Virtual 3D Interactive System with Embedded Multi-wavelength Optical Sensor Array and Sequential Devices

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ABSTRACT

We proposed a virtual 3D-touch system by bare finger, which can detect the 3-axis (x, y, z) information of finger. This system has multi-wavelength optical sensor array embedded on the backplane of TFT panel and sequentail devices on the border of TFT panel. We had developed reflecting mode which can be worked by bare finger for the 3D interaction. A 4-inch mobile 3D-LCD with this proposed system was successfully been demonstrated already.

Keywords

Embedded multi-wavelength optical sensor, 3D interactive system

1. Introduction

Interactive systems are interfaces between users and machines. Most of them are limited to only obtain 2D position of the object [1]. However, 3D display [2] has become main stream today. Thus, 3D interactive systems will be needed and many methods and constructions have been presented to achieve 3D interaction. Recently, the 3D interactive systems can be classified into machinery, camera and optical sensor based, as shown in Fig. 1. The machinery based interactive system [3] exploits head-mounted component, glove and other machine to achieve 3D interaction, but it needs many inconvenient devices on hand or head. As for camera based, depth information can be calculated by using different

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methods. For example, BrightShadow [4] which is presented by Tokyo University combines two cameras and two groups of light emitters to get shadows of finger. The distance between two shadows used to calculated depth value. Although the camera based system provides high resolution image and accurate 3D position of object, there are still some issues such as narrow viewing angle and large volume. Narrow viewing angle refers to the working range of this system is far away the panel. To decrease volume of interactive system and achieving approach sensor, embedded optical sensor based [5] is one of solutions.

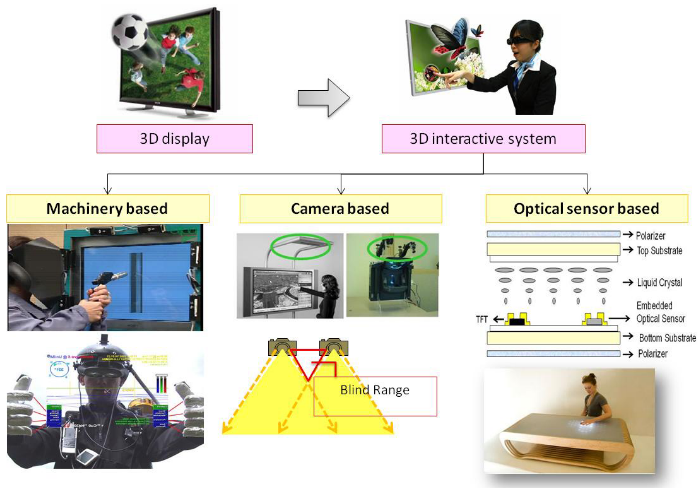


Figure1. Classification of 3D interactive system

2. Motivation

Based on embedded optical sensor, the system could be distinguished into lighting mode and reflective mode, as shown in Fig. 2. The lighting mode was proposed by using light pen to interact with panel in three dimensions [5], as shown in Fig. 3. However, lighting mode suffers from inconvenience caused by extra device on hand. Moreover, optical sensor has lower resolution than CMOS and non-uniform sensitivity. Therefore, the resolution of sensors also affects the accuracy of 3D coordinates.

