

# Development of 3D endoscope for Minimum Invasive Surgical System

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**Abstract:** One of the interesting surgery visualization that has helped the surgeon is in the field of endoscope. Endoscopic surgery is rapidly spreading in various areas since it is less invasive than conventional open surgery. Further, it helps the surgeon to have the internal view of the human body to identify and localize the damaged area. The recent and upgraded 3D endoscope enables the surgeon with depth perception and stereo vision. Stereo vision adaptability plays an important role in depth perception and is usually present in human beings and animals in predator's category. The estimation of depth provides an approximation of the distance of various objects in the scene from the miniature cameras. The paper presents an approach for generating an anaglyph view of the scene using two images generated by a stereo sensor. The algorithm runs in real time to generate a stereo video using two video streams from the sensors. The processed output is in 3D, which helps surgeon in estimating the depth of the internal organs.

**Keywords—** Image Processing, Anaglyph, Image Rectification, Camera Calibration, Stereo Matching, Depth, Disparity Map, Minimum Invasive Surgery (MIS)

## I. INTRODUCTION

Recent development in visualization technology has transformed the tools available to the surgeons in a remarkable way. Out of the many-sophisticated visualization techniques, such as magnetic resonant imaging (MRI) and X-ray computed tomography (CT scanning), endoscopy enable the surgeon to visualize the internal damaged area of the human body and subsequently enabling him to identify the disease. Traditionally, 2D endoscope was used to perform the surgery. However, it has severe drawbacks such as lack of depth perception and image distortion. We, Human beings are 3D creatures living in 3D world but our eyes can show us only two dimensions. The depth we can see is a trick of our brain; it puts together two 2D images in such a way to extrapolate depth leading to stereovision. The eyes are located at a small distance to each other. Therefore, they can present the slightly offset images captured by left & right eye to their brains. It creates a depth illusion of the scene seen as shown in Fig 1 [1]. To have the similar depth of field and stereoscopic vision, 3D endoscopy has been recently developed. The main idea behind stereo vision is to simulate the depth measuring technique of human eye using computer and computer vision based algorithms. It works by reconstructing the object back to its 3D form by analyzing the 2D information from two images. The image from a 3D

scene projects onto a 2D plane, during which the depth information is lost [2]. The 3D point corresponding to a specific image point is constrained to be on the line of sight. From a single image, it is impossible to determine which point on the line of sight corresponds to the image point. If two images are available, then the position of a 3D point is the intersection of two projection rays through triangulation. The important parameters of 3D image are perceived image quality, perceived image depth, perceived sharpness, and perceived eyestrain [3].

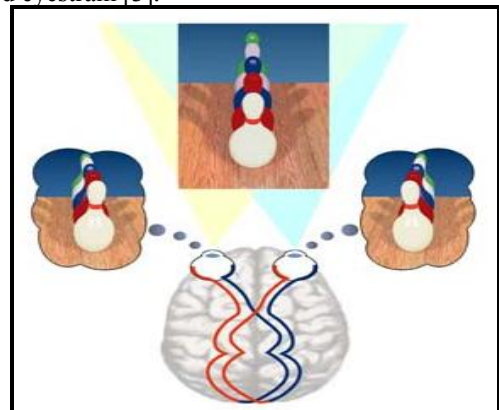


Fig 1: Stereo construction in Human brain[4]

The stereovision systems consists of a series of processing steps like image capture, camera calibration, feature extraction, stereo matching, and depth information computation[5-7].

The article consists of seven sections. Stereo imaging is described in Section II consists of stereo imaging. Section III contains the logic description followed by stereo system in Section IV. Section V contains the algorithmic implementation of the technique. The results and conclusion are in Section VI and VII.

