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Variable Pulse Mode Driving IR Source Based 3D Robotic Camera

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Abstract

There has shown a significant interest in a high performance of, at the same time, a compact size and low cost of, 3D sensor, in reflection of a growing need of 3D environmental sensing for service robotics. One of the important requirements associated with such a 3D sensor is that sensing does not irritate or disturb human in any way while working in close and continuous contact with human. Furthermore, such a 3D sensor should be reliable and robust to the change of environmental illumination as service robots are required to work day and night. This paper presents a 3D IR camera with variable pulse mode driving source that is human friendly and robust enough for application to home service robots. IR pulse mode driving method is chosen as the sensing medium in order to meet the requirement of human friendliness and robustness to illumination change. A Digital Mirror Device (DMD) is employed to generate and project variable patterns at a high speed for real-time operation. In this paper, DMD is positioned to reflect IR directly so that efficiency is maximized. In implementation, we emphasize the integration of modular components to support real-time sensing and compactness in size. The experimental results have demonstrated that the implemented 3D IR Camera is robust to illumination change, in addition to its advantage of human friendliness.

1. Introduction

3D sensors are used in various fields such as service robots, medical imaging, and security surveillance systems because they provide valuable 3D information about the environment. Especially, robots can perform essential tasks such as navigation, localization, recognition, and manipulation more easily and efficiently with the help of a 3D sensor.

In many applications stereo vision has been used to obtain 3D information since it is fast [1]. However it suffers severely if the illumination varies. This problem has been fairly overcome by using structured visible light based 3D sensors. However, visible light patterns can make human uneasy or nervous. Finally, although the laser based 3D sensors, that use time-of-flight for measuring distance, are very accurate for far objects, nonetheless their accuracy is degraded when used to measure the distance to close objects.

There are many commercialized 3D sensors that are either work based on triangulation or time-of-flight [2][3]. For instance, Bumble Bee from Point Grey and Rainbow series from Genex are using triangulation while LS200 from SICK and SR2 from CSEM are based on time-of-flight [4][5][6].

In this paper, we present how to use IR structured lights to overcome the problem of variation in the illumination and visibility with variable pulse mode driving IR source.. Furthermore, we show how to implement the system using DMD, FPGA based decoding and control, IR camera, and Optical components.

2. Problem definition

Home surroundings have limitation in space and it is full of cluttered objects. Home service robots are expected to perform service tasks by locomotion and manipulation at home surroundings. In order to perform fast and accurate manipulation, the capability to construct 3D images of objects in real-time is a must. Since robots use manipulators of limited length to perform functions such as turning on/off switch, pressing buttons, and grasping cups, it is critical to have accurate 3D sensing performance at close range. On the other hand, home is a place in which people and service robots may spend lots of time in close proximity. If robots employ visible light to perform 3D sensing, human could be irritated and nervous due to the light visibility. Moreover, it is a discomfort to human if the service robots wander around the house, performing 3D sensing function, at night with light on. Finally, a service robot should be able to perform 3D sensing under illumination variation and little texture. Previous 3D sensing platform proposed by Sukhan Lee et al used commercial projector's optical components optimized for visible light and high power lamp so that its measurable distance is less than 1 meter.

Our approaches to meet the above requirements are as follows.

First, Variable pulse mode driving IR source is employed in order to achieve human friendliness, robustness in illumination variation and measurable distance longer than 2m.

Second, DMD is employed to perform real-time 3D sensing using variable patterns.

Third, Hardware (FPGA) based decoding and control is applied to make 3D sensing platform compact and fast.

3. System configuration

Proposed system consists of IR source, DMD, FPGA based decoder/controller and IR camera/interface. Diagram of system configuration is depicted in Figure 1.

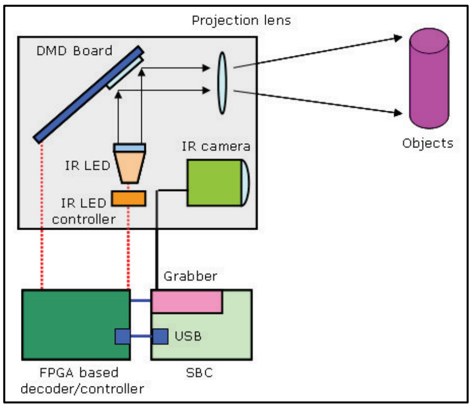

Figure 1. A diagram of system configuration

3.1 IR source

IR LED is chosen for this research because compact and low power consumption is critical factors for 3D camera on robots. Lamps or Laser diodes are not suitable for robot applications. As for lamp, high rate pulse driving is not possible and its bulky size, heat and power consumption can be a problem. As for laser diode, it requires controller of which size is proportional to its power capacity and price is relatively high.

