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First steps in enhancing 3D vision technique using 2D/3D sensors

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Abstract *In this paper, a novel imaging technique for enhancing 3-D vision is proposed. The enhancement is achieved with the help of 3-D time-of-flight camera, this 3D camera delivers the intensity and depth information of the scene in real time. Although this kind of 3-D cameras provide accurate depth information, its low 2-D image resolution tends to be a hindering factor for many image processing applications. This limitation can be inundated with the proposed setup; a 2-D sensor (CCD/CMOS) with higher resolution is used to improve the image resolution. The 2-D and 3-D cameras are placed in a special housing, so that the field-of-view (FOV) is nearly same for both the cameras. The 2D/3D data fusion becomes facile for mapping and/or image registration. Hence the new system provides better image quality with range data. Within this paper, we discuss the initial results and findings of the proposed system.*

1 Introduction

The anthropomorphous thinking often convinces human being to consider the camera as a technical eye. The conventional image sensors (CCD/CMOS) measure the intensity of the scene, but it lacks the depth information of the scene. As the nature introduces severe physical limits to acquire remote 3-D information, contact less extraction of depth information is still one of the key task in image processing.

The insensible depth information is generally solved by two means. By using mathematics, the computer vision community in the past decades have strived to develop a suitable method for 3-D vision. This was often done with the help of 2-D images, using techniques drawn mainly from linear algebra and matrix theory. Other means of finding the unfound depth are based on the laws of physics using methods such as - interferometry, triangulation or time-of-flight (TOF) methods [5]. The innovation of laser scanners and range sensors gave a big helping hand on this issue.

1.1 Need for 3 Dimensional Sensors

Nowadays, 3-D image acquisition and processing appear to be on the verge of a comparably stormy and far-reaching development. Three-dimensional optical form measurements deliver the absolute 3-D geometry of objects that are largely independent of the object's surface reflectivity, the distance of the objects from the sensor, and illumination conditions. Thus, 3-D optical sensors deliver in real scale the dimensions of an object, which are rotation- translation- and illumination-invariant. Most of the problems of industrial inspection, reverse engineering, and virtual reality require data about the geometrical shape of objects in 3-Dimensional space [2].

At last, a novel idea of measuring the depth of the scene, with time-of-flight principle using incoherent optical modulation came in the form of solid state device. This sensor overcomes several drawbacks faced by the commercial 2-D sensors. The time-of-flight camera has an edge over the other 3-D measuring devices, which contains moving mechanical parts. The aging and wearing could create inaccuracies in the system, since it uses moving parts. The commonly known time-of-flight systems [PMD,Swiss Ranger,Canesta] [12] produce the 3-D information using slightly modified techniques, does not have any moving or mechanical parts.

2 Related Work

The basic component of the 3-D vision a time-of-flight sensor system which has been presented in this paper is a well known and evolving 3-D vision technique. To the knowledge of the authors, no system exists with this 'optical insitu measurement (with common lens)' for 2D/3D vision systems. However there is a combination of 2D-3D sensor system [9]which consists of movable-mechanical components. The main goal of this paper is to show the procedure to increase the image resolution of the 3-D sensor, which is currently available about 19,000 pixels. In the following section, we will discuss about a TOF camera and its measuring (sensing) techniques. In section 3, we introduce 2D/3D imaging technique. Then in section 4,5 about characterisation and experimental setup. In section 6, we show some initial results from the 2D/3D setup as well as its future perspectives.

3 2D/3D Camera Concept

The 2-D sensors (CCD/CMOS) come up with very high image resolution (millions of pixels), one can use intelligent image processing algorithms to calculate the depth information of the scene, recover the shape or reveal the structure. These are extracted at high computational cost. Further, it is obvious for many real world problems it cannot achieve the required robustness with intelligent image processing algorithms.

Even if it were possible the same algorithm often cannot solve other problems due to illumination, reflectivity of the surface and other ambient problems.

