Study on Elemental Image Generation Algorithms for Integral Imaging 3D Display Systems

Mst. Nasrin Akhter | 15301126

Nusrat Jahan Suchi | 15301127

Afiunnahar | 15301128

Department of Computer Science and Engineering

BRAC University.

Supervised by Dr. Md. Ashraful Alam

Abstract

In recent years, demands of three dimensional (3D) displays have increased due to its attractive application. Nowadays, Integral Imaging (II) is one of the most promising and fascinating research topic since it can fulfill all requirements of a true 3D display. In this thesis, different algorithms of elemental image generation for 3D integral imaging display systems is studied and analyzed. Integral imaging is an attractive autostereoscopic 3D display techniques that produces full color, full parallax, continues true 3D images without any eyeglass or supplementary devices. Despite tremendous benefits it has some drawbacks like-insufficient resolution, small viewing angle, shallow image depth. A numerous researches have been conducted to solve the problems. Elemental image generation algorithms play an important role for integral imaging 3D display systems. We studied and analyzed several elemental image generation algorithms to identify and suggest the effective algorithm for efficient 3D integral imaging display systems. The experimental data for the analysis are presented in this thesis.

At first, we studied about direct pickup method of integral imaging 3D display system. In this method, the object information are captured through a array of small lenses called elemental lenses and each lens produce an elemental image by tracing the ray emanating from the object specific lenslet of the lens array. As a result, an array of elemental images can be directly captured by a CCD camera. This method causes noise with the captured elemental image.

Secondly, we studied computer generated elemental image (CGEI) method which allows to reduce the noises that causes in direct pickup method. Several algorithms for CGEI method have been studied and analyzed. CGEI method can only generate elemental images from synthesized 3D object points from a 2D image which are not real depths of a 3D object.

Thirdly, we studied about elemental image generation method using real depth and color information of a real object which can overcome the limitation of CGEI method. Hence, viewing angle is a problem of this method.

Lastly, we studied the Directional Elemental Image Generation and Resizing (DEIGR) algorithm and multi-directional projection schemes that could be a breakthrough of integral image display.

CHAPTER 1

INTRODUCTION

1.1 Motivation

Physical world, however, is three-dimensional (3D), in contrast most of the traditional display devices present two-dimensional (2D) images without the depth information. Actually human visual system is complex and it permits us to perceive the surrounding world in three dimensions. Since, photons travel through their optic components, a two-dimensional representation is created on the retina, once for each eye. This planar picture from both eyes is used by human brain to reconstruct a three-dimensional (3D) model of our environment. In the last few decades, 3D display has become exoteric due to its fascinating advantages and application in diverse field. The overarching motive to create 3D display systems is to present content to the human visual system in a manner that facilitates the formulation and clarity of mental impressions concerning the geometric form of image entities, and of their distribution over 3D space. Besides, 3D vision is a promising new branch in the entertainment industry that encompasses applications for cinema, television and video games alike. Due to the revolutionary development in the sectors of Electronics, optics, laser, photonics and computer technologies real world 3D implementations in terms of display is within the reach and can be tried out commercially to establish a place in the market. Nowadays 3D TV, 3D movies, 3D games, 3D mobile devices have increasingly demanded true 3D display without the need for any supplementary eyeglasses (i.e., auto-stereoscopic)

1.2 Three-Dimensional (3D) Display Technologies

The principle of 3D display is to separate the picture into two so that one view is seen by one eye and another view is seen by the other eye. Actually, these two images are interpreted by our brain to give a perception of depth. The process of separation of the two images is usually done by wearing special glasses. In modern times, some displays are designed to be used without these glasses. Since, both technologies (old fashioned and up-to-date) are being actively investigated together which has mainly made the 3D display technologies interesting. After the successful release of 3D display product researches paid attention on stereoscopic display. On the other hand, auto-stereoscopic display renders a ray field of a 3D image. Again, holography mainly replicates a wave field of it. Many researchers have investigated to reduce the existing limitations. Still 3D display is a concept close to the ultimate goal of presenting seamless virtual images. Although it is far away from practical use, efforts have been made to resolve issues such as occlusion problems [1]

With the rapid progress in the field of electronics, optics, laser and photonics true 3D display technologies are making their way into the market space. Nowadays 3D display having no eyeglasses is essentially required by the 3D movies, 3D TV, 3D mobile devices and 3D games.

1.2.1 Stereoscopic

The images of stereoscopic display consist of two different view angles named as a stereo-image pair. Special eye glasses are required for the observers to separate left and right views, and not sending them directly to the correct eye. Because of having features such as high resolution, full color and multi observers this display is widely used. The reasons behind its popularity is- Image resolution not reduced compared to 2D image, Wide field of view, Compatible with head tracking, Allows for limited number of multiple viewers. One of the major drawbacks of this display is the inconsistency of depth cues, a phenomenon called accommodation-convergence conflict

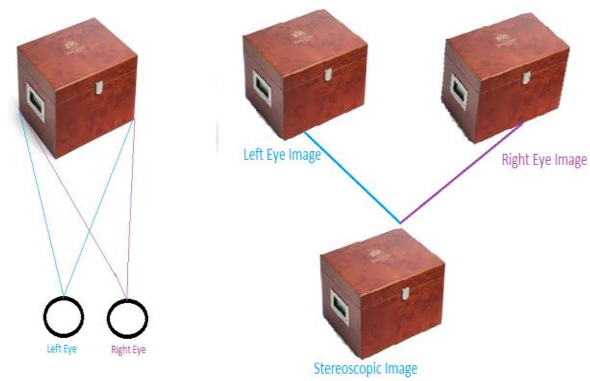


Figure 1.1 : Basic Concept of Stereoscopic Display

Moreover, in stereoscopic display an independent image is presented to each eye through the use of some means of separation.

• Polarization of light

• Spectrum of light

• Spatial

• Temporally

Advantages of stereoscopic display:

i) Image resolution not reduced compared to 2D image
ii) Wide field of view
iii) Compatible with head tracking
iv) Allows for limited number of multiple viewers
v) System can be switched to 2D eliminating the need for glasses

Disadvantages of stereoscopic display:

i) Require sophisticated glasses
ii) Inconsistent accommodation and convergence cues
iii) Reduced image brightness
iv) Provides only horizontal parallax

1.2.2 Autostereoscopic Display

Autostereoscopic displays can generate a 3D effect without having to rely on any extra devices like shutter glasses. The ambition of the manufacturers is applying optical tricks to aim the waves of light emitted by the monitor directly at the viewers' eyes. In autostereoscopic display, the scene will appear to be in 3D if the viewer's head is within a certain area in front of the screen, the so-called stereo zone.

Considering the exact position of the viewer's head and eyes, the system mainly apply an eye tracking technique so that the viewer's left eye can always see the L image and the right eye can see the R image. The technique automatically adjusts the position of the projected L and R images to keep them in the correct alignment for optimum 3D viewing. As a consequence the viewer can move from side to side or vertically, without losing the 3D effect. [2]

There are three groups in the auto-stereoscopic 3D display technologies- multiview 3D display, volumetric 3D display and holographic display.

Multiview 3D Displays

A multiple 3D display system provides both stereo parallax and motion parallax depth cues to its viewer and it is capable to propagate various images in multiple angular positions. Moreover, it does not require any special glasses. Integral imaging is one of the most attractive multiview auto-stereoscopic 3D display techniques. Integral imaging which is also known as integral photography was first proposed by Lippmann in 1908 is a method which is used for displaying three-dimensional (3D) images. Again, integral imaging uses incoherent light, which is suitable for 3D television and visualization [3].

Among all 3D imaging techniques, integral imaging (II) system is a promising technology because: a) it produces auto-stereoscopic images, which does not require special viewing devices; b) gives images with full parallax and continuous viewing points; c) it is passive in the sense that it does not require special illumination of the scene; d) it can operate with regular incoherent daylight; e) its system configuration is compact; f) its implementation is relatively simple.

Volumetric 3D Displays

Volumetric display was first proposed by Luzy and Dupuis in 1912. Actually, volume filling 3D image are produced by volumetric displays. Each volume element which is also known as voxel in a 3D scene transmits visible light from the region it appears. To acquire true 3D sensation, human brain mainly uses four major physical depth cues. First come accommodation, which measures how much the eye muscles force the eye lenses to change shape when focused on an image of a specific 3D object in a scene. Convergence which comes second to measures the distance eyes have to cross to observe a 3D object simultaneously. The third, motion parallax, offers depth cues by comparing the relative motion of different elements in a 3D scene. And finally, binocular disparity refers to differences in images acquired by the left and right eyes.

Traditional 2D displays are unable to provide these 3D depth cues to viewers. Besides, at the time of presenting high dimensional graphics/data it creates ambiguity and confusion. By contrast, volumetric 3D display technologies can provide all the above-mentioned depth cues by displaying 3D volumetric images in a true 3D space [4].

Holographic Display

Holography, first introduced by Gabor in 1947, is a three-dimensional (3D) display technique that provide realistic images without the need for special eyewear, making them valuable tools for applications that require situational awareness, such as medical, industrial and military imaging [5]

Holography technique is applied to display objects in 3D. The holograms can record and replay all the characteristics of light waves, including amplitude, phase and wavelength. Moreover, the hologram is capable to reconstruct an object without any conflict of depth cues, since it has the ability to provide all four major physical depth cues- accommodation, convergence, motion parallax and binocular disparity. However, it has attracted considerable public interest as it was depicted in the original “Star Wars” film in 1977. But, the inferiority of sufficient computational power to produce realistic computer generated holograms and absence of large area and dynamically updateable holographic recording media have prevented realization of the concept [6]

1.3 Thesis overview

This thesis is organized as follows:

Chapter 2 introduces the pros and cons of Integral imaging such as-basic principle, viewing characteristics, advantages, disadvantages and so on.

Chapter 3 describes the direct pickup method for generating elemental image. It has some limitations which were also narrated in this chapter.

Chapter 4 presents a different method named Computer generated Elemental Image (CGEI). Along with these, several algorithms have been studied and analyzed for CGEI method. By computer experiments we compared the efficiency of efficient algorithm with direct algorithm.

Chapter 5 describes Elemental Image generation method using real depth and color information of a real object. This method does not require any kind of lens array like conventional pickup process, which actually simplified the optical setup of the pickup process.

Chapter 6 describes about Directional Elemental Image Generation algorithm and multidirectional projection scheme that can solve most of the drawbacks of Integral Imaging.

Chapter 7 provides the summary and overall conclusions of the dissertation.

CHAPTER 2

INTEGRAL IMAGING

2.1 Introduction to Integral Imaging

Integral imaging was invented in 1908 by Nobel Prize laureate G. Lippmann [7] and was originally named integral photography (IP). The term "Integral Imaging" was introduced recently to reflect the imaging and image processing nature of modern applications [8]. Actually, Integral imaging is a kind of auto-stereoscopic three-dimensional (3-D) display and has been actively studied because no special viewing aids are required such as polarization glasses, which is modified from integral photography. The integral imaging is consists of the two main processes, the pickup and the display processes. In the pickup process, charge-coupled device (CCD) is used to capture a number of images that have different perspectives. A set of these captured 2D scenes is called the elemental image that is displayed by liquid crystal display (LCD) in display process.

In a nutshell, the technique of integral imaging has many advantages as follows.