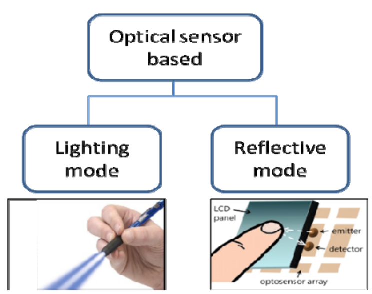


Figure2. Classification of optical sensor based

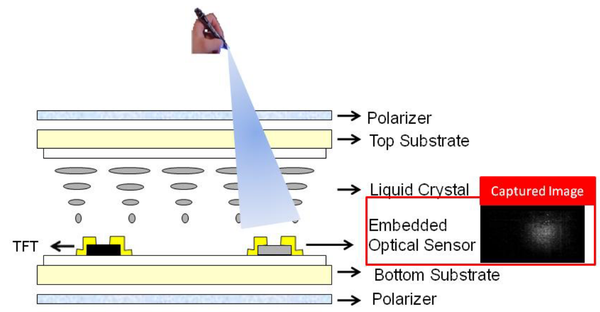


Figure3. Lighting mode of embedded optical sensor structure

The presented system takes reflecting mode to overcome those issues. Reflecting mode [6] means that the extra light sources placed on panel would emit light and be reflected by finger. Furthermore, we proposed a “region based depth” algorithm. According to this algorithm, the depth value (z) is calculated by overall integrated intensity of captured image in reflecting mode system. Thus, the depth value (z) will not be much affected by the resolution of sensors.

3. **Construction**

The construction of reflecting mode system consisted traditional display, embedded optical sensors, sequential light sources and IR backlight, as shown in Fig. 4. The light sources were placed on two side of panel and emitted light with different tilt angle sequentially. Moreover, the optical sensors included blue and IR sensors. Based on this construction, a 3D coordinates (x, y and z) of object could be obtained by a flow chart. There are three steps and shown in Fig. 5. The first step, the IR backlight passed through the panel and was reflected by finger. An image could be obtained and calculated for 2D coordinates (x, y). The second step, the light sources at two side of panel would emit light with different tilt angles sequentially and synchronize with optical sensor, as shown in Fig. 6.. Therefore, it meant that first optical sensor frame correlated with a tilt angle of θ. Following, the next frame correlated with 2θ. If the maximum tilt angle was n*θ, n images from step 2 could be obtained. Finally, a group of images (n+1) could be processed for 3D coordinates (x, y and z) of object by proposed algorithm.