## II. STEREO IMAGING

The stereo imaging computes the 3D location of points. It uses the stereo cameras consisting of two or more sensors, which allows camera to simulate human binocular vision [8]. As, the stereo system is designed to view inside human body, the sensors have to be of miniature size. Small size cameras allows the endoscope size to be reduced further along with the light source mounted over them. Therefore, we have used NanEye Stereo sensors measuring 1mm x 1mm with pixel size  $3\ \mu\text{m} \times 3\ \mu\text{m}$  as shown in Fig.2.

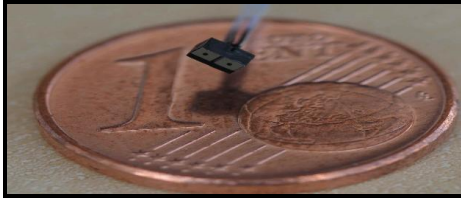


Fig 2. NanEye stereo sensor

Stereo imaging consists of a sequence of steps:

- Removal of lens distortion called “Un-distortion” [9-10].
- Adjustment of angles and distances between cameras called Rectification [11].
- Finding same features in the left and right camera views called Correspondence.
- Finding geometric arrangement of cameras triangulation called re-projection of images that helps in turning disparity map into distances as mentioned in [12-13].

### III. LOGIC DESCRIPTION

#### A. Stereo Calibration

Calibration is the process of calculating the camera parameters such as intrinsic, extrinsic and distortion parameters.

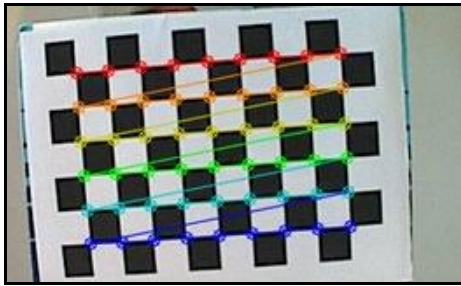


Fig 3. Isolated corners of chessboard

A known structure such as chessboard aligns opposite to camera to perform the calibration. It has many identifiable points i.e. corners as shown in fig 3. After viewing the chessboard from a variety of angles and positions, it is possible to calculate the location and orientation of the camera as well as the intrinsic parameters of the camera at the time of capture of each image [14]. On completion of stereo calibration, the following parameters are calculated.

1. The rotation and translation vector between the two cameras denoted as R and T
2. The intrinsic matrices of the two cameras
3. The distortion matrices of the two cameras

After Stereo calibration is completed, the stereo pair images are undistorted by applying the corrections of lens distortion.

#### B. Stereo Rectification

Stereo rectification performs the re-projection of the image planes of the two cameras so that they reside in the same

plane of frontal parallel configuration. In the same plane, the images are re-projected followed by align of the two images in the same line. The last step is to crop the overlapping area of the two images. To make the stereo correspondence more reliable, align the image rows between the two cameras so that interest points in corresponding images falls on same row [15].

#### C. Stereo Correspondence

Stereo correspondence is all about finding matching points in the same line on both images and finding disparity between the images. The stereo correspondence does the image matching. We had used the Block Matching algorithm for this. It finds only strongly matching (high-texture) points between the two images [16].

#### D. Anaglyph Image Generation

Anaglyph is a three dimensional display technique used to view stereoscopic images using colored spectacles. The whole system used in minimum invasive surgery using endoscope works in real time and generates a stereo view of internal body of patient [17]. Anaglyphs uses colors to control which image go to which eye. They send the red information of one image to the left eye and the blue and green information of the other image to the right eye. The brain perceives the depth, and combines the colors to give a fair approximation of the original colors of the image [18].

When the red filter blocks the blue/green components of the anaglyph image, the left eye sees only the red image formed from the left image and similarly the blue/green filter blocks the red component of the anaglyph, the right eye sees only the blue/green component formed from the right image. As a result, we view the 2D anaglyph as a 3D scene. The system finds application in minimum invasive surgery that leads to fast recovery of patient and is less infection prone [19].