- It requires no special viewing-aids (autostereoscopy).
- It provides continuous viewpoints within the viewing angle.
- It provides full parallax (both horizontal and vertical parallax).
- It provides natural depth perception with relatively low eye-fatigue.
- It can display full-color and real-time 3D animated (dynamic) images.
- Multiple observers can see 3D images freely within the viewing angle.
- Display devices of current 2D technology can be easily adopted.

However, conventional integral imaging technology also suffers from the following drawbacks.

- Limited viewing-resolution
- Limited viewing-angle
- Limited image-depth range
- Difficulty in compatibility with 2D images

2.2 Basic Principle of Integral Imaging

2.2.1 Principle of Integral Imaging

Figure 2.1 illustrate the basic concept of II. Integral imaging is consists of the two main processes, the pickup and the display processes. In the pickup process, charge-coupled device (CCD) is used to capture a number of images that have different perspectives. A set of these captured 2D scenes is called the elemental image that is displayed by liquid crystal display (LCD) in display process.

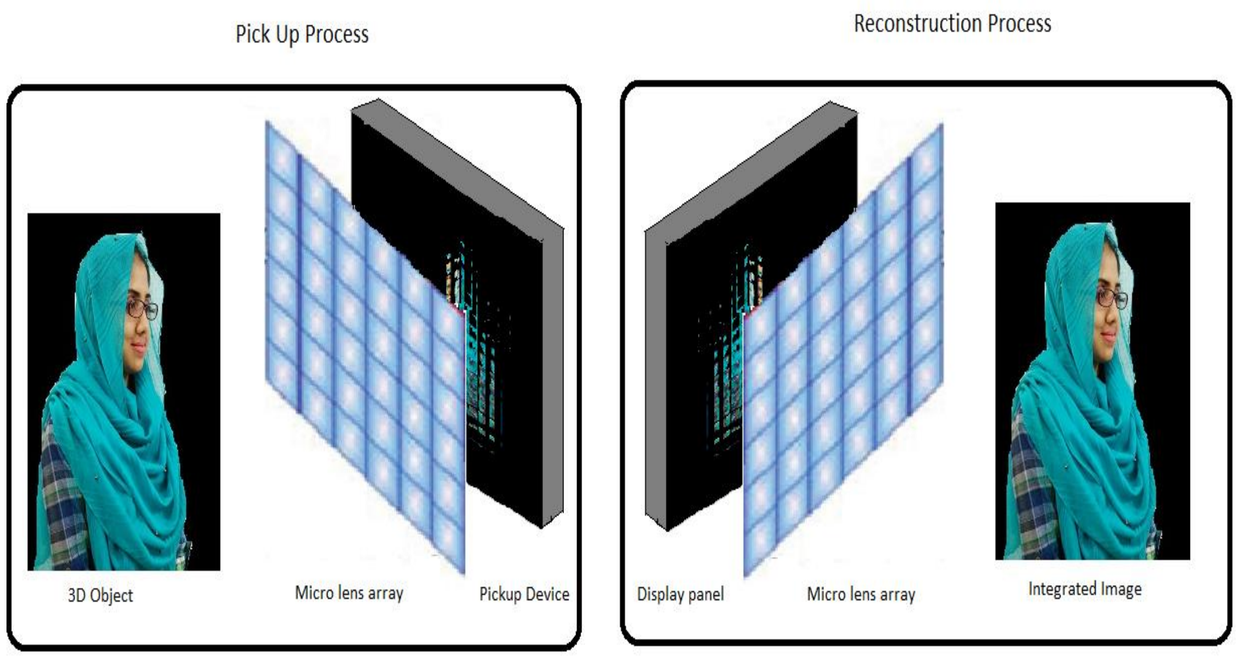


Figure 2.1: Basic concept of integral imaging, pickup and display processes

2.2.2 Viewing characteristics of Integral Imaging

The Integral Imaging system has unique viewing characteristics because the reconstructed images of the system must be observed through a lens array consisting of elemental lenses. It has three different display modes- real, virtual and focused modes, which are induced by the characteristics of the convex lens [9-12].

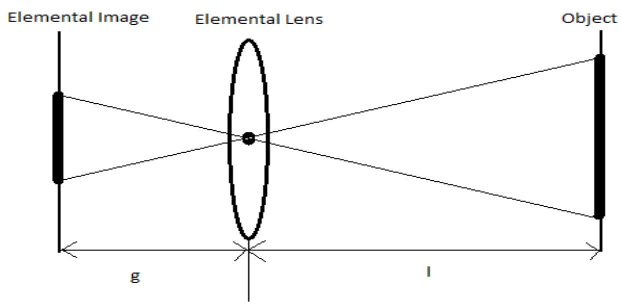


Figure 2.2: Basic concept of Gaussian lens

When the gap g between the lens array and the display device is longer than the focal length f of the elemental lens, i.e., g>f, the image focused by the elemental lens is located in front of the lens array. Here, the focal plane (image plane for each elemental lens) of the lens array is named as the central depth plane (CDP). The isolation of the CDP from the lens array is given by the Gauss lens law (imaging equation):

$$\frac{1}{g} + \frac{1}{l} = \frac{1}{f} \quad \text{…………..……….(2.1)}$$

2.3 Application and challenges of Integral Imaging

Integral Imaging is one of the most promising auto-stereoscopic 3D display technique, because: a) it produces auto-stereoscopic images, thus not requiring special viewing devices; b) it provides the observer images with full parallax and continuous viewing points; c) it is passive; i.e., it does not require special illumination of the scene; d) it can operate with regular incoherent daylight; e) its system configuration is compact; f) its implementation is relatively simple. There is a scope of 3D TV, 3D cinema, 3D game, medical imaging, 3D microscopy, remote sensing, security purpose and many other demanding areas.

CHAPTER-3

DIRECT PICKUP METHOD

Basic concept of Direct pickup

In direct pickup process, to display 3D image it follows two steps –pick up and display. In this method, the object information are captured through a array of small lenses called elemental lenses and each lens produce an elemental image by tracing the ray emanating from the object specific lenslet of the lens array. As a result, a array of elemental images can be directly captured by a Charged Couple Device (CCD).

Figure 3.1 : Charged Couple Device (CCD) camera

In display process, the elemental image is displayed by a display panel such as liquid crystal display (LCD) and the rays emitted from the elemental image retrace reconstructed 3D integrated image. Fig (3.2) shows the direct pick up process.

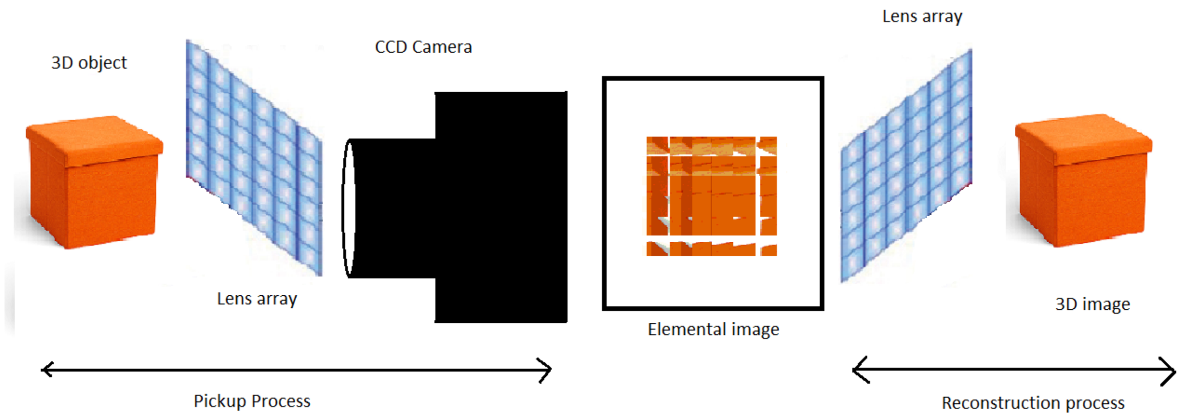


Figure 3.2 : Basic concept of direct pickup method.

Disadvantages of Direct Pick up:

Direct pick up process fails to place the lens array and a CCD camera in the exact position. Besides, it allows unnecessary beams to pass through the lens array which obstruct for generating elemental images. Again, decomposition of the lenses defense for the post processing of generated elemental images. Further, it is really complex for the camera lens and lens array to generate elemental images from large objects

CHAPTER-4

COMPUTER GENERATED ELEMENTAL IMAGE (CGEI)

4.1 Basic concept of CGEI

In some applications, it may be necessary to display an object that does not actually exist and whose structural information is stored in the form of electrical signals. Due to its simple structure and wide application areas integral imaging mixed with computer graphics is highly attractive.

An imaginary object is imagined that contains 3D information. If it is defined that the adjacent plane which is parallel to the display panel as the x-y plane, the information relative to depth is represented by z direction. An imaginary object possesses information concerning a 3D location (x,y,z). This information can be transformed into the form of a 2D elemental image array assuming observation from different viewing directions through different elemental lenses in a lens array. Therefore, a point in 3D space is mapped to an array of 2D dots. It refers the process as 3D to 2D mapping. This mapping is performed for points that are used to build up a 3D object.

Instead of using pickup process, in CGEI, computer is used to generate elemental images of imaginary objects. Only one lens array and conventional display devices make it compact and cost effective. The animated image can also be presented by the time-varying elemental images. As a result, auto-stereoscopic images were observed in real time with full color and full parallax. Moreover, this method can be applied to a quasi-3D display system. If each camera picks a scene which is a part of total view and elemental images are generated so that each scene has different depth, real objects captured by ordinary cameras can be displayed in quasi-3D. In addition, since it is easy to change the shape or size of elemental images in this scheme, we can observe the effect of several viewing parameters. This helps us to analyze the basic Integral Photography (IP) system [13]

The basic concept of the imaginary pickup process is shown in fig (4.1) .The rays coming from the object point actually penetrate the centers of the elemental lenses and are recorded in the pickup plane under the ray-optics assumption. The whole elemental image is of the same size as the overall lens array and the image region of each elemental lens is the region behind the lens.

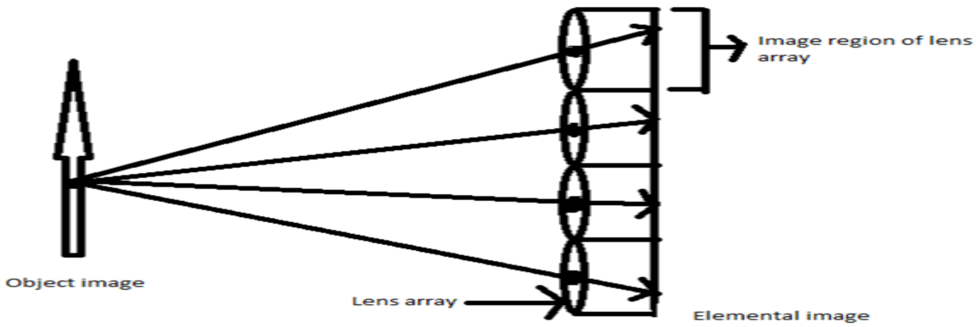


Figure 4.1: Basic concept of the imaginary pickup process in Computer Generated Integral Imaging

Direct Algorithm:

Generation of elemental image by applying direct algorithm is shown in fig (4.1).Firstly, the physical locations of every pixel of inside the object images is calculated comprising the surfaces of the object. Next, by using pre-calculated center locations of all elemental lenses, determine the locations where rays from the pixel location of the object should be focused on the pickup plane. Then, check whether the focused locations are within the image region of each elemental lens. In the end, convert the locations in focus to the pixel index of the elemental images and record the information. This way of generating elemental images is called the direct algorithm (DA).

