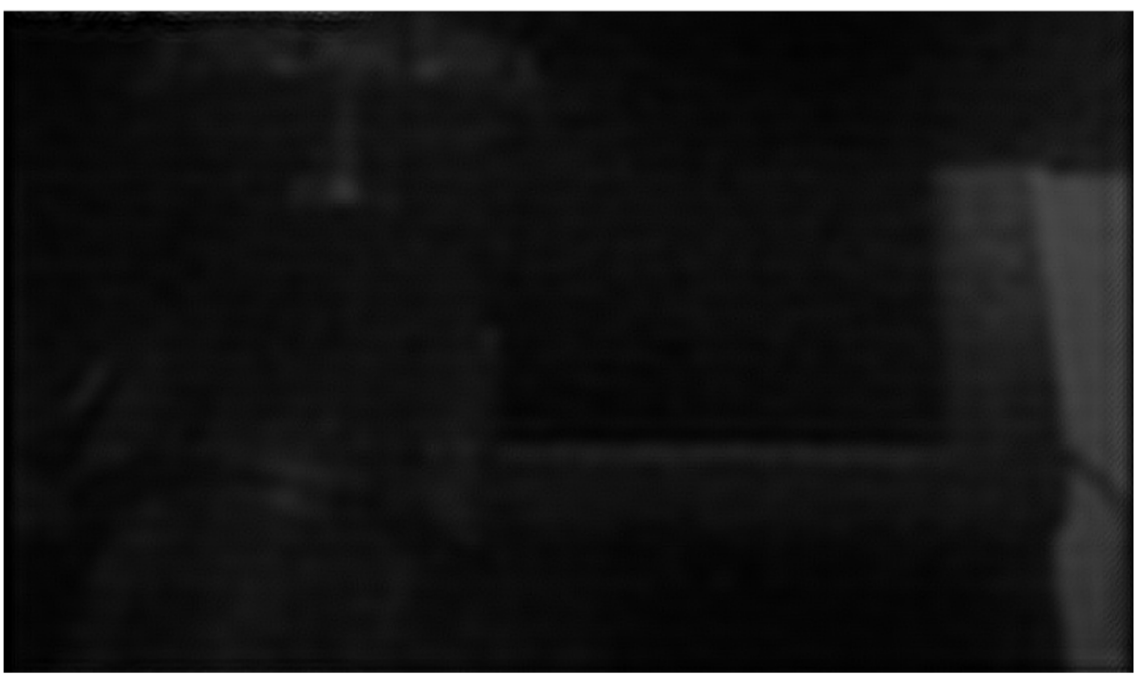


Fig 5 : Image with Noise (above) and the noise removed (below)