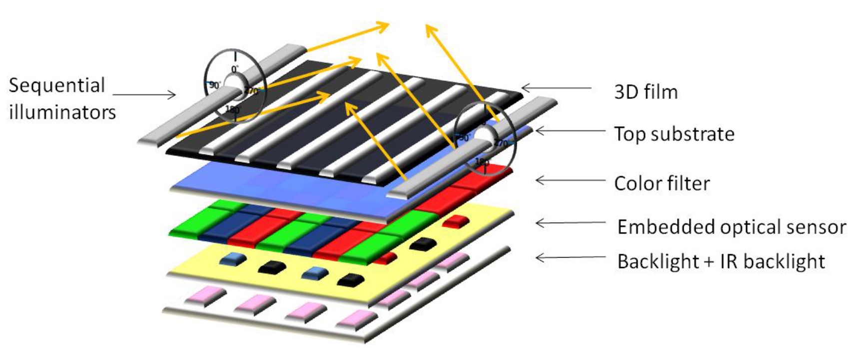


Figure4. Construction of reflecting mode system

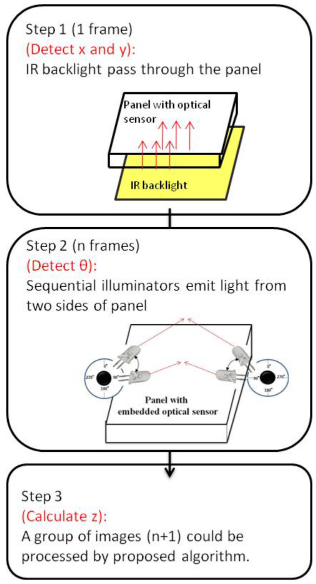


Figure5. Flow chart of reflecting mode

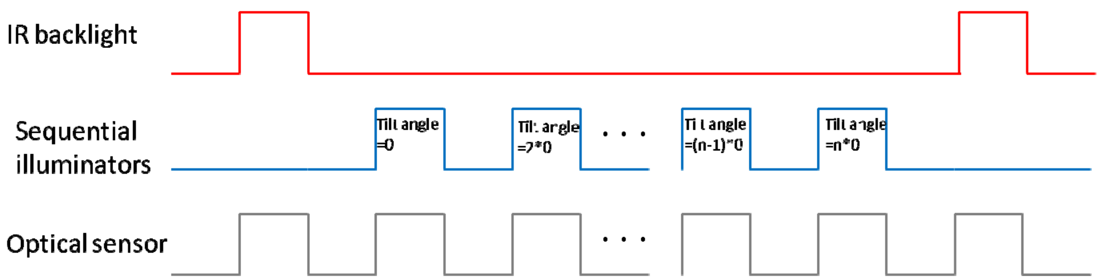


Figure6. Timing specification for sequential reflecting mode system

4. Region Based Depth Algorithm

The working range of reflecting mode system in x and y plane was covering the whole panel, yet in height was only detectable under few centimeters. It was limited by the reflectivity of fingers and the sensitivity of the current IR sensor array. Therefore, we proposed a "region based depth algorithm" to classify the scanning area to three regions, as red area shown in Fig. 7. When the object was placed at different regions, the intensity-tilt angle curve was different. The intensity-tilt angle curve was that accumulating all intensity of an image correlated with tilt angle in every frame. A frame implied that optical sensor captured an image when light sources emitted light with a kind of tilt angle. Furthermore, the light sources could illuminate the object at the same tilt angle when the object was placed at region I, which is the central line of the scanning area. Thus, the intensity-tilt angle curve only has single peak. In region II, two peaks appeared in curve because the object was illuminated by light sources at two side of panel with different tilt angles. And in region III, the light sources with maximum tilt angle at near side could not illuminate the object. Then, there was only single peak could be obtained.