For compactness, low power consumption, and extended measurable distance, pulse mode driving and multiple IR LED are employed. IR LED can be driven with high speed and pulse mode can lower the power consumption by only turning on the IR LED when used.

Considering IR LED's output power and distance needed for our application, total 3 IR LED are used. It is difficult to condense the whole rays to a point or circle shape because IR LED can not be treated as a point or collimated source. In order to maximize the condensing rate, optical components such as lens for IR LED, optical mirror coated with IR reflecting material and focusing lens are designed and fabricated.

Peak wavelength of IR LED is 880nm and its output power is 9W. Mirco-controller is employed to control the timing of On/Off. Signal from DMD controller is triggering the interrupt routine in micro-controller so that variable pulse mode driving is performed. In performing variable pulse mode driving, duration of 3 IR LED can be set different from each other. Implemented IR source and controller are depicted Figure 2 and Figure 3, respectively.

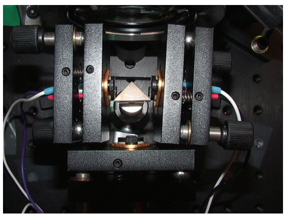
Figure 2. IR source

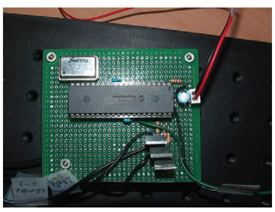
Figure 3. IR source controller

3.2 DMD and projection lens

DMD is a semiconductor based optical switch integrated with micro mirrors. Micro mirrors tilt about $\pm 12^{\circ}$ at on/off operation. The tilting function provides the capability of reflecting or blocking the lights to a designated direction. Intensity control is performed by regulating the length of reflection time [7][8].

DMD is used to generate variable patterns and project the patterns to the desired direction reliably. Figure 4 shows a DMD device and its structure. An image like a bitmap image consisting of 1 and 0 could be obtained by switching each mirror to on/off state. In order to make gray-scale images, PWM (Pulse Width Modulation) is used to adjust on-time of mirrors. For example, 100% duty ratio means that mirrors maintain on-state during the whole PWM period and 50% duty ratio means that mirrors are on for half period and off for the other half period.

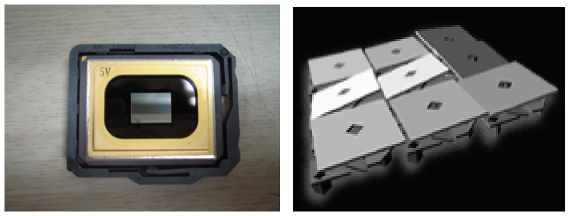
Figure 4. DMD (left) and its structure (right)

DMD board employed in this paper is shown in Figure 5. DMD board is composed of DMD and interface chipsets. Figure 6 shows an image on DMD made by DMD controller. Dark region is represented by mirrors maintaining off-state and bright region is represented by mirrors maintaining on-state.

A projection lens has been used to project images from the DMD to objects under scan. A commercial projector's lens has been used in previous 3D sensing platform. Since commercial projection lens is made for visible light, attenuation of infrared is presented. In fact, 25-30% of attenuation is identified in experimentation. Attenuation could be reduced to 0.2% per lens by IR AR (Anti Reflection) coating [9].

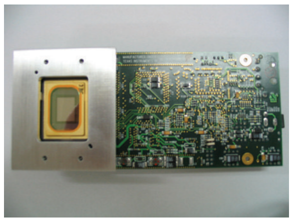
Figure 5. DMD board

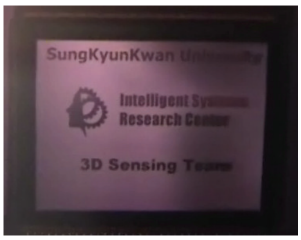

Figure 6. Image on DMD

3.3 FPGA based decoder and controller

FPGA based decoder performs following processes: receiving 17 images from image capture device (PC), calculating of depth image by HOC (Hierarchical Orthogonal Code) algorithm [10], and transferring result depth image to PC for display. FPGA based decoder can process HOC algorithm in 17 ms. In previous platform using PC (Pentium 4), processing time for the same algorithm is about 2 to 4 min.