Because we must watch the nearest object in the display process when multiple objects overlap, this algorithm must be executed on the furthest object first. Moreover several pixels of the objects are over recorded which is unnecessary. This algorithm entirely rely on the total number of pixels and if the total number of pixels in the objects is N, the time complexity is O(N).

The distance between the display panel and lens is indicated by ‘g’. In addition (x,y) defines the physical location of a pixel. Again, ‘L’ shows the distance between object and lens. Moreover, (cX,cY) indicates center of the elemental lens. The index of (sX,sY) is indicated by (iX,iY). Flowchart of Direct Algorithm has shown in fig (4.2)

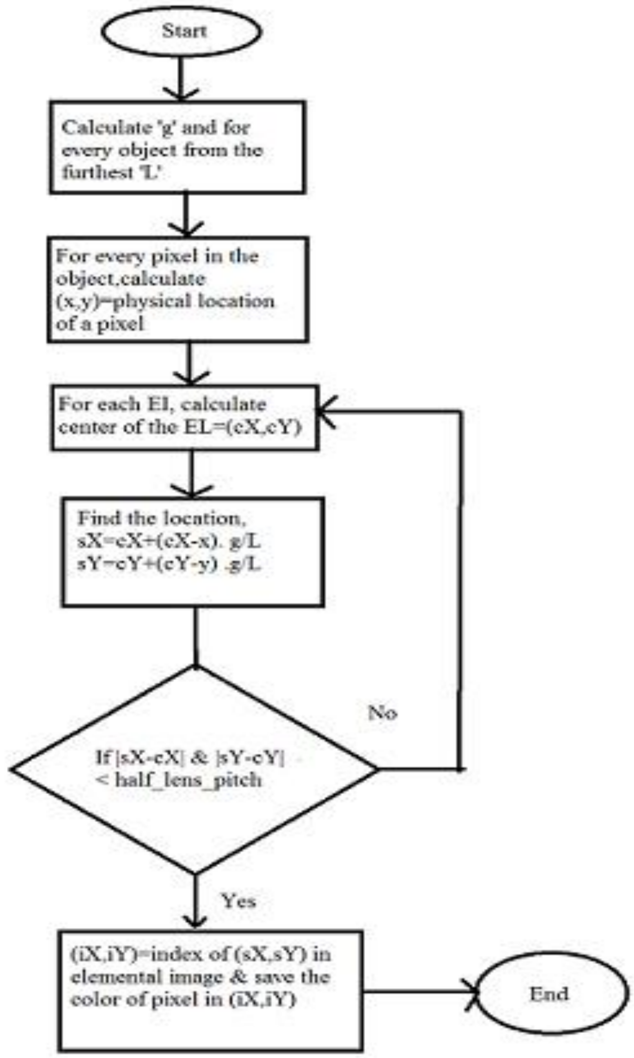


Figure 4.2 : Flowchart of Direct Algorithm

Efficient Algorithm: The complete process of efficient algorithm is given through the Fig (4.3)

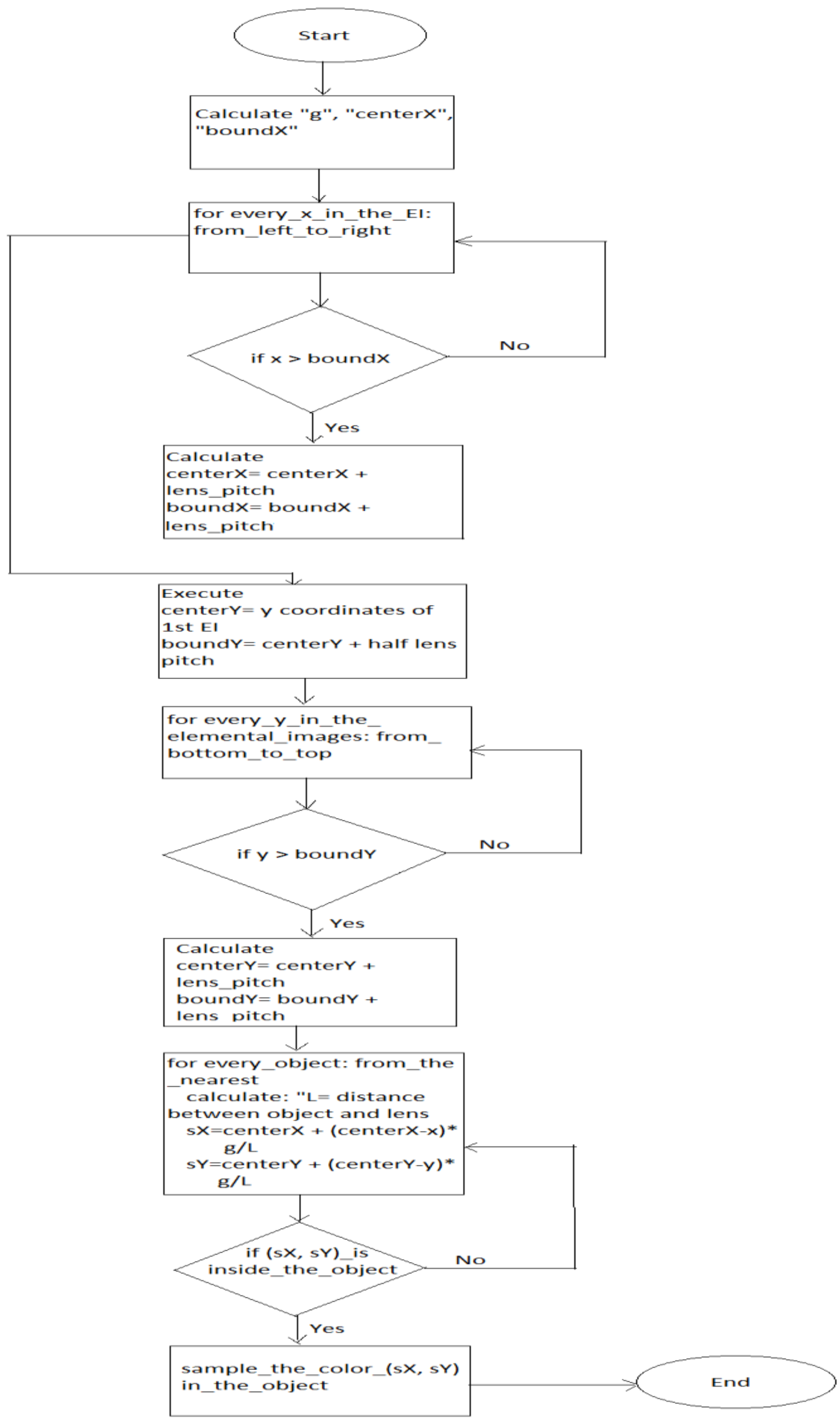


Figure 4.3 : Flowchart of Efficient Algorithm:

Efficient Algorithm was introduced to increase the efficiency of Direct Algorithm. It takes less calculation time since emergent information are recorded by it exclusively. In the fig(4.3) g determines distance between display panel and lens, centerX describes x coordinate of first elemental lens, boundX defines sum of centerX and half lens pitch and L describes distance between object and lens.

4.2 Comparison between Direct Algorithm and Efficient Algorithm

During elemental image generation some pixels are recorded recurrently that has an effect in calculation time in direct algorithm whereas efficient algorithm takes less calculation time since emergent information are recorded by it exclusively.

Images	Time calculation by using direct algorithm (sec)	Time calculation by using efficient algorithm (sec)
Image1	27	24
Image2	26	23.5
Average	26.5	23.75

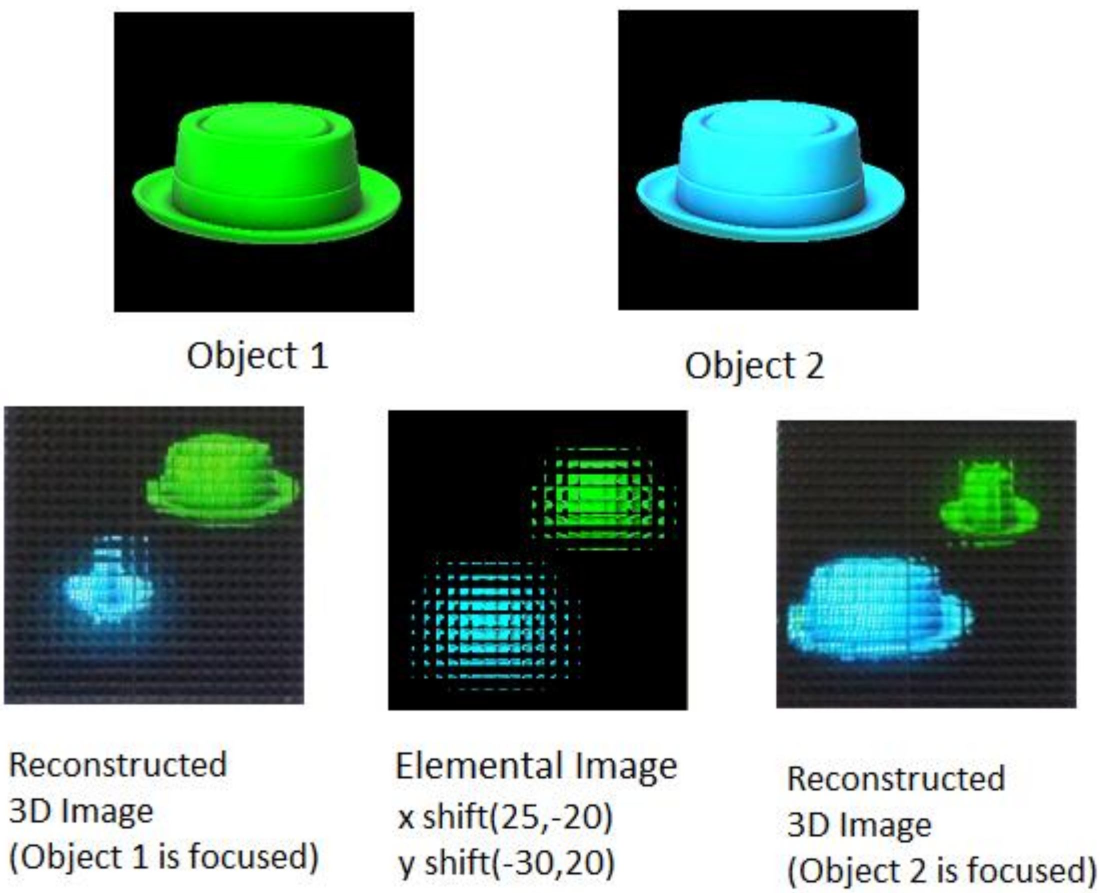
Table 4.1 : Time calculation by using direct and efficient algorithm