### IV. STEREO SYSTEM

The proposed stereo system consists of a NanEye evaluation set shown as block diagram in. Fig 4.

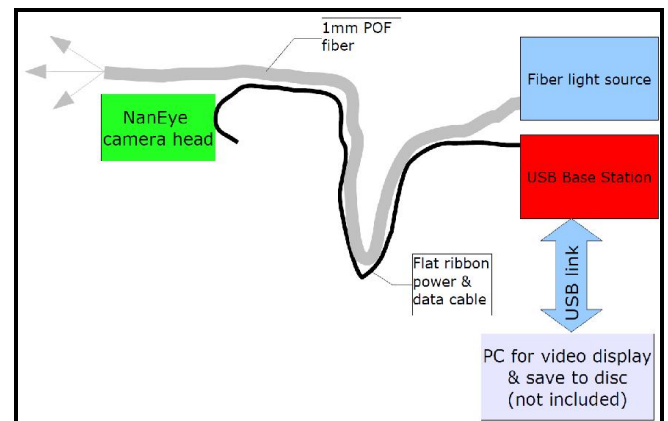


Fig 4 NanEye evaluation set overview block diagram

It consists of two miniature Naneye CMOS sensors connected through USB base stations to the PC. To illuminate the target, a cold light source is encapsulated in the same assembly as of sensors and connected through optical fibre. The complete system after assembly looks as shown in fig 5.

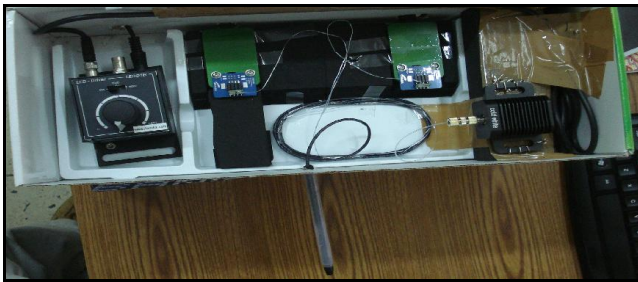


Fig 5 Nan Eye Evaluation Set (System Set Up)

### V. ALGORITHM IMPLEMENTATION

For generating an anaglyph, the following steps were performed

1. Minimum of eight corresponding points across the image pairs were found. In this work, we manually found these points.