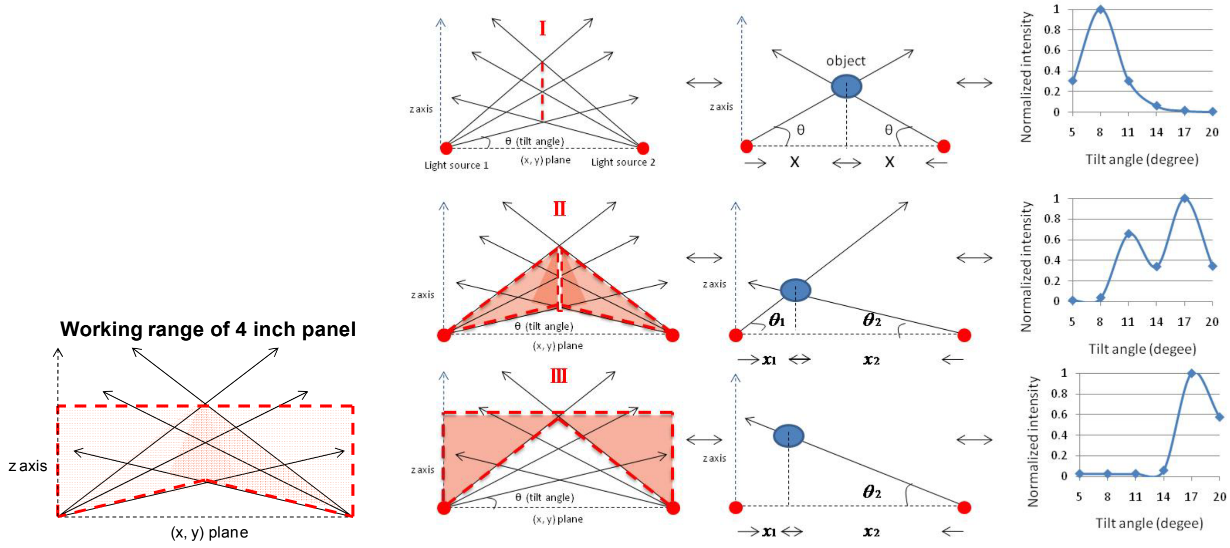


Figure7. Correlation between working range and intensity-tilt angle curve

According to the classification of working range, a group of images would be processed, as shown in Fig. 8. In region based depth algorithm, the first image of a group images was used to obtain 2D coordinates by full-search. Furthermore, the horizontal distance was distinguished into central position or not. Following, the special tilt angle was obtained by images from others. Special tilt angle meant that the sensors could capture an image with maximum intensity when light sources emitted with this angle. In other words, the special tilt angle is the peak of intensity-tilt angle curve. If the object was placed at region I, the light sources on two side of panel could be reflected at the same tilt angle. It meant that there was only one special tilt angel. But if object was placed at region II, there were two special tilt angles and the small distance and large tilt angle were chosen. However, the other condition was that the object was placed at region III. This condition implied that light sources with maximum tilt angle on nearer side could not illuminate the object. Thus, only large distance and small tilt angle were used. Finally, once we detected the special tilt angle (θ) and combined with corresponding horizontal distance (x), the depth value can be calculated by trigonometric function to figure out the depth value (z), as shown in Fig. 9.