4.3 Experimental result of CGEI

Result of Direct Algorithm

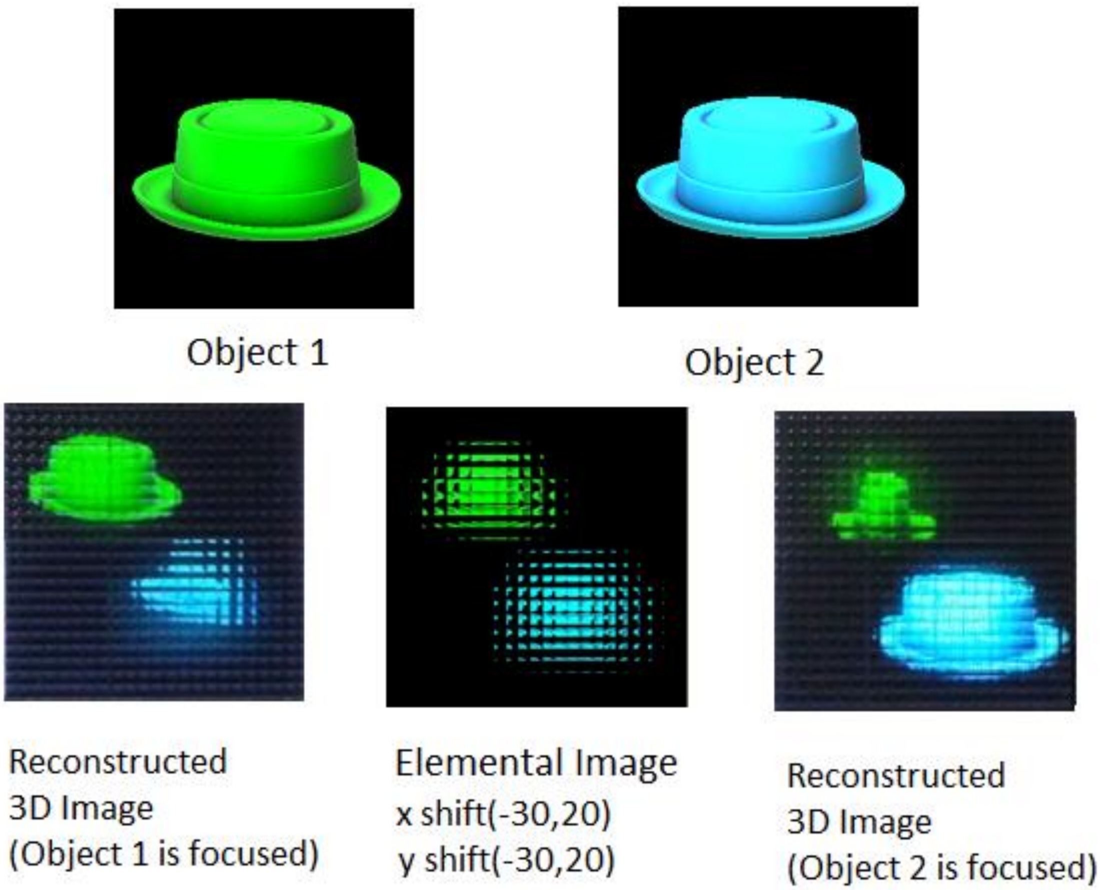
In type 1, green color hat is considered as Object 1 and blue color hat is considered as Object 2. During elemental image generation we have fixed the position of the both object (0, 0) that assist for image overlap.

Position of object 1 is (x_1, y_1) = (25,-30) and position of object 2 is (x_2, y_2) = (-20, 20) has taken to reduce the trouble.



Type-1

In the same way, in type-2 the position of object 1 is (x_1, y_1) = (-30,-30) and position of object 2 is (x_2, y_2) = (20, 20) has taken to reduce the trouble.

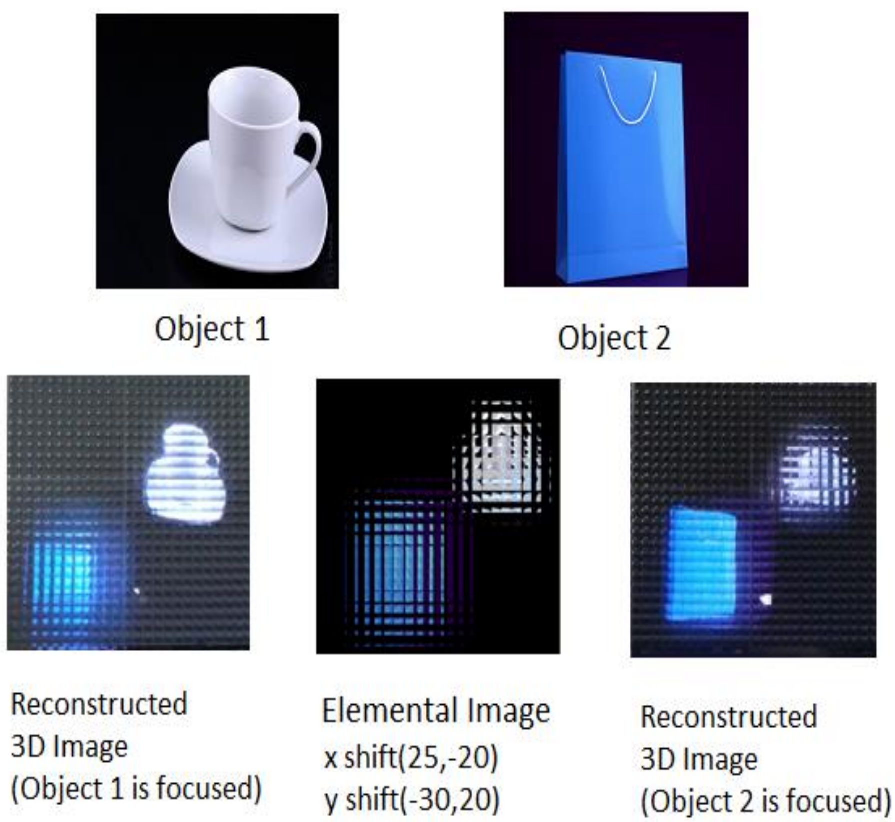


Type-2

Figure 4.4: Experimental result using Direct Algorithm

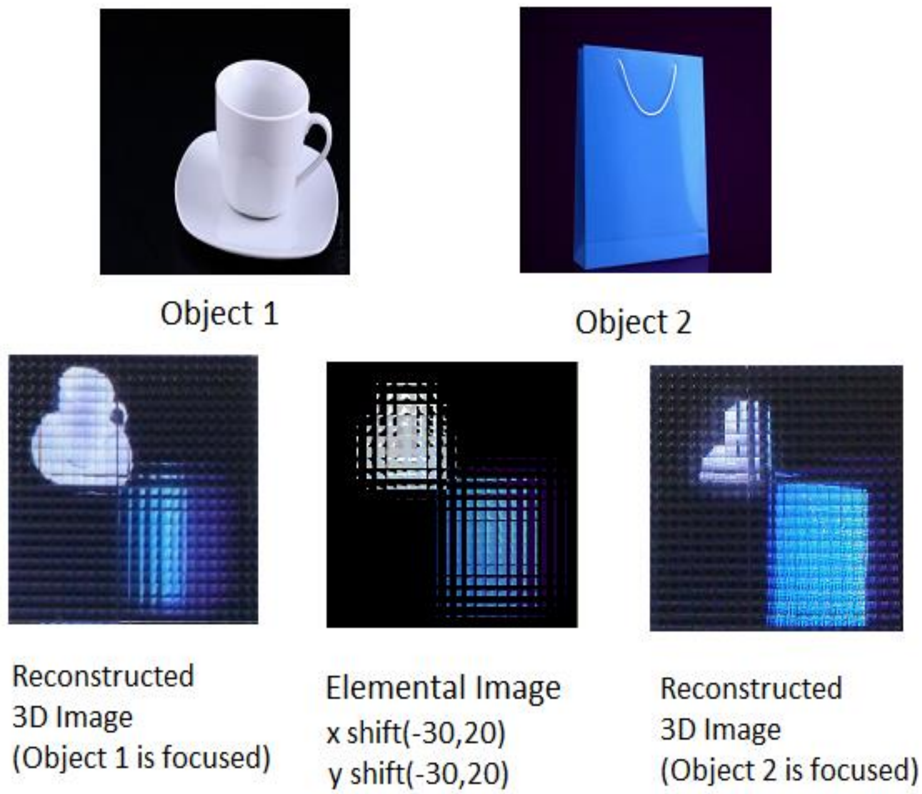
Result of Efficient Algorithm

In type 1, cup is considered as Object 1 and bag is considered as Object 2.
During elemental image generation we have fixed the position of the both object (0, 0) that assist for image overlap.
Position of object 1 is (x_1, y_1) = (25,-20) and position of object 2 is (x_2, y_2) = (-30, 20) has taken to reduce the trouble.



Type-1

Similarly, in type-2 the position of object 1 is (x_1, y_1) = (-30,20) and position of object 2 is (x_2, y_2) = (-30, 20) has taken to reduce the trouble.



Type-2

Figure 4.5 : Experimental result using Efficient Algorithm

CHAPTER-5
ELEMENTAL IMAGE GENERATION METHOD FOR REAL OBJECTS USING DEPTH CAMERA

5.1 Basic Concept

In the integral imaging pickup process, the elemental images are captured by a charge-coupled device (CCD) camera where a lens array is used so that each elemental lens forms a corresponding image of the object. The conventional pickup method has some disadvantages due to using lens array. It fails to place the lens array and a CCD camera in the exact position. Along with that it allows unnecessary beams to pass through the lens array which obstruct for generating elemental images. Again, decomposition of the lenses defense for the post processing of generated elemental images. Further, it is really complex for the camera lens and lens array to generate elemental images from large objects. Hence, new method is proposed to solve the problems and the outline is given below:

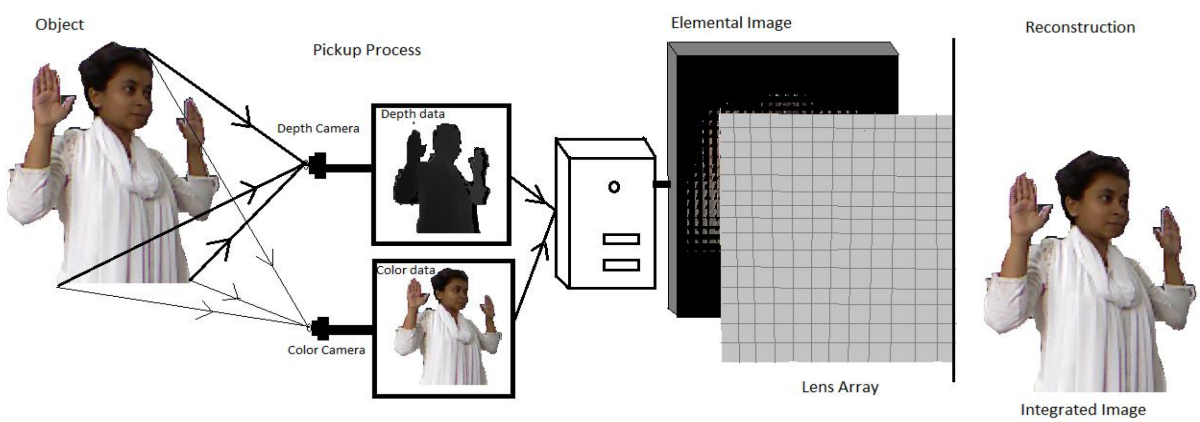


Figure 5.1 : Concept of Elemental Image Generation Method for Real Objects Using Depth Camera

The new method is efficient to generate elemental images from a real object except any kind of lens array. Since it does not require any kind of lens array like conventional pickup process, it has actually simplified the optical setup of the pickup process. The new method can generate elemental image using depth camera.