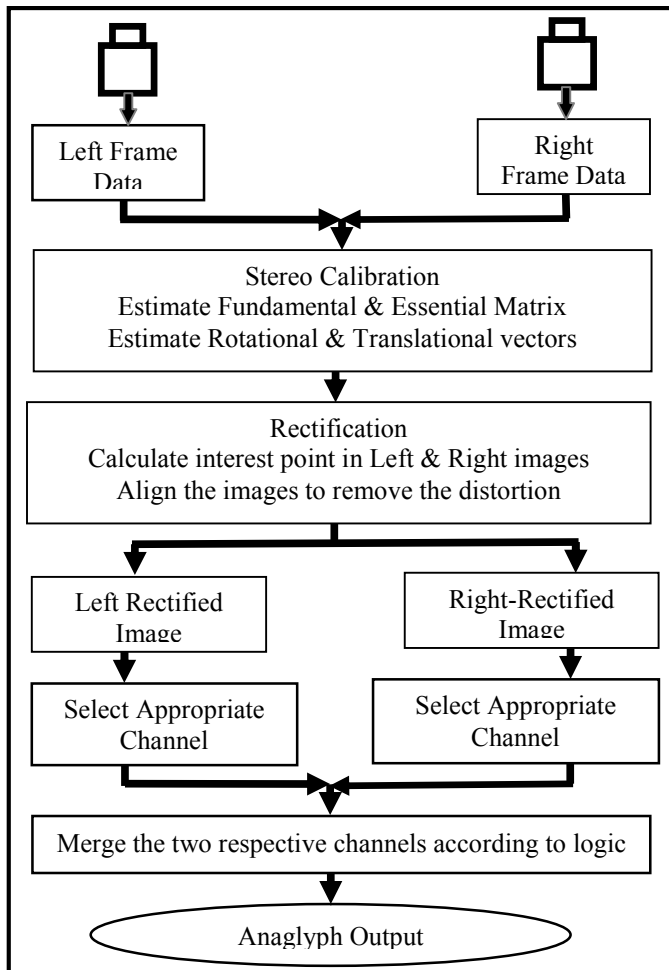


Fig 6 Flow chart of the Anaglyph generation process

2. The fundamental and the essential matrix were calculated. It helped in encapsulating the geometrical relationship between the positions of the two cameras.
3. The pair of images was rectified. The aim of rectification was to make the epipolar lines parallel and horizontally with the same vertical position in the rectified pair of images.
4. Finally, the anaglyph image was generated by encoding the left and right rectified images using red and cyan filters and merging them into a single picture. Apply the formula to calculate the  $r_a$ ,  $g_a$  and  $b_a$  (anaglyph frame) from the RGB values of the original left ( $r_1$ ,  $g_1$ ,  $b_1$ ) and right image ( $r_2$ ,  $g_2$ ,  $b_2$ ) for each pixel as mentioned in the anaglyph section.

Fig 6. shows the flow diagram for the proposed technique. Two color filters were used to classify the anaglyphs. Earlier two projectors with different color filters was used to display images but now, they are processed by program and projected as shown in fig 7.

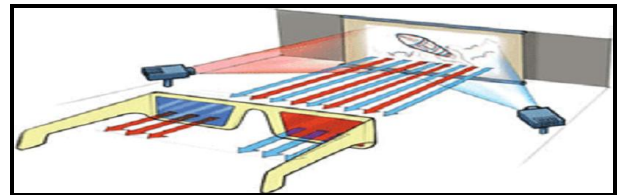


Fig 7 How Anaglyph method works [20]

Around the three RGB colors, monitor can choose the three anaglyph filters. All three colors must reach at least one eye for anything approaching full color. We tried to implement the different types of anaglyph based on the different matrices and channel combinations. For each pixel of the resultant anaglyph image, the logic was applied to obtain the respective two images [23].

The different types of anaglyphs are:

1. True Anaglyph: It results into a darker image with deep purple shade as shown in fig. 14. The color reproduction is also very poor and leads to ghost effect.

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0.299 & 0.587 & 0.114 \end{pmatrix} \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

2. Gray Anaglyph: Reproduce all the colors using gray scale as shown in fig. 11. The result leads to more rivalry between the eyes and has ghost effect.

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0.299 & 0.587 & 0.114 \\ 0.299 & 0.587 & 0.114 \end{pmatrix} \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

3. Color Anaglyph: The result is good as compared to the true and gray anaglyph with partial color reproduction in the final image as shown in fig. 15. The final image leads to retinal rivalry.

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

4. Half Color Anaglyph: The color reproduction of this anaglyph is not as good as color anaglyph but the retinal rivalry is not to that much strain causing when compared to color anaglyph as shown in fig. 12.

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

5. Optimized Anaglyph: In this, the final image has only partial color reproduction when compared to color anaglyph, the poorest result occurs for the red color. The advantage is that the retinal rivalry (due to the brightness differences of colored objects) is almost zero in this anaglyph as shown in fig. 13.

$$\begin{pmatrix} r_a \\ g_a \\ b_a \end{pmatrix} = \begin{pmatrix} 0 & 0.7 & 0.3 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_1 \\ g_1 \\ b_1 \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} r_2 \\ g_2 \\ b_2 \end{pmatrix}$$

## VI. RESULTS

As the sensor type and scene framed are not consistent with the techniques, the comparison of the results is a little difficult task [21, 22]. However, based on the following few factors we can say the technique is promising because