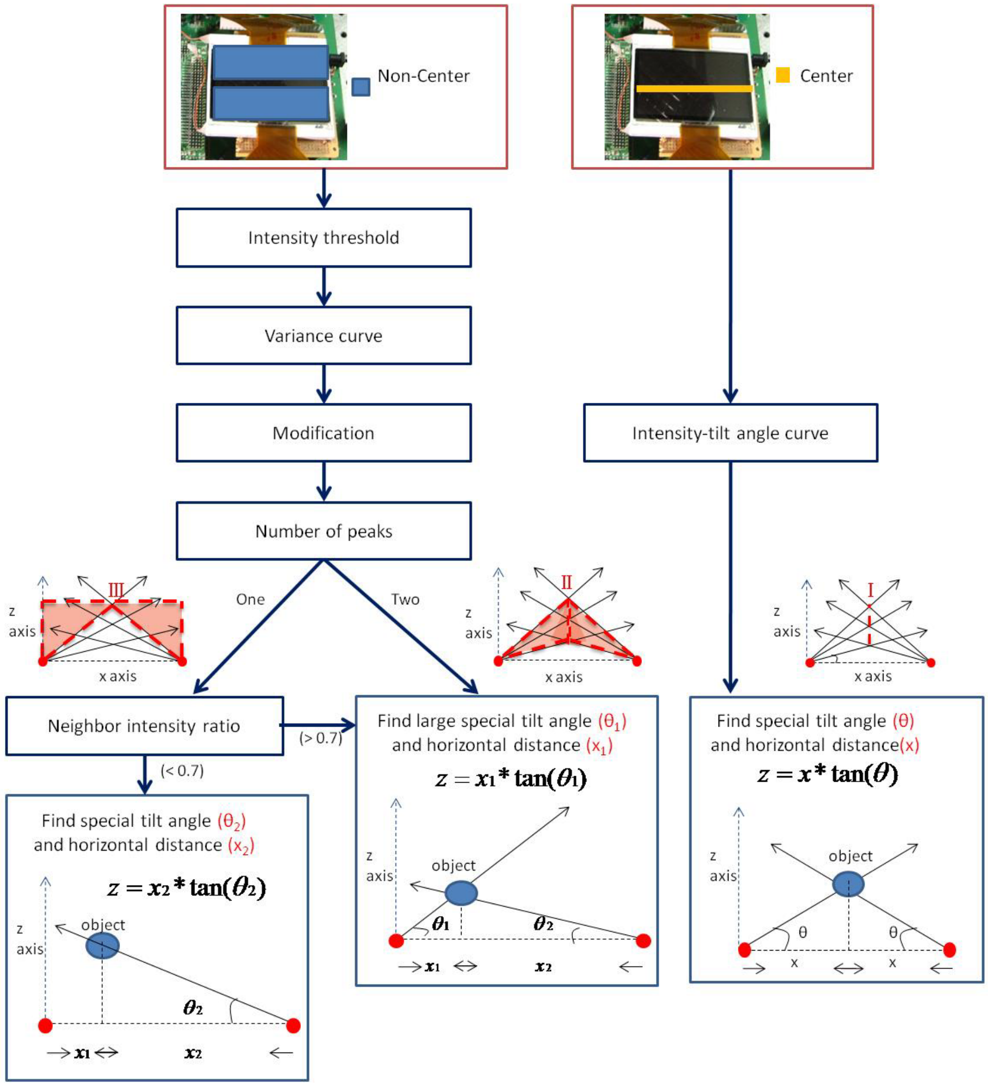


Figure8. Flow chart of region based algorithm

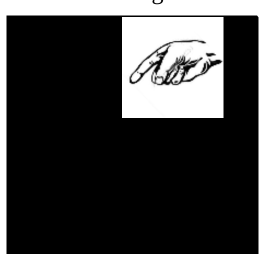
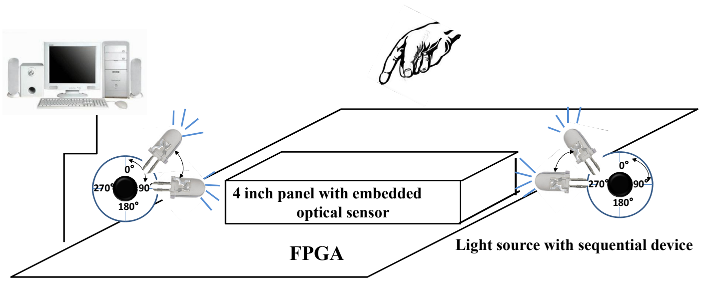


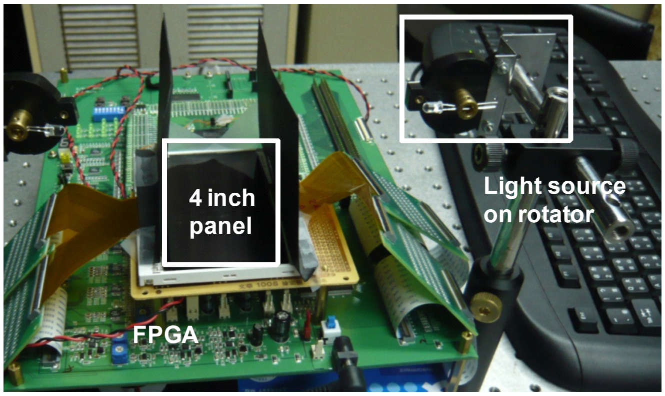
Figure9. Sketch of trigonometry

5. Experimental Results

To demonstrate the algorithm preliminarily, the sketch of experiment is shown as Fig. 10 (a) and the experimental platform is shown as Fig. 10 (b). The small divergence angle LED with wavelength of 450 nm was used to be the light sources. There are two reasons for these conditions of light sources. First, the blue sensors were used because of the high sensitivity. But blue sensors were affected by ambient light easily. Thus, the experiment was operated under dark environment. Second, the fixed object could be illuminated at neighboring tilt angles when divergence angle of light sources was large. Thus, the small divergence angle LED was chosen. However, if the sensitivity of IR sensor and intensity of IR light sources could be increased, this reflecting mode system could be used by using IR wavelength. Finally, this system could be operated under normal ambiance because the IR light is not affected by ambient light.



(a)



(b)

Figure10. (a) Sketch of experiment (b) Experimental platform

Based on this construction, the height was changed from 1 cm to 3 cm and the increment was 1 cm. Tilt angle of sequential light sources was adjusted from 6 degree to 48 degree and the increment was 6 degree under fixed 3D coordinates. According to those conditions, the experiment was designed.