5.2 Required software and hardware

Requirement for this method is- Kinect sensor, PC and LCD monitor. Kinect is a motion-sensing device which was originally developed for the Xbox 360 gaming console. The kinect sensor bar contains color camera, depth sensor, a special infrared light source, and four microphones. A tilt motor working as the base enables the device to be titled in upward and downward direction. The main components of the kinect sensor is given below

Figure 5.2 : Components of Kinect sensor

5.3 Elemental image generation using a depth camera

Fig(5.3) shows architecture of the elemental images generation. There are mainly three steps and they are- input, calculation and display. Firstly, input stage perceives the color and depth information of real object. According to the information of the input, calculation stage performs pixel mapping process. Lastly, in the display stage elemental image is generated.

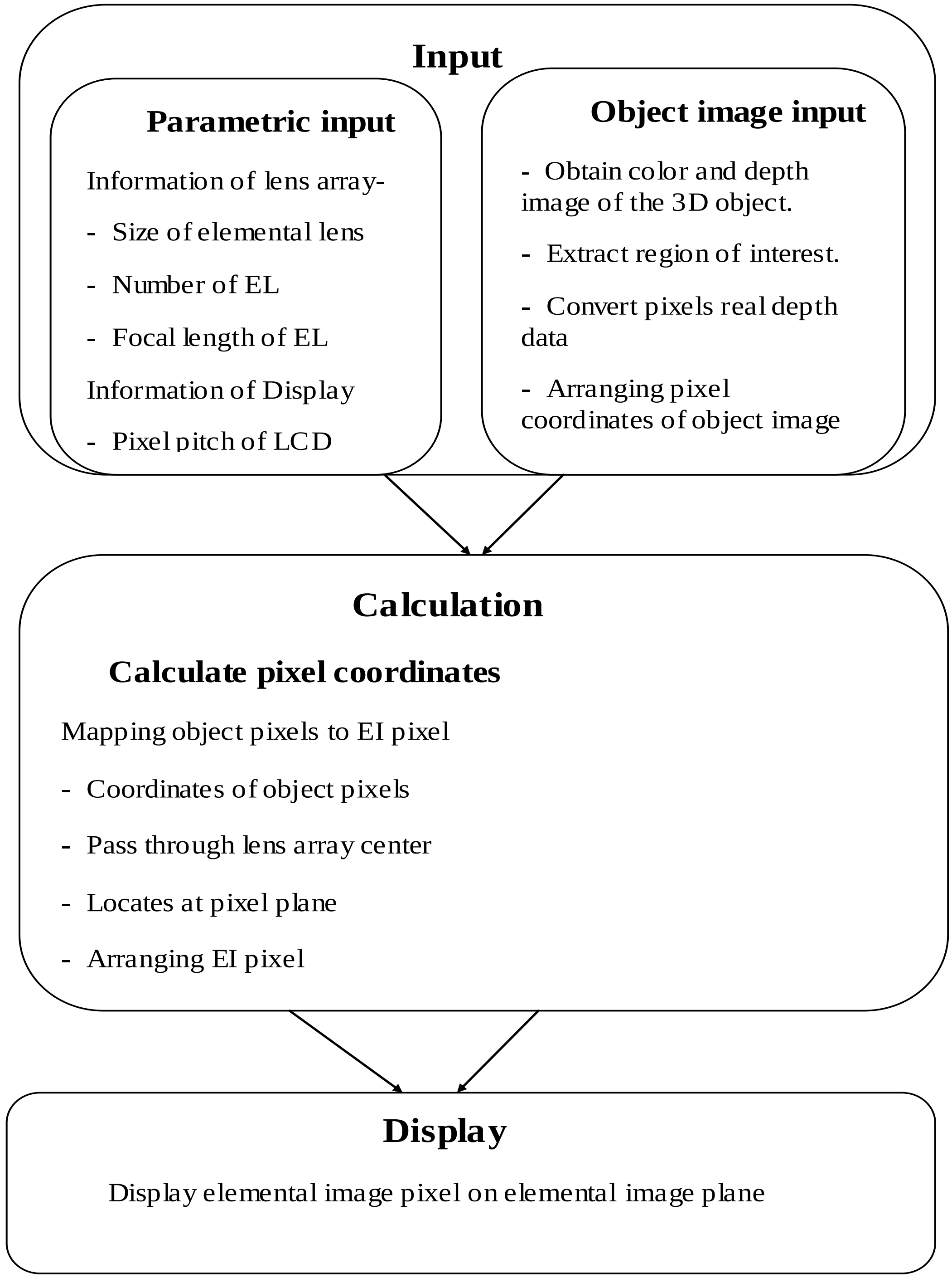


Figure 5.3 : Architecture of Elemental Image Generation Method for Real Objects Using Depth Camera

5.3.1 Input stage

In input stage two types of input-Parameter input and Object image input are taken. Moreover, in parameter input, the information of the lens-array like number, size, focal length of elemental lens is stored. Similarly, Information of display like-pixel pitch of LCD, gap between lens and display are taken.

As input, object image obtain color and depth image of the 3D object. Again, it extract region of interest of 3D object and convert the real depth data of the object. Lastly, it arranges the pixel coordinates of object image.

5.3.2 Calculation and generation stage

In calculation stage, three buffers are needed to create where first buffer is used to store the information of every object pixel, second buffer is used to reserve for the center coordinates of the elemental lenses and the third buffer store the calculated elemental image pixel set.

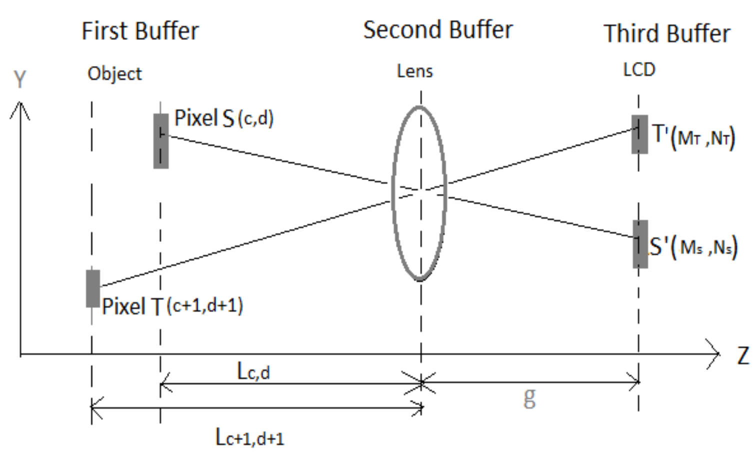


Figure 5.4 : Geometry for pixel mapping of Elemental Images Generation.

fig (5.4) shows the geometry of pixel mapping through an elemental lenses from object pixels to the elemental image. Actually, the coordinates of the elemental lenses center are calculated based on lens pitch and elemental lens indices. Fig.(5.4) shows that, object will be located at the positions of elemental image plane S'(m, n) after passing the ray of the object pixel S(c, d) through the center of the lens. The pixel coordinate (m, n) is given by

$$m = P_L.c_L - (c.P_I - P_L.c_L).\frac{g}{L_{(c,d)}} \ldots\ldots\ldots\ldots\ldots\ldots (5.1\ )$$

$$n = P_L.d_L - (d.P_I - P_L.d_L).\frac{g}{L_{(c,d)}} \ldots\ldots\ldots\ldots\ldots\ldots(5.2)$$

Where, $P_L$is the pitch of elemental lens, P_I is the pixel size of the object image, g is the gap between lens and display, c and d are the object pixel indices in the x and y axis , c_L and d_L are the indices of the lenses on x and y axis, $L_{(c,d)}$ is the depth data.

Data collected from Kinect sensor:

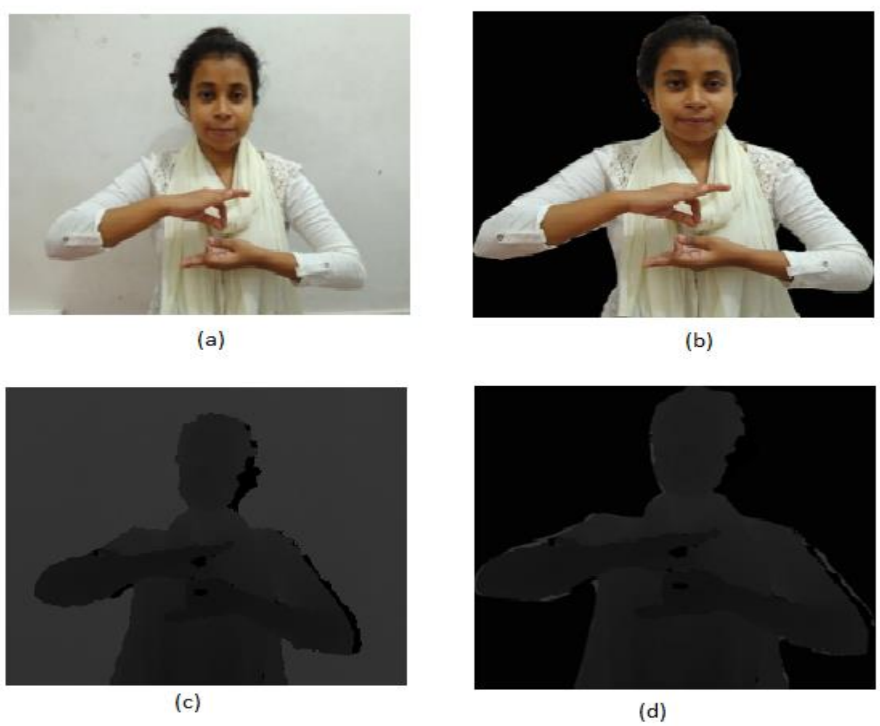


Figure 5.5 : (a) color images of the object (b) interested region of color image

(c) depth image of the object (d) interested region of the depth image.

The color image and depth image was collected through the kinect sensor. By using image processing background was avoided from the object image and the interested area was extracted which is shown in fig (5.5)

By using color and depth information of the object elemental image is generated. Here, matLab was used to create the elemental image. Fig(5.6) shows the elemental image generation.