Rather in the quasi-straightforward approach such as a 3-D TOF sensors, which have a maximum of about 19,000 pixels till date. This resolution is quite insufficient for some applications like navigation or autonomous transport system. So a combination of 2-D and 3-D sensor can address the issue of intelligence. Therefore our approach addresses this issue, such that an intelligent image processing algorithm can be supported by intelligent camera systems - such as 2D/3D system.

To overcome the drawbacks and to increase the resolution (primarily image, later also depth) of the sensing system, a special optical setup is designed. This imaging setup comprises of some key components such as a special optics - called as image multiplier, a CCD camera and a PMD camera system.

3.1 Image Multiplier

The image multiplier is an optical device which makes a continuous multi-shutter operation possible and affordable. Through a mutual recording and data transferring of both cameras (PMD and CCD in our case) the exact over lap is achieved. This image multiplier is made up of prisms and mirrors which deliver the same information to both the eye-pots. The optics helps in providing nearly the same field of view for both sensors. The figure 1 shows the image multiplier. This makes the image registration or mapping more efficient. Therefore the pixel correspondence also becomes trivial.

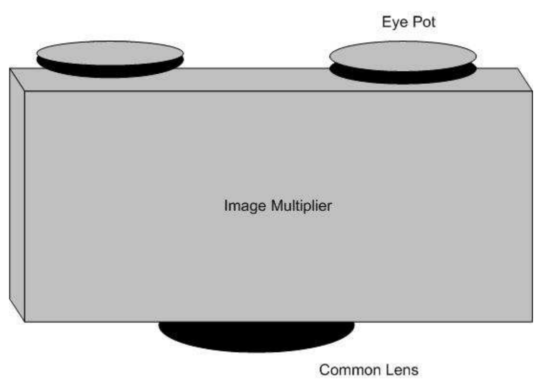

Figure 1: The Image Multiplier used in the 2D/3D setup- the 2D and 3D cameras are mounted on the eye-pots which have two C-mounts

3.2 Time-of-Flight Camera System

As the 3-D TOF cameras measure depth information using time-of-flight principle, the RF-modulated light signal with variable phase shift is sent to the 3-D-object and reflected back to the camera system. The PMD (Photonic Mixer Device) pixels mix the modulated light directly in optical active area in the sensing process, which leads to a smart operation. The distance information is weighted on each pixel independently. A 3-D information is obtained by evaluating at least two frames. The distance information can be calculated inside the camera system, only the 3-D data is transferred to the PC. All these operations are be performed in the PMD system as it has an in built 32 bit (AMD Elan SC520) microprocessor running under ELinOS operating system. The timing requirements are met by the FPGA (Field Programmable Gate Array) circuitry inside the system. The PMD camera system has a frame rate up to 50 fps (frames per second).

3.2.1 Lighting Module The PMD camera system has its own lighting module. The array of infrared LED's are used for scene illumination. These LED's are modulated with 20 MHz. The system emits an RF modulated optical radiation field (typically 20 MHz or higher) in the infra-red spectrum. The diffused backscattered signal from the scene is detected by the camera. Each pixel has the capability to demodulate the signal and detect its phase, which is proportional to the distance of the reflecting object. The signal frequency of 20MHz defines the unambiguous distance range of 7.5 m.

The PMD sensor with 1024 pixels is used in this experiment,since it has a matured technology and a key advantage of rejecting back ground illumination. This is done by means of an active Suppression of Background Illumination (SBI) circuitry in each pixels of the chip, which makes it efficient, to operate indoor (even in the dark) and outdoor (with ambient light) with its own active illumination and not affected by ambient light including sunlight.

3.3 CCD Camera

The CCD camera used in this case, is a black and white camera with SVGA resolution (780 (H) x 582 (V)) (AVT MARLIN F-046B) is used, which is equipped with a SONY 1/2" type progressive CCD array. The full frame rate is up to 53 fps. This camera allows to select the ROI (Region Of Interest) easily, this is quite an advantage for the experimental setup which is currently used. It also makes data transmission and image processing efficient in terms of time and data size.