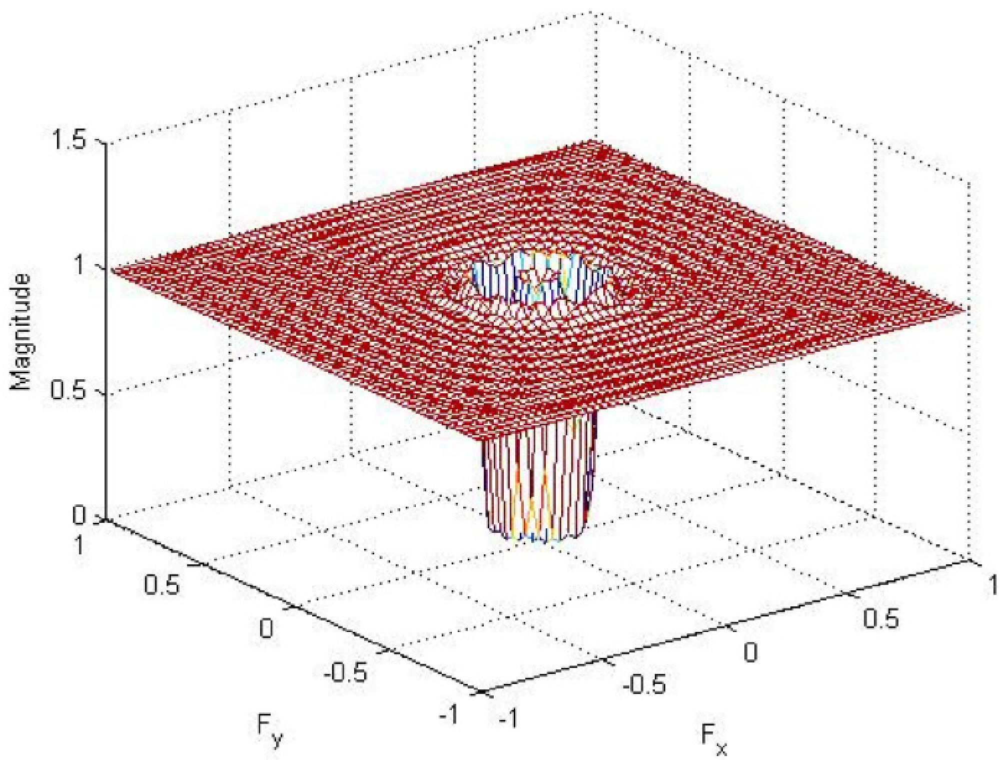


Fig 6 : Notch Filter Simulated using MATLAB

Cost Estimation

OV6920 CMOS Image Sensor :	**$ 45**
OPA360	**$ 0.35**
VSP2566	**$ 4**
TMS320CDM355	**$ 15**
THS8135	**$ 5**
LCD	**$ 30**
SMT LED	**$0.50**
LABOUR	**$ 50**

TOTAL ELECTRONIC COMPONENT COST + COST OF BIO COMPATIBLE MATERIALS : 150 + 100(in USD)

Total Cost : $250

Results :

• The distal and the proximal end electronic modules of the bronchoscope were successfully constructed.

• The encoded video from the processor was displayed on a 5” TFT LCD Screen.

• The encoded video from the processor was successfully processed using IPIPE for periodic noise elimination.