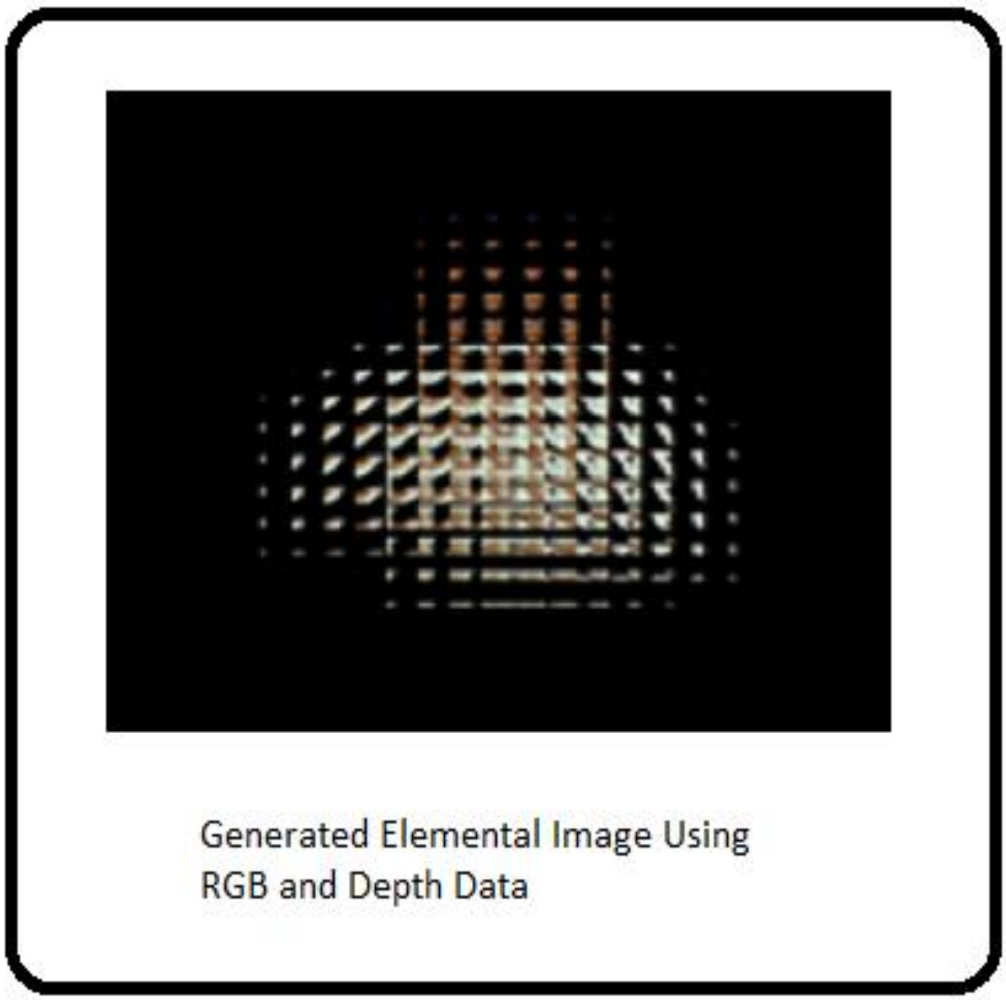


Figure 5.6 : Elemental image generation using color and depth data

In display process, elemental image pixel is displayed on elemental image plane.

5.3.3 Experimental result

We have captured Reconstructed 3D Images from different views (center, top, left, right, bottom). The result is given below-

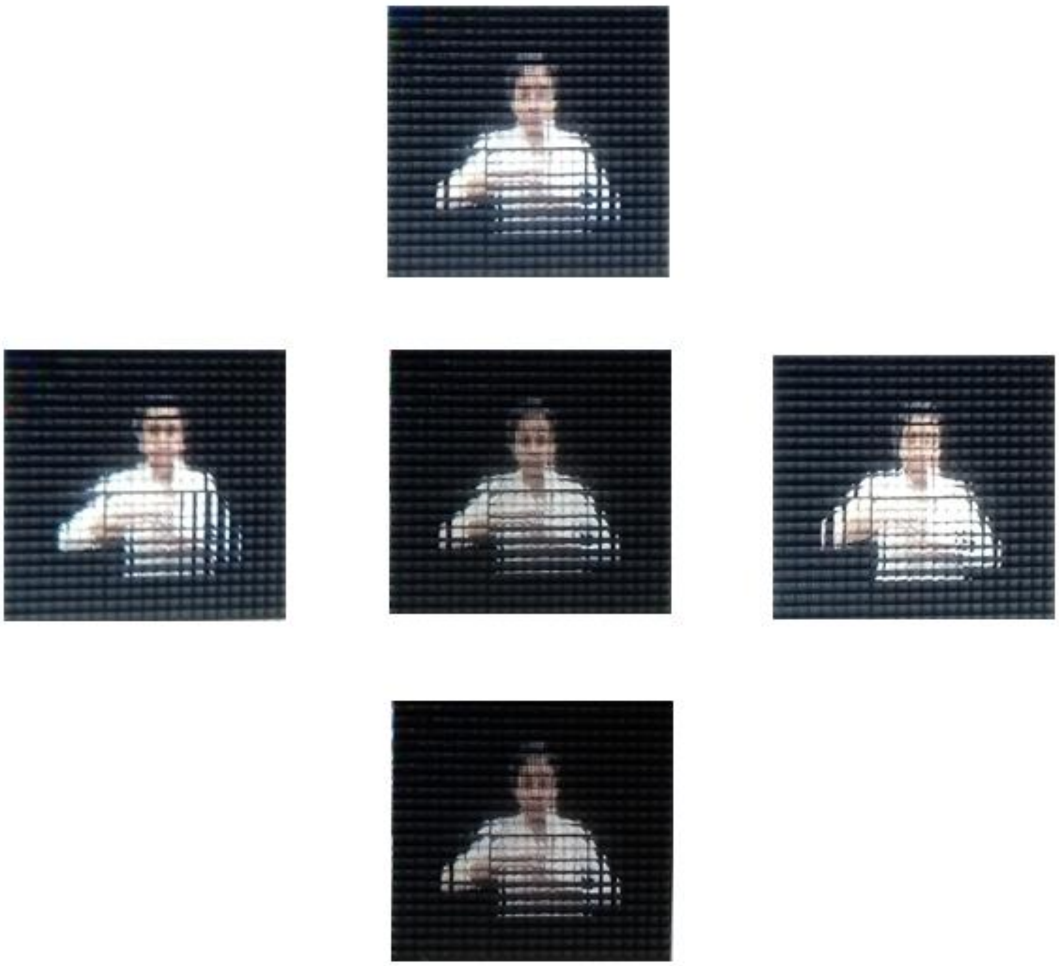


Figure 5.7 : Reconstructed 3D Images from five different views

CHAPTER 6
ENHANCEMENT OF VIEWING ANGLE BY DIRECTIONAL ELEMENTAL IMAGE GENERATION ALGORITHM AND MULTIDIRECTIONAL PROJECTION SCHEME

6.1 Viewing zone control of Integral Imaging Display using a Directional Projection and Elemental resizing method

Integral imaging (II) that can provide a full color, full parallax, real 3D image with continuous viewpoints and it does not require any supplementary glasses or tracking devices to view the 3D image that's why Integral Imaging is one of the most promising auto-stereoscopic 3D display techniques. In spite of having lots of benefits, conventional integral imaging technology also suffers from the following drawbacks-limited viewing-resolution, limited viewing-angle, limited image-depth range and difficulty in compatibility with 2D images. Among those limitations, the narrow viewing angle is the most serious drawback in II which acts as an obstacle for commercial implementation. Actually, the main reason behind this problem is limited area where each elemental (constituent) image can be displayed. To solve this problem, various techniques have been developed such as the curved lens array technique [14], the lens switching method [15], moving lenslet arrays with low fill factor [16], micro-convex-mirror arrays [17], multiple axis telecentric relay system [18], and two display devices and a lens array [19]; hence those techniques are not an appropriate solution for commercial application. Along with these, Choi et al. showed a multiple-viewing-zone II display using a dynamic barrier array that produces multiple viewing zones by guiding the light rays emanating from the elemental images (EIs) using a dynamic barrier array [20]. But, it is not appropriate for real time operation since mechanical movement is inefficient and speed is low.
Baasantseren et al. proposed a method for wide-viewing-angle II display using two EI masks [21]; where the light rays emitted from EIs are directed by two masks into corresponding lenses.

Shin et al. also demonstrated an II display with viewing direction control using 4f optical relay and a dynamic aperture to control diverging ray directions [22]. Although this method controls viewing direction by moving the aperture from the center of the optical axis of the lens, it is difficult for practical implementation because of its inefficient and heavy optical setup.

Recently, another new method developed which mainly use a directional projection of EIs at a predefined projection angle to control the viewing zone of the integral imaging display and the viewing zone shifts in terms of the projection angle [23]

A special type of elemental image-generation algorithm-i.e., a directional elemental image generation and resizing (DEIGR) algorithm was introduced in the new method based on a pixel-mapping algorithm by considering the directional projection geometry for each pixel according to the directional projection angle, and an elemental image resizing function. There was a mismatch between the EI and elemental lens pitch of the lens array, which occurred due to the directional projection. To solve this problem EI generation algorithm was applied. It does not require any barrier array to tilt the ray emerging from each EI. Unlike the systems demonstrated by Choi et al.[20], Baasantseren et al.[21], Shin et al.[22] the system indirectly directs light rays with directional projection of EIs without any ray-guiding equipment or technique. By using multi- directional projections of multiple sets of EIs, the viewing angle can be enhanced by two to three times that of a conventional II display system, depending on the number of EI sets used and the angles of projection.

The principle of this method is to control the viewing zone of the II display using directional projection of EIs with an EI resizing method. With directional projection of EIs, the point light sources (PLSs) produced by the micro lens array shift a distance apart from the focal point of each micro lens according to the directional projection angle. As a result, diverging ray direction and viewing zone changes with respect to the central projection. On the other hand, same sized micro lens pitch and directional projection of EIs create a mismatch since the shape of each EI is changed by the directional projection geometry. Due to solve the EI mismatch EI resizing method introduced.

The distance of the PLS shift relates to the projection angle and can be expressed as

$$d = f \tan\alpha \quad \text{........................ (6.1)}$$

where f= focal length of the microlens, α = projection angle, d= distance.

Again, α_L = left directional projection angle, α_R = right directional projection angle

$$\alpha_L = \tan^{-1}\left(\frac{P_L}{2f}\right) \quad \text{and} \quad \alpha_R = -\tan^{-1}\left(\frac{P_L}{2f}\right)$$

The viewing angle of a conventional II display can be expressed as

$$\theta = |\theta_L| + |\theta_R| = 2\tan^{-1}\left(\frac{P_L}{2f}\right) \text{......................} \ (6.2)$$

6.1.1 DEIGR algorithm for DEI generation

The lens pitch is indicated by P_L, coordinate of elemental image pixel is given by e_x, e_y and the projection angle is defined by α

The DEIGR algorithm is given below

Step 1:Arrange the coordinates by depth direction

Step 2: Take input (x,y,z)$\rightarrow$[object]

Step 3: Calculate pixel of each image using mapping function considering the projection angle for each object point.

Step 4: If :

$$| e_x - g\tan\alpha - lenscenter(1) | < \frac{P_L}{2} \,\&\&\, | e_y - lenscenter(2) | < \frac{P_L}{2}$$

Step 5: Define EI pixel for object point.

Step 6: Else:

Back to step 3

[if yes]

Step 7: Save EI pixel in EI buffer.

