3D TOF CAMERA BASED OBJECT METROLOGY

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Abstract: Range cameras that determine both range and intensity at each pixel has matured in the last decade and is on the verge of revolutionizing the metrology market in retail, automotive, aerospace and many other. In this paper, we present an algorithm for measuring 3D geometry (height, width and depth) of rigid object using Time of Flight (TOF) camera. The method exploits geometrical structure of object such that intensity and range image compliments each other for a reliable measurement. We discuss the performance of algorithm under varying operating conditions.

1 INTRODUCTION

In the past few years, many industries have adopted automation in order to increase the productivity. Extracting 3D information about the object at different stage in the production cycle is a key and yet challenging task for automation. For example, logistics companies adopt automation at several stages in the entire supply chain to stay in this highly competitive business. However, certain aspects of billing procedure still require human intervention. For example, measurement of consignment geometry (size, length, volume etc.) requires human effort. Any non-contact, automated measurement of 3D information about the object helps in achieving higher productivity, unambiguous billing and customer satisfaction.

In the past few decades, researchers have been implementing different methods to measure 3D object geometry. Considerable effort has been directed towards developing optimal systems which can construct a three dimensional image (x, y, z). Specifically, optical methods are a widely researched and well developed field. Optical distance measurement methods include Interferometry, Stereo/Triangulation and Time-of-Flight. A more detailed explanation and review of these methods can be found in (Dorrington, 2006). In the recent past, researchers have shifted the focus on Time of Flight (TOF) camera based application for 3D object scanning and analysis. For example, the TOF cameras have been demonstrated for applications such as 3D object scanning (Cui, 2010) and localization (Distante, 2010). The authors (Bostelman, 2006) uses TOF camera to detect obstacles and travel path detection applications to guide visually impaired through stereo audio feedback.

In this paper, we present an algorithm for accurate 3D geometry measurement of rigid objects. With suitable experimental results, we show how we reliably measure object dimension irrespective of distance (to object), illumination condition and background complexity.

The following section presents basic information on 3D TOF camera and its utility for metrology application. The experimental set up and problem formulation for developed methodology is discussed in section 3. In section 4, we present step by step details of proposed algorithm. Experimental results and sensitivity analysis of developed methodology for several operating parameters are presented in section 5. The paper is summarized with some concluding remarks in section 6.

2 BACKGROUND

2.1 Time of Flight (TOF) Cameras

Time-of-flight (TOF) cameras are specialized active camera sensors that determine both range and intensity at each pixel by measuring the time taken by light to travel to the object and back to the camera. The capability of 3D TOF sensor to offer depth measurements at video frame without

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scanning opens up new applications beyond gaming. In our work, we have used TOF camera developed by PMD Technologies Inc. (Chiabrando, 2009).

2.1.1 D TOF Camera for Object Metrology

In the last few years, non-contact object imaging and geometry estimation using 3D TOF camera has been demonstrated in applications such as automated inspection for quality control. Most of these involves two broad steps namely object segmentation and geometry estimation. The availability of depth data for each image pixel in 3D camera enables relatively easy object segmentation and geometry estimation compared to 2D imaging.

The algorithm proposed in (Sobers, 2011) deals with object geometry reconstruction using 3D TOF camera. Using camera calibration information, the method filters range data in order to segment the object from background. Authors then perform data fitting using least square method for fitting curves of different polynomials. The algorithm provides the geometry of the object i.e. height, length, radius, circumference, slope angle, groove, etc. for the given object. The algorithm however has limitation in not extracting the 3rd dimension of the object (i.e. depth). However, most of the metrology applications such as logistics industry necessitate extraction of object depth as well. In this paper, we demonstrate 3D geometry measurement for rigid rectangular object using 3D TOF camera.

3 MEASUREMENT EXAMPLES

3.1 Experimental Setup

We demonstrate the potential of our system for object dimension measurement with a simple laboratory set up. As shown in Figure 1 (a), 3D TOF camera is placed in front of the target object such that at least three sides of the object are seen. The data from the camera consists of amplitudes of the reflected signal from the objects, intensity values and range values for each pixel. The higher the amplitude value of a pixel, the more reliable is its corresponding distance value. The camera returns depth value for each pixel directly in Cartesian coordinate with known information on Field of View (FOV) and lens properties. The intensity image is similar to a simple gray scale image from a traditional 2D camera.
To demonstrate the approach that we have followed for automated dimension measurement application,

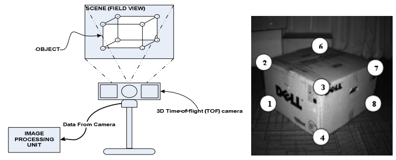


Figure 1: Experimental set up (a) data acquisition system (b) test object.

we have considered rigid packaging object shown in Figure 1 (b). It has six flat sides with edges orthogonal to each other.