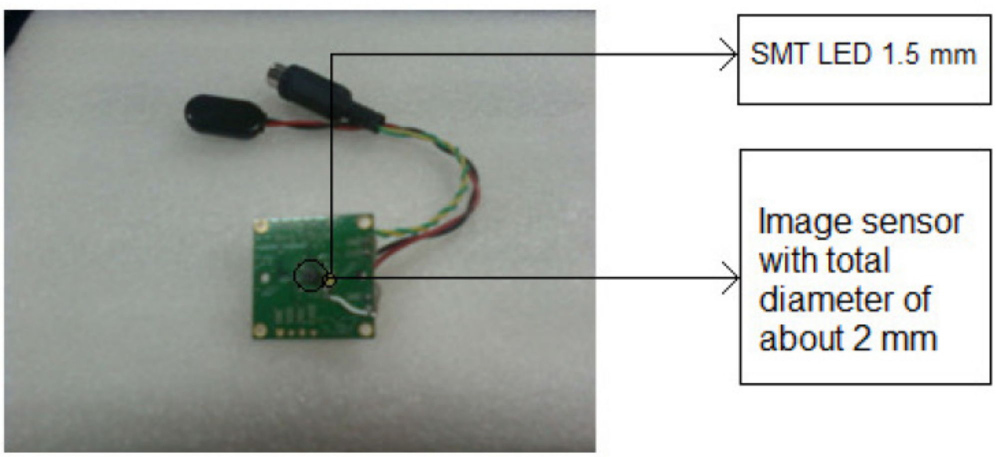


Fig 7 : OV6920 CMOS Image Sensor

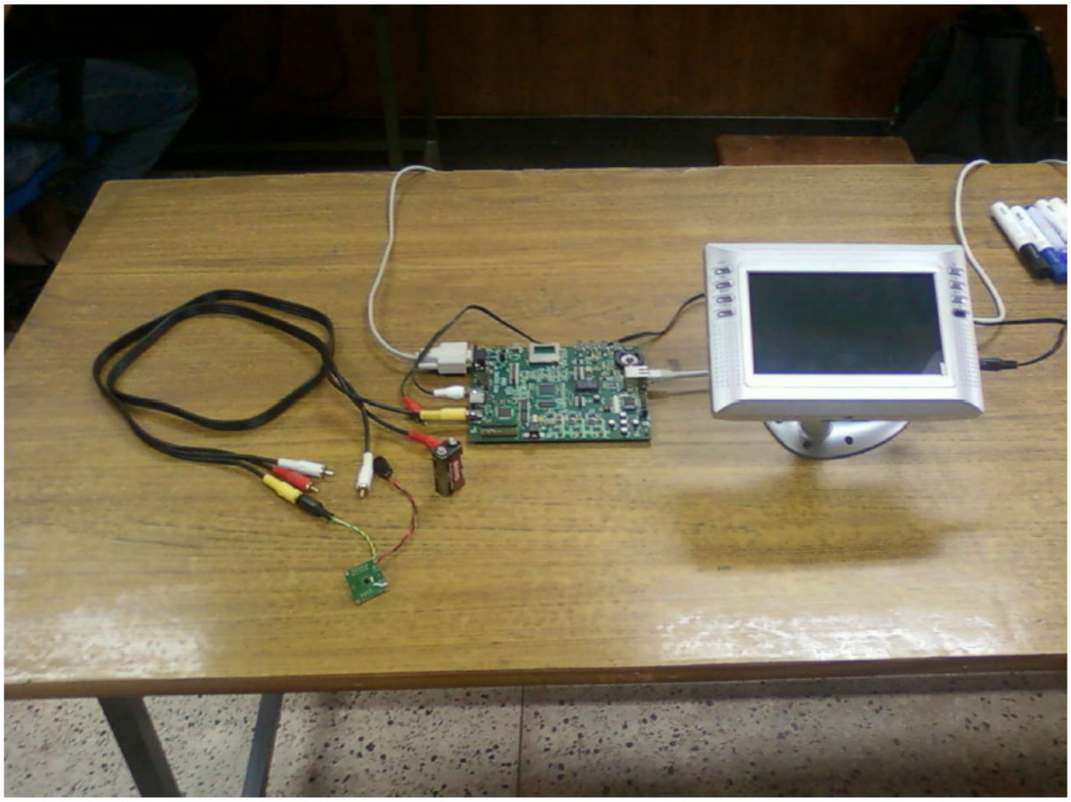


Fig 8: Overall System of Video Bronchoscope

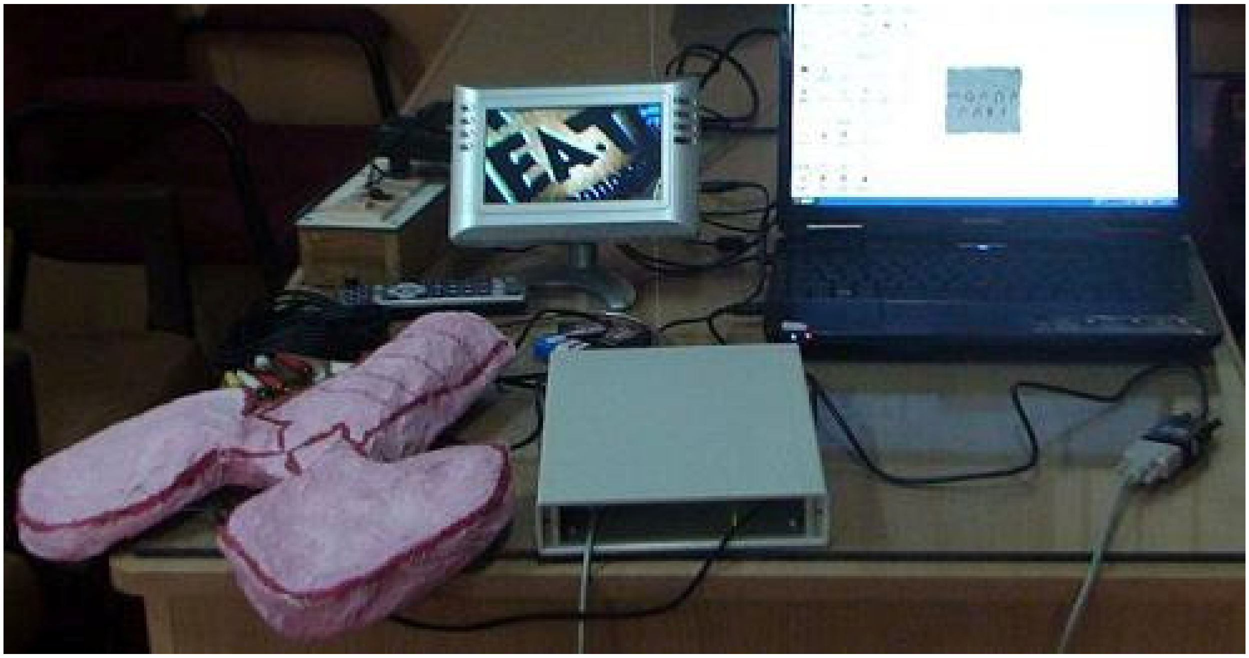


Fig 9 : Overall System with Phantom

Future Trends:

The present system can be used to for clinical purposes after it meets the standards of the medical engineering. The presently built system is a far cry from the device required. It is but a starting point in realization of the vision that any small time pulmonary clinic must possess a bronchoscope. The casing of the bronchoscope is to be made of a biocompatible material that does not cause any harm to the subject. It must be easily sterilizable. Some additional features can be added such as wipers for actually removing the red effect caused due to the phlegm. Also the device can be enabled with four degrees of freedom unlike the conventional device with two degrees of freedom. The CMOS Image sensor can also be re fabricated into a flexible cylindrical one.