Step 8: If

New point found

Step 9: Back to step 2

Else :

Step 10 : Resize EI

For Horizontal DEI (x,y)= $\left(P_L \cos\alpha, P_L\right)$

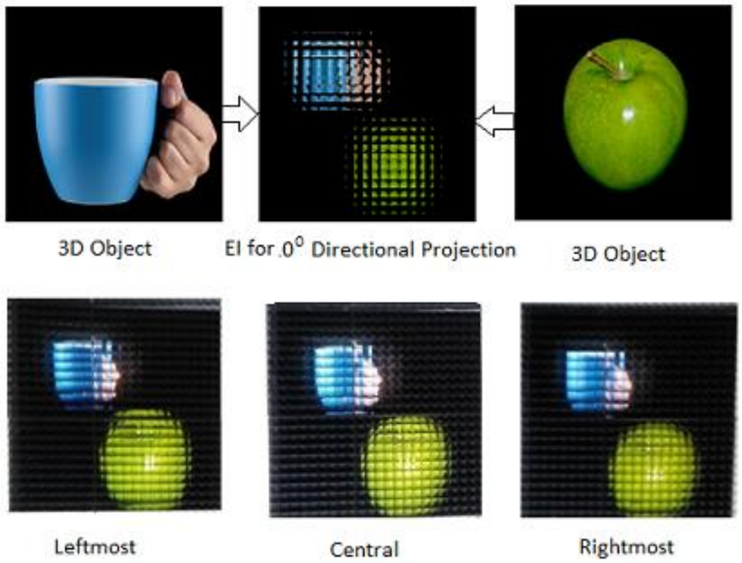
For Vertical DEI (x,y)= $(P_L, P_L \cos\alpha)$

Step 11 : Complete set of DEIs

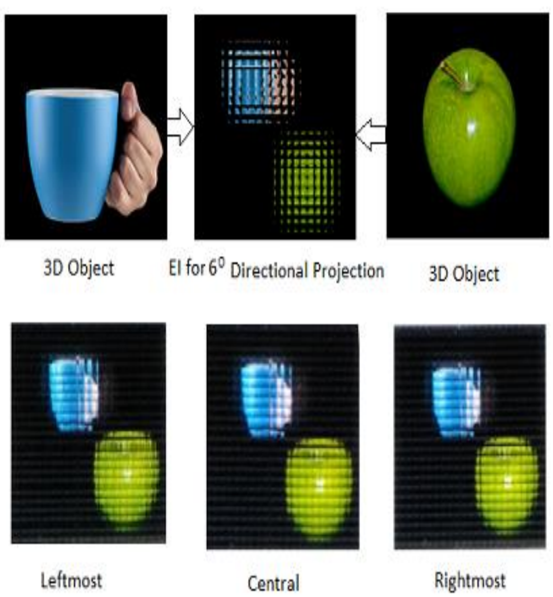
Step 12 : End

6.1.2 Experimental Results

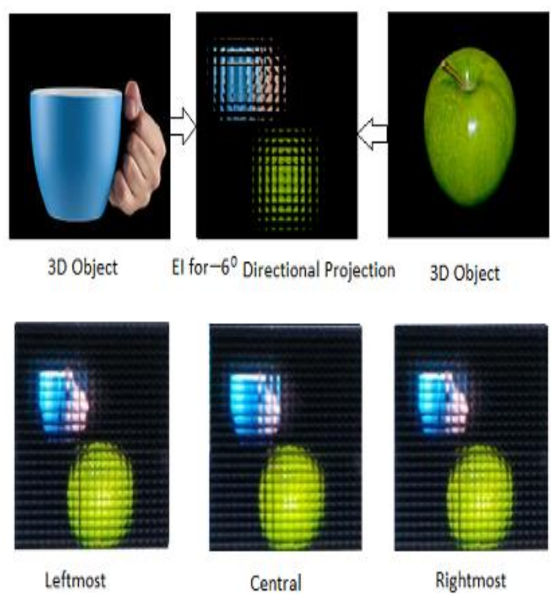
During experiment we have collected data for different directional projection angle which is shown in Fig. (6.1)



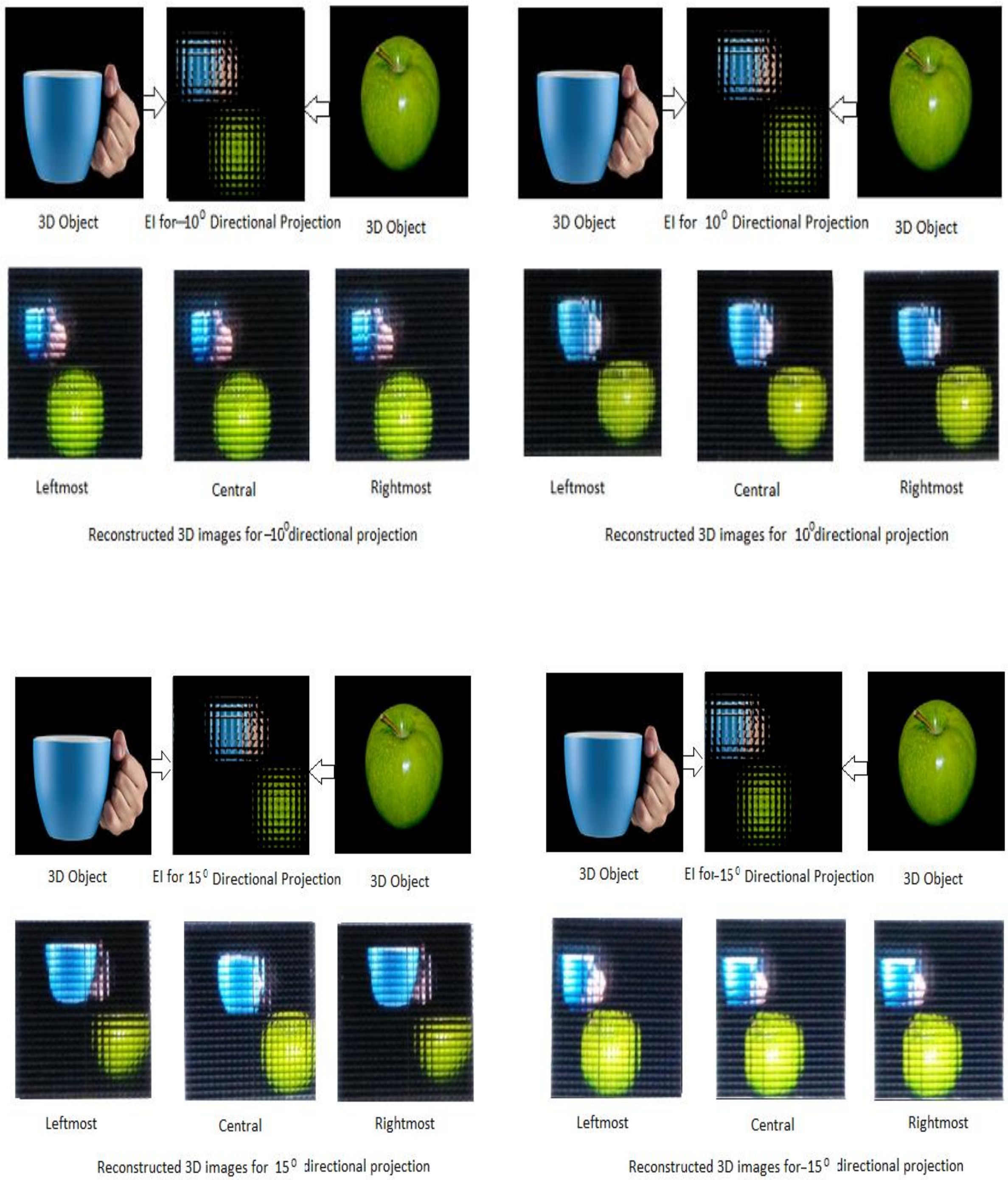
Reconstructed 3D images for 0^0 directional projection



Reconstructed 3D images for 6^0 directional projection



Reconstructed 3D images for -6^0 directional projection



r

Figure 6.1 Reconstructed 3D images from different directional projection

6.2 Viewing angle enhancement using a Time-Multiplexed Two-Directional Sequential Projection Scheme and a DEIGR Algorithm

Viewing-angle-enhanced integral imaging display (VAEIID) system was introduced and implemented by using a time-multiplexed, two-directional sequential projection (TTSP) scheme and a DEIGR algorithm. VAEIID system is composed of three main parts: acquisition, processing and display. Firstly, Microsoft Kinect Sensor is used to collect depth and color information of a real object [24]. Two sets of directional elemental images (DEIs) are then generated by synthesizing the extracted depths and color information of the real object for two different angular perspectives using the DEIGR algorithm. Lastly, these two sets of DEIs are projected through the proposed VAEIID system in a time multiplexed sequential manner with two digital light processing (DLP) projectors using a TTSP scheme.

To achieve an enhanced viewing angle of almost two times the conventional method, the two directional projection angles can be determined depending on the parameters of the display components of the VAEIID system from the following expressions:

$$\alpha_L = \tan^{-1}\left(\frac{P_L}{2f}\right) \text{ and } \alpha_R = -\tan^{-1}\left(\frac{P_L}{2f}\right)$$

α_L = left directional projection angle, α_R = right directional projection angle.

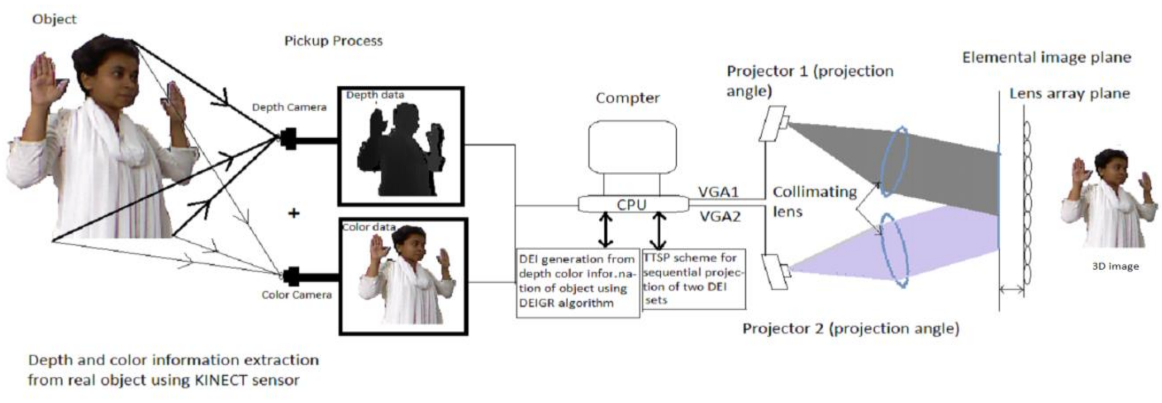


Figure 6.2 **:** Architecture of Viewing-Angle-Enhanced Integral Imaging Display (VAEIID) system.

The architecture of the VAEIID system is shown in Fig. (6.2). The VAEIID system follows three main steps:

i) Acquisition of depth and color information of a real object,

ii) Information processing and generation of two sets of DEIs using a DEIGR algorithm

iii) The TTSP scheme for the two-directional sequential projections of two sets of DEIs.

The specific functions of these three steps are as follows.

Step 1: In acquisition process, the depth and color information of a real object is extracted by Kinect sensor and the Open CL Library. The information (depth and RGB) are to be used in the elemental image generation process for creating two sets of DEIs in order to project them in two different directions using the TTSP scheme.

Step 2: In this step, the extracted information of the real object generates two sets of DEIs by using a DEIGR algorithm. The DEIRG algorithm can generate different DEI sets in terms of predefined angular directions by synthesizing the information (depth and color) extracted from the real object. The directional projection angles are determined by

$$\alpha_L = \tan^{-1}\left(\frac{P_L}{2f}\right) \qquad \text{and} \qquad \alpha_R = -\tan^{-1}\left(\frac{P_L}{2f}\right)$$

$\alpha_L =$ left directional projection angle, $\alpha_R =$ right directional projection angle.

Step 3 : By using a TTSP scheme, two DEI sets are projected. In this scheme, the two DEI sets can share the same projection screen as well as be retraced through the same lens array which avoids elemental image overlap.