4 Characterisation of the 2D/3D Sensor Setup

This device needs to be calibrated for better results. The calibration can be classified into three steps for such a system; Calibration using Optics (Image Multiplier), Calibration using Intensity Information and Calibration using Range Information. More about the special calibration device and technique used for this 2D/3D system is discussed in [1].

4.1 Calibration using Optics

Initially the optics is calibrated, so that the image multiplier provides the exact overlap between the two sensors. As the CCD and the PMD sensor have different chip and pixel size. The image multiplier is calibrated with a grid plate to calibrate the cameras in order to have minimum mismatch.

4.2 Calibration using Intensity Information

The intensity information of the 3-D time-of-flight camera has relatively less number of pixel and the large pixel size. This makes them to become less reliable for the gray scale image. The intensity data is calibrated with the planar surface such as checker board. And the pixel error of 2 and 3.5 are obtained for horizontal and vertical axis.

4.3 Calibration using Range Information

The sensor performs a time-of-flight measurement by detecting the phase shift in the modulated emitted signal, which can in turn be translated into a distance. In practice, due to propagation delay in the driving circuits of the camera (PMD), a distance offset has to be included. Due to the optics the range information has some inaccuracies. To over come this, the 3-D TOF camera system is placed before the planar surface (such as card board or wall). By knowing the actual distance and comparing the measured value a linearity existed. This linear value is added to the measured data for compensation. The range information had resolution of about 1 cm.

As the system has a special optical setup a new calibration procedure is yet to be accomplished and it is still under investigation [1] for better accuracies. The improved calibration technique will be derived from the techniques used in planar surface (checker board) and/or using a laser pointer in the case of multi-camera calibrations [8].

5 Experimental Setup

The pre-processed data was acquired from the RPC (Remote Procedure Call) server in the PMD system via the Ethernet interface to the PC, where the registration is performed. The pre-processed 3-D data are acquired into the MATLAB, using Java RPC client. This automated process was achieved in near time because of the stable RPC technology. The PMD camera system also has IEEE1394 (FireWire), which was not used in this experiment. The 2-D data from the CCD camera was acquired by IEEE1394 - DCAM standards. Then the 3-D image enhancement was done in the MATLAB.

Figure 2 shows the components used in the experimental setup. This setup was used to register the image for a static scene.

Table 1: Pixel information of the 2-D and 3-D sensors

Sensor	PMD(H)x(V)	CCD(H)x(V)
Number of Pixels	64 x 16	780 x 582
Pixel Size (μm)	155.3 x 210.8	8.3 x 8.3

The above table describes the PMD to CCD pixel mapping. Approximately 475 CCD pixels fits into one PMD pixel. This shows that lots of information such as edges and corners could be missed by the PMD system.

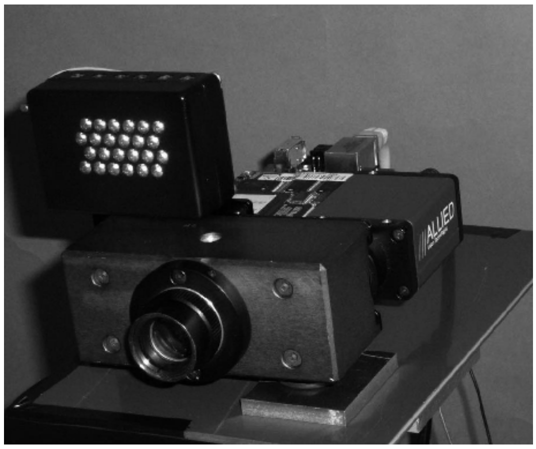

Figure 2: 2D/3D camera setup with PMD, RF modulated optical source, CCD and the Image Multiplier

6 Steps involved in Enhanced 3-D Vision

The enhanced 3-D vision is attained by interpolating the range data and registering it with the 2-D data. As the size of the 3-D data set is smaller than that of the 2-D data interpolation becomes essential. The Figure 3 shows the steps involved in the enhanced 3-D vision.