When object was placed at region I, the light sources on two side of panel were reflected at the same tilt angle. In Fig. 11 (a), there was one peak appeared when height varied from 1 cm to 3 cm. But if object was near to one side, this condition could be classified into region II or III. In region II, the light sources on nearer side illuminated the object with larger tilt angle and on another side correlate to smaller tilt angle. Therefore, there were two special tilt angles, as shown in Fig. 11 (b). When height of object was higher than a threshold value, the object was at region III. Because the light sources on nearer side with maximum tilt angle still could not illuminate the object, there was only one peak, as shown in Fig. 11 (c) These results coincide with the proposed algorithm of reflecting mode system.

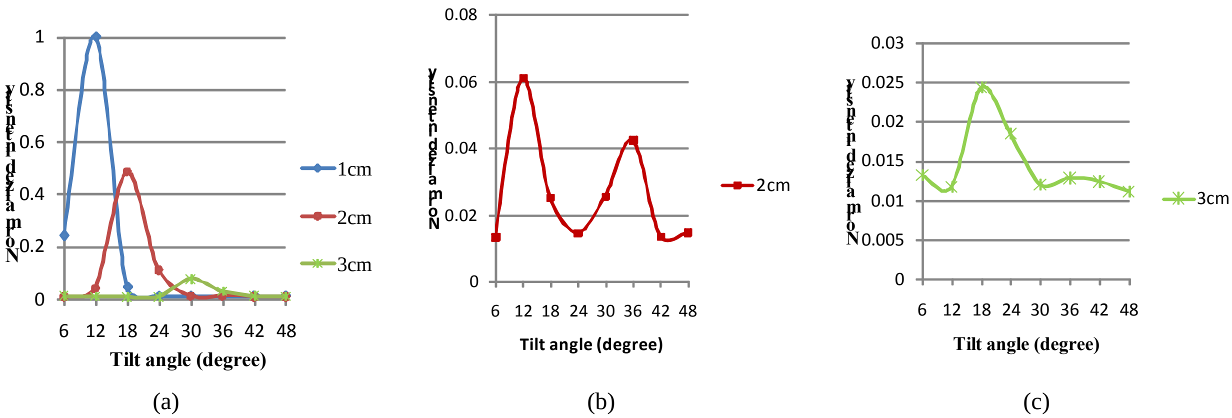


Figure11. Peaks of output light with different height. (a)Region I. (b) Region II. (c) Region III.

The image from step1 could be processed by full search and a size n window was putted on image. Following, the intensity of the window were accumulated and the window was moved on the image. Finally, the accumulated intensity was center value of window and the maximum value would appear at 2D coordinates (x and y) of object, as shown in Fig. 12. The magnitude of errors in 2D coordinates was small. Moreover, when the horizontal distance (x) and correlated special tilt angle (θ) were obtained, the depth value (z) could be calculated. Finally, the rectifiable depth values are shown in Fig. 13 (a) and (b). The maximum magnitude of errors was small than 0.4 cm. Those results meant that the resolution of height in reflective mode system is 1 cm and the depth could be obtained accurately.