A DEIGR algorithm is used for generating two DEIs sets from information (depth and color) of a real object extracted by using a Kinect sensor, in order to project them in two different directions. The DEIGR algorithm is capable of synthesizing the extracted depth and RGB color information of the real object with different angular perspectives.

The appropriate projection angles are determined by some parameters such as elemental lens pitch (PL), gap between the EI plane and the lens array (g), the displacement of the PLS (d). Then, two DEI sets are generated by using the DEIGR algorithm. The DEIGR algorithm is based on a pixel mapping algorithm [25] and considering the directional projection geometry of each pixel for the object's planes, as well as the elemental image plane in terms of directional projection angle. [26]

Experimental Results

The color image and depth image was collected through the kinect sensor. By using image processing background was avoided from the object image and the interested area was extracted which is shown in fig (6.3)

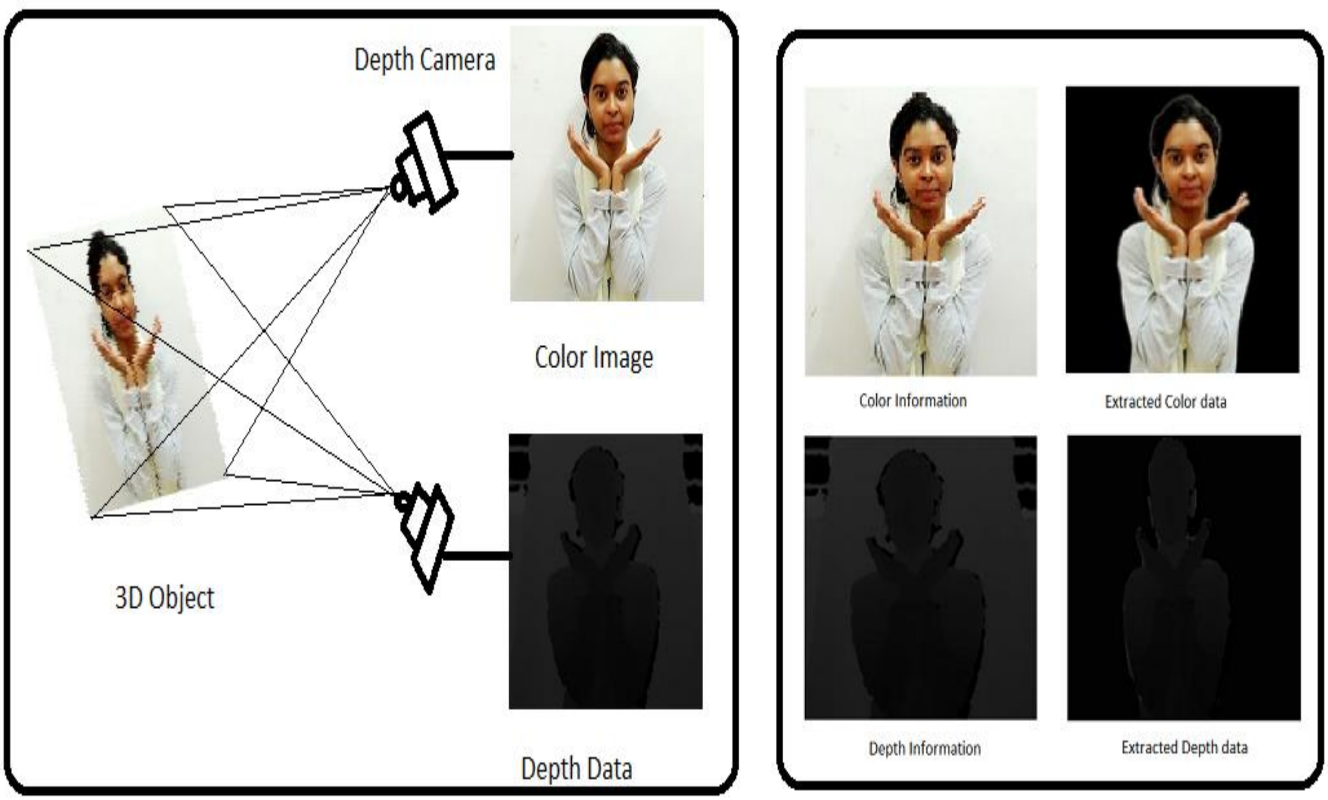


Figure 6.3: Extracted interested region of color and depth image from 3D object using depth camera

Generated Elemental image using RGB and Depth data and constructed 3D images captured from different viewing angle (-14, 0, 14 degree)

RGB Data

Depth Data

Elemental Image for 0 Degree Projection

leftmost captured Image(-14^0)

Central Captured Image(0^0)

Rightmost Captured Image(14)

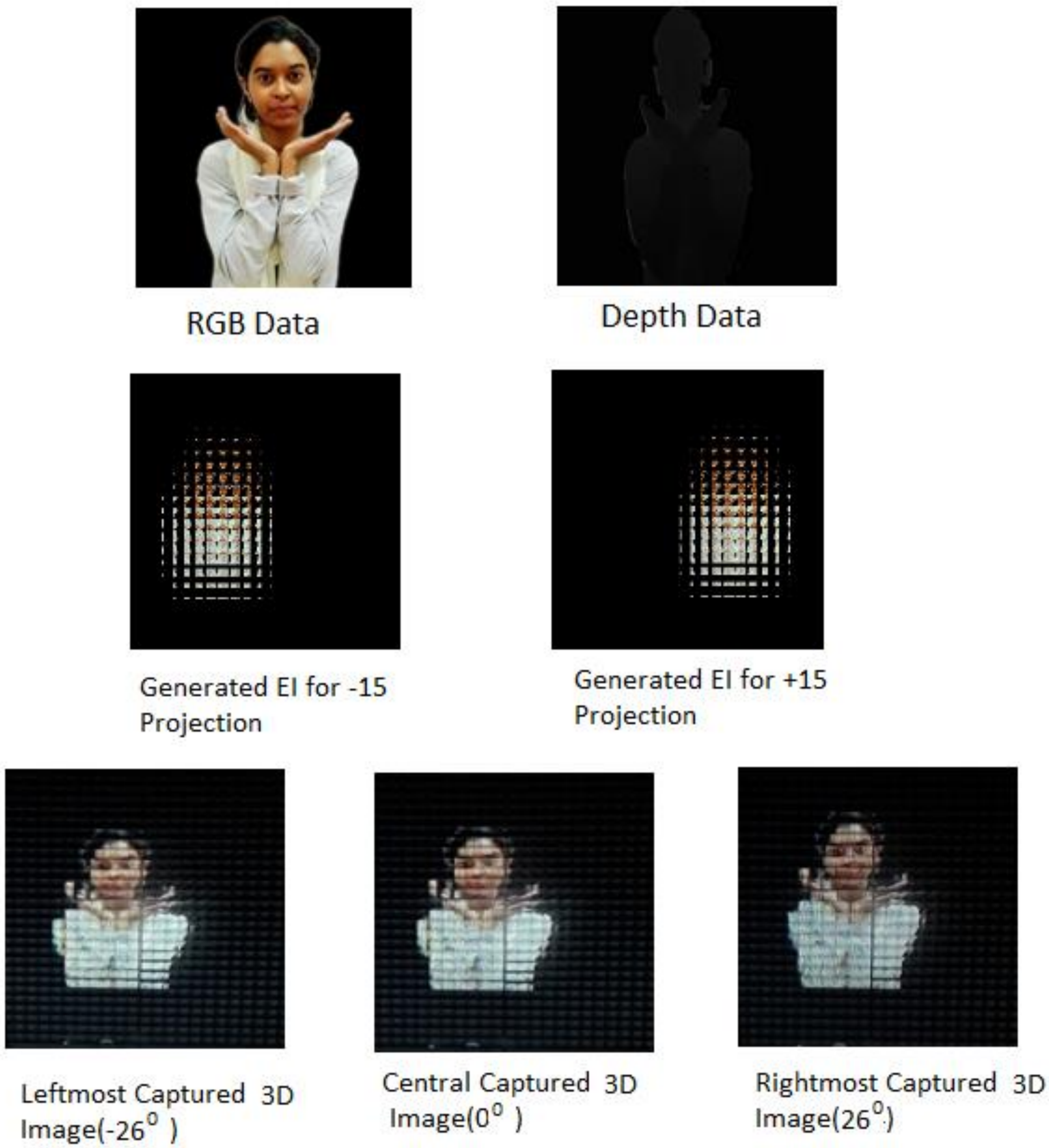
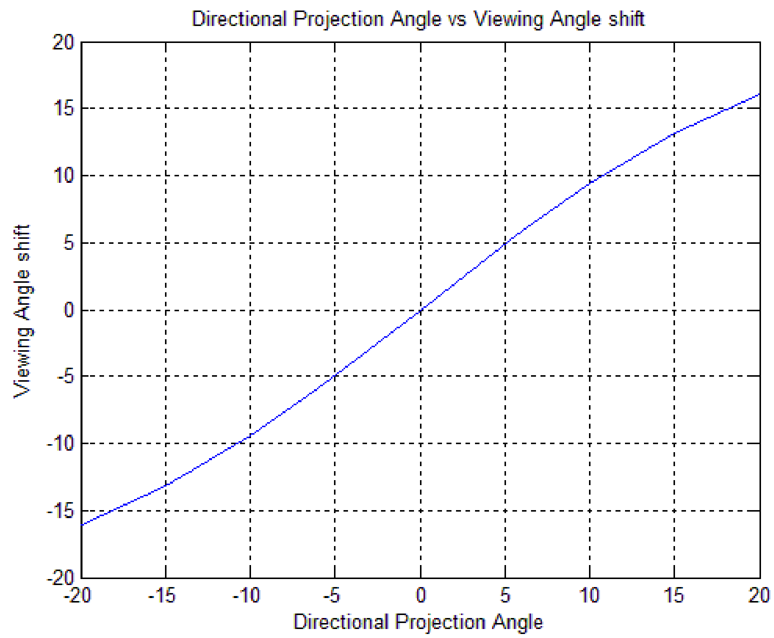


Figure 6.4 Generation of Elemental Image and reconstructed 3D Images from different viewing angles

From experimental data analysis, we found that viewing angle is proportional to Directional Projection angle. If Directional projection angle increases viewing angle also increases.



Graph 6.1: Directional Projection Angle vs viewing angle shift

CHAPTER 7

SUMMARY AND CONCLUSION

At first, we studied about direct pickup method of integral imaging 3D display system. In this method, the object information are captured thorough a array of small lenses called elemental lenses and each lens produce an elemental image by tracing the ray emanating from the object specific lenslet of the lens array. As a result, a array of elemental images can be directly captured by a CCD camera. This method causes noise with the captured elemental image.

Secondly, we studied CGEI method which is capable of eliminating the noises that causes in direct pickup method. Several algorithms for CGEI method have been studied and analyzed. CGEI method can only generate elemental images from synthesized 3D object points from a 2D image which is not real depth of object information.

Thirdly, we studied about elemental image generation method using real depth and color information of a real object which can overcome the limitation of CGEI method.

Finally, we studied the DEIGR algorithm and multi-directional projection schemes that can solve most of the drawbacks of integral image display.

From the study and analysis, we can conclude that multi-directional elemental image generation and projection schemes can be the breakthrough of integral imaging display technique and can be commercially implemented for a true 3D display system.

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