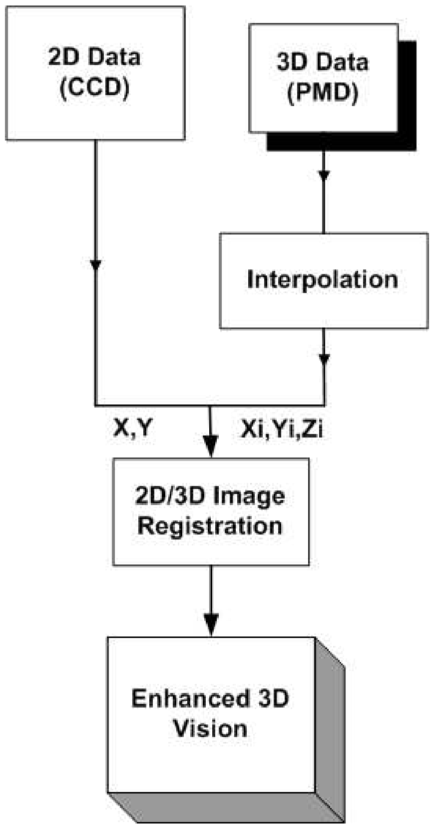

Figure 3: Steps involved in enhanced 3-D vision technique

The 2-D image received from the CCD sensor is shown in figure 4. The 2-D gray scale image obtained from the PMD camera has low resolution, this is shown in the figure 5 with the grid. This low resolution image from the PMD reduces its application in the field of machine vision or other image based applications. More about the problem is discussed in [1]. The 3-D range information obtained from the PMD is plotted in figure 6. The captured 2-D image has relatively high resolution, so the 3-D data set is interpolated to the size of 2-D data set. The result of interpolation is shown in figure 7. The registered 2D/3D image is shown in figure 8. Thus a 3-D image with higher resolution is obtained in near time. Figure 9 shows the tilted view of the registered 2D/3D image in order to partially see the depth map.

The nearly exact overlap of the 2-D and 3-D data makes the 2D/3D image registration relatively faster, resulting up to 10 fps (frames per second). The speed of the image registration could play more important role for the dynamic scene or moving objects.