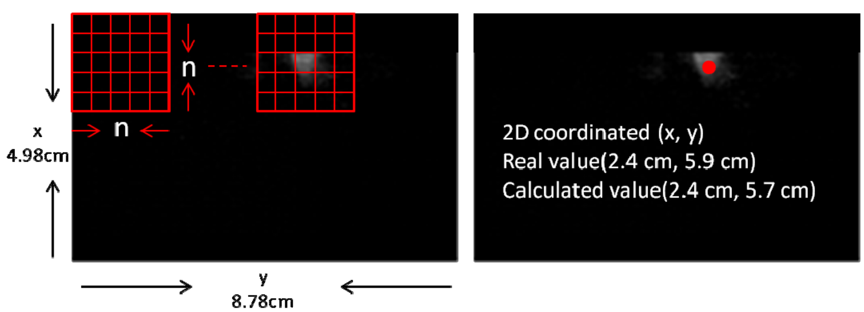


Figure12. 2D coordinates of image

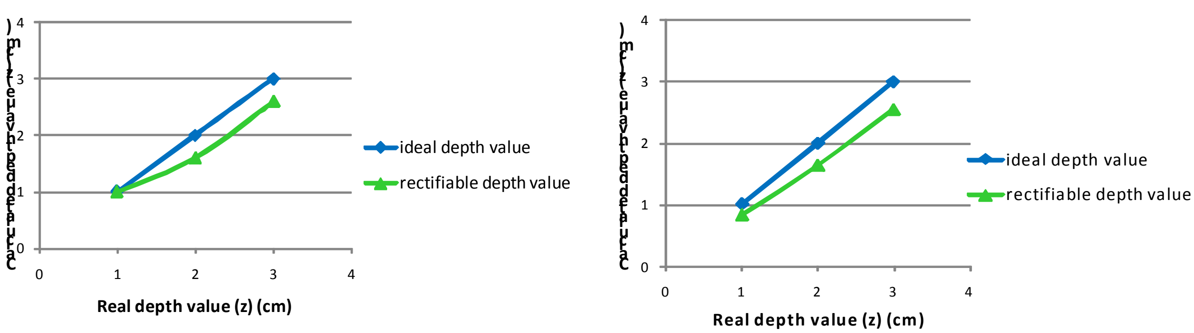
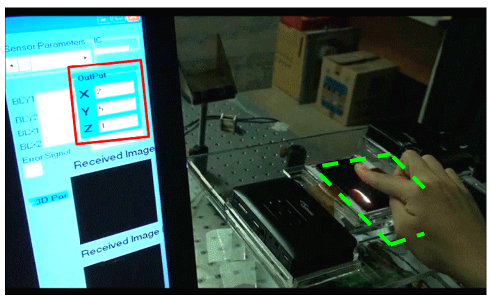


Figure13. Results of depth value when object (a) In region I (b) In region II and region III

6. Conclusions

In reflective mode system, the IR backlight, sequential illuminator and embedded optical sensor were added on traditional display. The IR backlight could be reflected by object and the captured image was used to calculate the 2D coordinates (x and y) by full search algorithm. Moreover, the sequential illuminator would synchronize with optical sensor and every frame would correlate with different tilt angles. Following, those frames were processed by "region based depth" algorithm when the object was placed at different working range. Instead of shape or size of images, overall reflectance of images was used to calculate the depth value (z). Therefore, resolution of detecting sensors did not much affect the accuracy of depth value (z). Consequently, the 3D coordinates (x, y and z) of object was obtained accurately by reflective mode system and region based depth algorithm. Finally, this sequential reflecting 3D interactive system had already been successfully implemented and demonstrated on a 4-inch panel with embedded optical sensor array, as shown in youtube link. Furthermore, the interactive range of finger height was currently as 30mm.



(Youtube link: http://www.youtube.com/watch?v=0ngBKf3iqxM)

7. References

[1] Andrew D. Wilson, "TouchLight: An Imaging Touch Screen and Display for Gesture-Based Interaction", ICMI, 69-76(2004).

[2] Yi-Pai Huang, Lin-Yao Liao, Chih-Wei Chen, "2D/3D Switchable Autostereoscopic Display with Multi-electrically Driven Liquid Crystal (MeD-LC) Lenses", J. Soc. Inf. Display Vol.18, 642-646, (2010).

[3] Steven Feiner, et al, " A Touring machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environmen ", ISWC, 74-81, (1997).

[4] Jun Rekimoto, et al, "Brightshadow: Shadow Sensing with Synchronous Illuminations for Robust Gesture Recognition", CHI, 2769-2774, (2008).

[5] Yi-Pai Huang, Guo-Zhen Wang, "3D Interactive Panel with parallax barrier", 3DSA, (2010).

[6] Steve Hodges, Shahram Izadi, Alex Butler, et al, "ThinSight: Versatile Multi-touch Sensing for Thin Form-factor Displays", UIST, 259~268, (2007).