References:

• Capstone CDR Group: AquaLung - Mir Minhaz Ali; Wilfredo Oteromatos; Greg Newcomb; Robin Elliott powerpoint presentation at the University of Colorado at Boulder

• United States patent numbered 4880015, by David M. Nierman

• Interventional Bronchoscopy by C.T. Bolliger, P. N. Mathur, Vol 30, By Karger

History of Events:

Feb ’09 - - - First meet at the Stanley Medical College, Chennai

Mar ’09 - - - Search for an ideal image sensor began

Apr ’09 - - - Call for TI Analog Design Contest 2009

Jun ’09 - - - OV6920 was decided to be used as the image sensor

Jul ’09 - - - Submission of the abstract to the TI India

Aug ’09 - - -Shortlisting of our abstract

Sep ’09 - - - Procurement of TI components

Oct ’09 - - - Layout of OV6920 with SMT White LED

Nov ’09- - - Initial Testing of CMOS Image Sensor

Interfacing ADC

Coding the DaVinci Processor

Preliminary results

Dec ’09 - - -Submission of the report to the TI

Jan ’10 - - - De noising using MATLAB

Feb ’10 - - - Qualified for the Final at Bangalore

Procurement of OMAP for Dummies from TI

Coding the IPIPE inside DaVinci

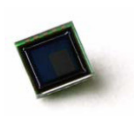
Mar ’10 - - - Hardware i.e. the casing for the bronchoscope

Mar 26, 2010 - - - The Second round at the TI Campus Bangalore

Appendixes

Appendix A

OV6920



OV6920 NTSC product brief

ultra small 1/18-inch CMOS camera-on-a-chip

lead free
available in a lead-free package

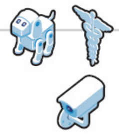
The OV6920 is a 1/18-inch optical format CMOS image sensor incorporating a high level of functionality and very low power consumption in an ultra-small footprint package. This makes it ideal for use in small disposable cameras for medical imaging applications such as diagnostic and intubation systems.

The 2.1 x 2.3 mm CSP packaged sensor enables a microscopic camera module with a 4.0 mm diameter, to make medical procedures even less invasive for the patient.

Having been designed for very low power operation, the OV6920 only requires a clock and a single 3.3-volt DC power supply to get the NTSC composite signal out to a direct interface with a VCR and TV monitor.

The OV6920 is built on OmniVision's proprietary OmniPixel2™ architecture providing the highest image quality, performance and clarity. It is an ideal solution for medical applications that require both color video and a very small footprint package.

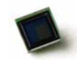
OmniVision



applications

- medical and dental equipment
- security and surveillance
- toys and games

OV6920



ordering information

- **OV06920-V09A**
  (color, NTSC, 9-pin CSP2)

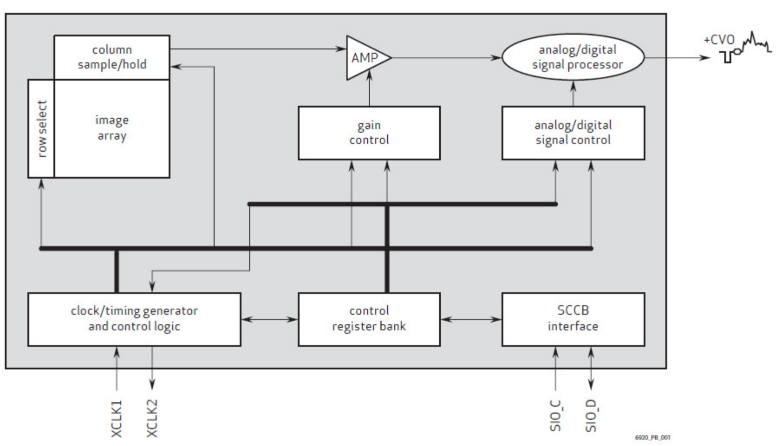
product features

- single chip 1/18" NTSC lens video camera
- composite video output
- automatic exposure/gain/white balance
- aperture correction
- gamma correction
- low power consumption
- +3.3V only power supply
- wide dynamic range, anti-blooming, zero smearing
- SCCB programmable controls:
  - color saturation
  - exposure
  - gain
  - gamma curve

product specifications

- **array size:**
  - **total:** 328 x 250
  - **active (NTSC):** 320 x 240
- **power supply:** 3.3VDC ± 5%
- **power requirements:**
  - **without loading:** 20 mA
  - **with 75 ohm loading:** 30 mA
- **temperature range:**
  - **operating:** 0°C to 50°C
- **electronic exposure:** 1/60s to 5.7 µs
- **output format:** composite video
- **optical size:** 1/18"
- **color mosaic:** RGB Bayer pattern
- **sensitivity:** 0.7V(Lux-sec)
- **S/N ratio:** 42 dB
- **dynamic range:** 42 dB
- **pixel size:** 2.5 µm x 2..5 µm
- **dark current:** 3 mV/sec
- **image area:** 820 µm x 625 µm
- **package dimensions:** 2135 µm x 2265 µm

functional block diagram



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