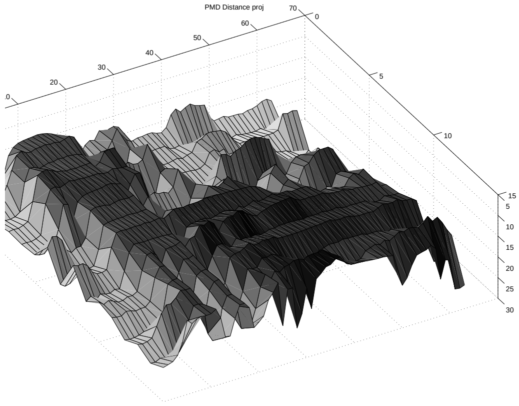

Figure 6: 3-D depth information from the TOF camera

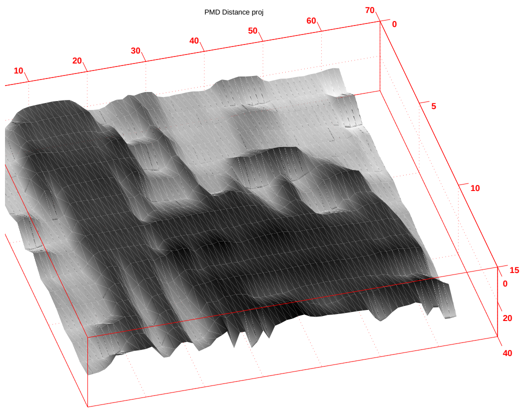

Figure 7: Interpolated range data

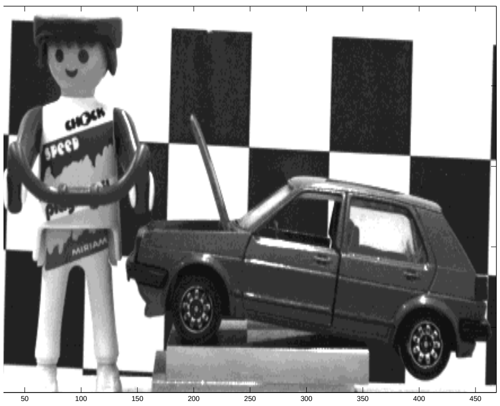

Figure 4: 2-D intensity image from CCD camera

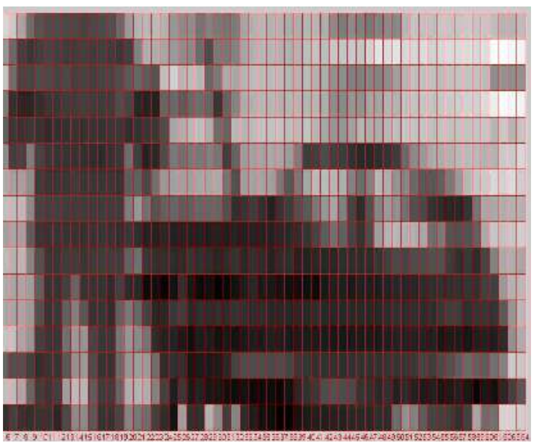

Figure 5: 2-D intensity image from PMD camera

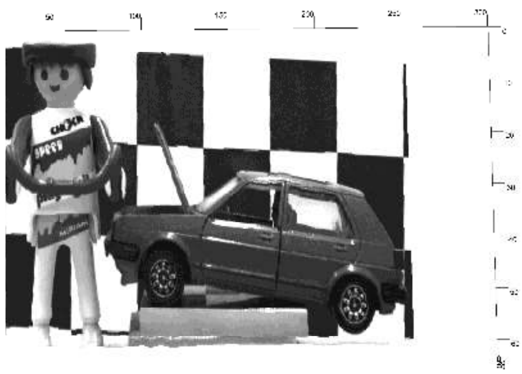

Figure 8: Registered 2D/3D image

The registered image has improved intensity. However the accuracy of the range resolution has to be increased, since it is about 1 cm. The range resolution can be more accurate by improving the optics (image multiplier) and also from the Shape from - Shading, Surface approximation and Motion [11] techniques.

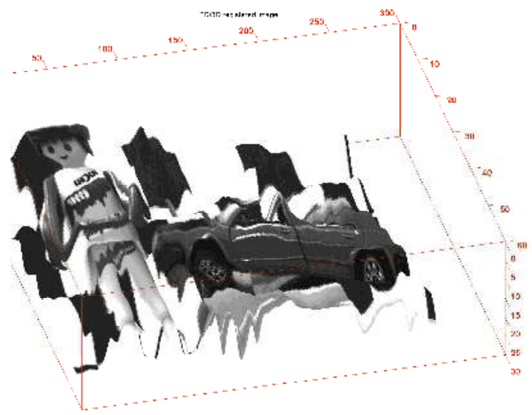

Figure 9: Tilted view of the registered 2D/3D image

7 Conclusion

A new state-of-art 2D/3D sensor setup with common optics is presented with the preliminary results and findings. The key advantage of the 2D/3D system is its ability to generate real 3-D range information and high intensity data in near time. Also this can be achieved at less computational cost and higher data rate. The results are promising. So the future work will be focused on this system to improve its range resolution (accuracy) using the improved optics and a device specific calibration technique. A common hardware for 2-D and 3-D cameras to meet the timing,digitising and data acquisition could increase the performance of the system.

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