FPGA based controller is for controlling DMD board. In order to make patterns at high speed, data are transferred through 64bit bus. FPGA based decoder and controller are depicted Figure 7 and Figure 8, respectively.

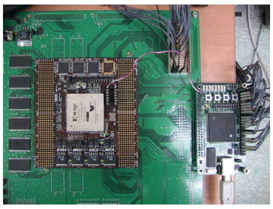

Figure 7. FPGA based decoder

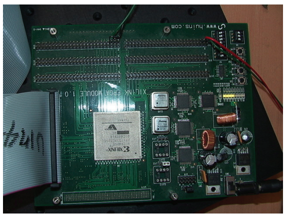

Figure 8. FPGA based controller

3.4 IR camera and interface

Human eyes can only detect light waves in the range between 380nm and 780nm [11]. Thus infrared is used to avoid discomfort to the human eye. Infrared, by itself, is classified into three ranges: near-infrared, mid-infrared, far-infrared. We employ near-infrared since CCD/CMOS sensors used in digital camera and camera phone can detect near–infrared [12][13]. This is because mid-infrared and far-infrared should be detected using special type of sensors such as InSb, PbSe [14]. Moreover, these sensors should be cooled down to cryogenic state because of the noise in normal temperature. In addition, cameras for detecting mid-infrared, far-infrared are expensive and more bulky than CCD/CMOS based camera [15].

CCD/CMOS sensors used for commercial digital camera is optimized for visible light so that sensitivity for near-infrared range is three times lower than visible light range. Since proposed system employs near-infrared region, normal CCD/CMOS sensors are not suitable. Therefore, CCD sensor sensitive to near-infrared is used for our sensing platform and variable focal length lens is employed.

Generally, digital cameras have a filter to prevent image distortion by screening infrared. Cold filter (which blocks infrared) is substituted with hot filter (blocking visible light) to use infrared in our research. Glass type of BW 093 from Schneider and film type of Wratten 87 from Kodak are employed since they block the whole visible light range [16].

IR camera is triggered by external signal from FPGA based controller. Integration time (Exposure time) can be adjusted by pulse width. Resolution of image is 320 by 240 and grabbed images are transferred to FPGA based decoder by USB interface. IR LED is also triggered by FPGA based controller for synchronization.

4. Experimentation

4.1 Intensity comparison

Reflected intensity of various surface colors are critical factors for acquisition of depth image. In order to investigate effectiveness of infrared and difference between infrared and visible light, experimentations on various surface colors are carried out. For infrared experiments, hot filter is used to block visible light. For visible light experiments, cold filter is applied. Other conditions are maintained identically. Figure 9 shows result of intensity comparison between infrared and visible light.

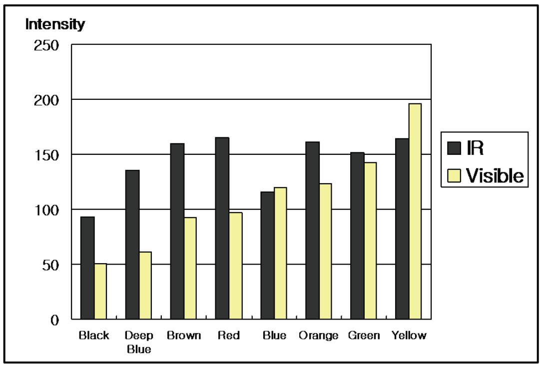

Figure 9. Intensity of an IR and visible light at various surface colors

According to a comparison graph, infrared represents more reflection from dark colors and some bright colors. As shown in the result, infrared can be used effectively for sensing with an advantage of invisible to human eyes.

4.2 Performance under illumination variation

Experiments are conducted to measure the correlation under illumination variation. Reference image is obtained without illumination in order to compare correlation with other images obtained at various illuminations. High correlation means that images are similar and less sensitive to illumination variation. As shown in Figure 10, correlations of all images are above 0.95 and 0.96 in average. This could be interpreted as robustness to illumination variation.