- i. Most of the techniques had been operated on static pair of images which were processed and then viewed. However we had worked on live video streams.
- ii. The sensor size in our case was very small only 1mm x 1mm. As a result, the images were not very bright and clear So more processing was required to enhance their reception.
- iii. Most of the existing 3D techniques for Minimum Invasive surgery require a separate Camera Control Unit(CCU) along with other necessary hardware for doing processing. However our computation had a requirement of a set of sensors along with PC for doing all computation and display of results.
- iv. The existing 3D viewing processes requires a dedicated 3D display and a pair of polarized glasses for viewing. While in our case the result could be seen on a standard display with a pair of red-cyan glasses and the depth perception was also good for the reported color Anaglyph.

The strength of the process was in the preprocessing steps, performed before the anaglyph generation i.e. the camera calibration, removal of distortion and alignment of images. Figure 8 shows the left distorted and right distorted image from the Bumblebee stereo camera by Point Grey. To

demonstrate the result of the process used in system, the images are shown using Bumblebee output.

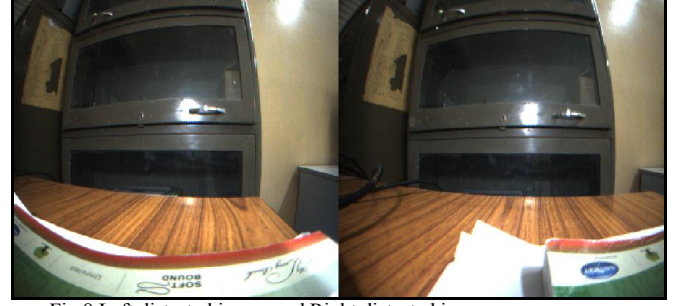


Fig 8 Left distorted image and Right distorted image

The processing of images is done to un-distort them as shown in Fig. 9. The left and right rectified image from the bumblebee camera are produced after being calibrated and rectified using the calibration information to un-distort and align the pictures.



Fig 9 Left undistorted image and Right undistorted image

Once we had the rectified and aligned images available, the next step was to produce anaglyph by computing RGB for each pixel. Fig. 10 shows the left and right rectified images from NanEye sensors. The different types of anaglyph are computed as explained in section V. The fig. 10, 11,12,13,14 & 15 shows the results of various anaglyph operations.



Fig 10 Left and Right frames from the NanEye sensor



Fig 11 Gray Anaglyph

Fig 12 Half Color Anaglyph

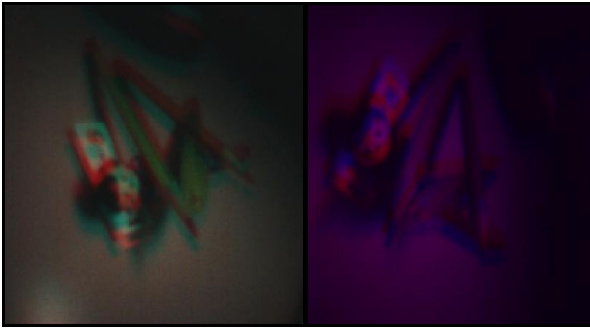


Fig 13 Optimized Anaglyph

Fig 14 True Anaglyph



Fig 15 Color Anaglyph

## VII. CONCLUSION

We have shown that reliable estimations about depth of three-dimensional objects can be quickly made by using the propose anaglyph technique. The basis of our proposal is an anaglyph based stereo system to help the surgeons in estimating the depth of the organs inside the human body while doing surgery. It has ample number of opportunities to find applications in Minimum invasive surgery where an endoscope provides the internal view of body. The system can generate 3D view in real time with no time lag and the sensors used are very small, i.e., 1 mm x 1mm. The main advantage of the process is the results with good color details and the depth computation in the scene in real time. Further refinements to our technique, including refinement of ghost effects, retinal rivalry and color enhancement, will lead to more effective view generation of inside body of patient.

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