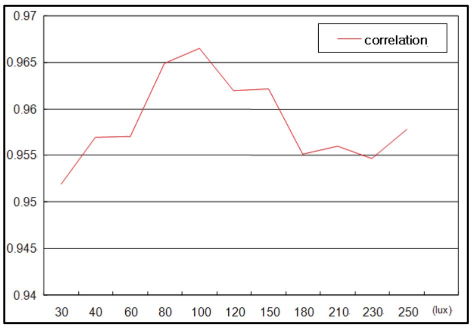

Figure 10. Correlation with respect to illumination

4.3 Infrared 3D images

Experimentations are performed on evenly patterned (embossed) sponge and cup. Distance between platform and objects was about 190cm and 17 orthogonal code patterns are used. Figure 11 shows original image and IR depth image of evenly patterned (embossed) sponge. Figure 12 shows original image and IR depth image of cup and sphere. It is noticed that objects at 190cm distance, infrared depth images present favorable results. In the depth images, white means that the distance from objects to platform is short. Similarly, dark region represent the long distance between objects and platform.

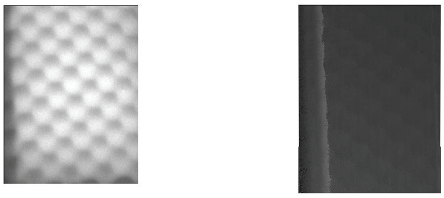

Figure 11. Original image (left), IR depth image (right)

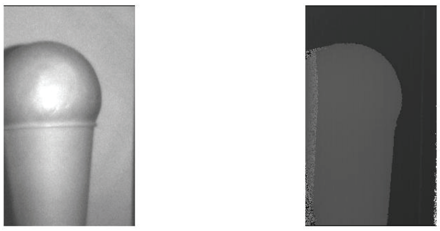

Figure 12. Original image (left), IR depth image (right)

5. Conclusion

This paper presents 3D IR Camera with variable pulse mode IR driving, designed and implemented for use in home service robots. Infrared is chosen to alleviate the problems associated with visible light: infrared could not be detected by human eyes and, thus, cause no irritation or disturbance to human. Experimental investigations indicated that pulse mode IR driving can extend measurable distance about three times than previous platform. By regulating duty ratio of IR LED, adequate intensity of pattern is made so that quality 3D depth images can be acquired. In addition, FPGA based decoder reduce the processing time significantly so that real-time capability is improved. By using FPGA based controller, DMD is able to make variable patterns faster, thus providing a means of generating a sequence of variable patterns very fast for real-time 3D sensing. Future work includes further improvement of dynamic range and DOF with an improved optical components and IR source as well as fabrication of compact platform installable on mobile robots for real demonstration.

Acknowledgments

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References

[1] J. Kim, S. Park, and E Lee, "A Study on Image Registration using Active Sensor and Passive Sensor," HIC2000

[2] J. Beraldin, et al, "Active 3D Sensing, The e-Way into Four Dimensions of cultural Heritage Congress," Vienna, Austria, April 8-12, 2003.

[3] 3D Sensor http://perso.club-internet.fr/dpo/numerisation3d/

[4] R Lange and Peter Seitz, "Solid-State Time-of-Flight Range Camera," IEEE Journal of Quantum Electronics, vol.37, no.3, pp.390-397, 2001.

[5] O.Wulf, and B. Wagner, "Fast 3D Scanning Methods for Laser Measurement Systems," International Conference on Control Systems and Computer Science, Bucharest, Romania, vol.1, pp.312-317, July. 2003

[6] Jan W.Weingarten, G.Gruener, and R.Siegwart, "A State-of-the-Art 3D Sensor for Robot Navigation," International Conference on Intelligent Robots and Systems, Sendai, Japan, 2004.

[7] D. Dudley, W. Duncan, and J. Slaughter, "Emerging Digital Micromirror Device (DMD) Applications," Texas Instruments, Inc.

[8] DMD, http://www.ti.com

[9] Near Infrared Achromats, http://www.edmundoptics.com

[10] Sukhan Lee et al, "An Active 3D robot Camera for Home Environment", IEEE Sensors 2004, Vienna, Austria

[11] A Ryer, Light Measurement Handbook, International Light Inc., 1998.

[12] http://www.apogee-ccd.com/

[13] B. Burke, et al,"640×480 back-illuminated CCD imager with improved blooming control for night vision," International Electron Devices Meeting, 1998, IEDM '98 Technical [Digest, International, Pages: 33 – 36, 6-9 Dec. 1998].

[14] Characteristics and use of infrared detectors, HAMAMATSU.

[15] D. Litwiller, "CCD vs. CMOS: Facts and Fiction," Photonics Spectra, January 2001.

[16] http://www.schneideroptics.com/filters/filters_for_still _photography/infrared/more_information/