3.2 Problem Formulation

The key to dimension (height, width and depth) measurement is reliable extraction of object edges and their corners. Ideally, if edges formed by corner pairs (1, 2), (3, 4), (7, 8) are reliably detected, the problem of dimension measurement is reduced to indexing corresponding range values. However, several reasons (varying lighting condition, complex object texture, poor reflection) makes edge extraction incomplete. In our algorithm, we are exploiting parallel property of certain edges in order to detect missing edges. Under perspective image geometry, such parallelism leads to condition wherein edges share common vanishing point. Consider two linear lines with slopes m_1, m_2 and their y-axis intersecting value of c_1 and c_2 respectively. The intersecting point (X_i, Y_i) is the common solution and is called Vanishing point of two lines.

As evident from Figure 1 (b), the measurement of length, width and depth can then be accomplished by computing Euclidean distance between range values belonging to designated corners.

4 ALGORITHM

4.1 Integration Time Setting

Selecting appropriate integration time (exposure time) is crucial for accurate range measurement in TOF camera. We have adopted an iterative method that determines appropriate integration value based on number of valid pixels, a flag that indicates if range measurement for a pixel is valid or not based on reflected signal strength. Invalid pixel count reduces as integration time increases until certain value after which it starts increasing. The integration time corresponds to global minima in number of invalid pixels is chosen as desired value. Table 1 illustrates the relationship

Table 1: Integration time vs. invalid pixel variation.

Integration time (msec)	No. of invalid pixels	No. of saturated pixels
100	7257	0
300	2644	14
⋮	⋮	⋮
1400	354	65
1500	**325**	**94**
1600	426	167

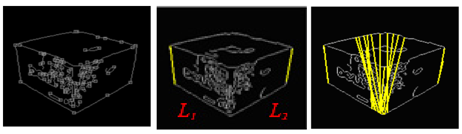
4.2 Object Segmentation

The target object is separated from scene by applying threshold to range image. It is equivalent of placing a virtual vertical plane in the scene. The content behind the plane are ignored. The threshold is either set manually (based on guideline that object be not placed beyond certain distance from camera) or determined automatically. Automated threshold estimation method include frame differencing between current scene and reference scene (taken one time with no object in the scene)

4.3 Corner Detection

The foreground object in amplitude image is then subjected to Canny edge detection followed by corner detection algorithm known in the literature. The corners *C* are archived with their (x, y) location information. Referring Figure 2 (a), the key now lies with locating corners that guarantees reliable dimension measurement. The depth information of the corner 6 is more un-reliable due to flying-pixel phenomenon (Cui, 2010) and hence any measurement with corner 6 as reference point will not be accurate. For reason that region around corner 3 is complex, we exclude it from consideration for further processing. Thus, the subsequent steps described below focuses on determining corners 1,2,4,7 and 8.

To determine above said corner points, we first fit lines for all edges using Hough transform. Given the fact that lines formed by corners (1,2), (3,4) and (7,8) are orthogonal to x-axis, we limit theta value in Hough transform to values closer to zero degrees.



(a) (b) (c)

Figure 2: (a) detected edges and corners (b) line fitting for extreme edges (c) projection of all vertical edges.

Experiments indicates line fitting along corners (1, 2) and (7, 8) are relatively simpler and accurate. Hence we process these outer edges separately first. Figure 2 (b) illustrates fitted lines L_1 and L_2. From these lines, the corners (1, 2, 7, 8) are located by searching in corner set *C*, for those which are closest to lines' neighbourhood (Euclidean distance).

As evident from Figure 2 (a), edges are cluttered along corner pair (3, 4) and hence line fitting turns out to be erroneous. Thus, in our algorithm, we exploit geometrical characteristics that line formed along corner pair (3, 4) is parallel with those of (1, 2) and (7, 8). In projective transform this property translates to common vanishing point for all three lines. Hence, we first determine vanishing point V_1 for lines L_1 and L_2. Subsequently, all other vertical lines in the image are projected (Figure 2 (c)) and intersected with horizontal line passing through V_1. The vertical line that intersects or closely intersects with vanishing point V_1 is finally picked up. The corner 4 is then searched in corner set *C* such that the Euclidean distance between line co-ordinate and corner co-ordinate is minimal.

4.4 Corner Validation

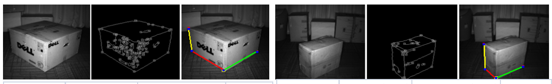
Generally, reflections from object edges have mixed-pixel effect, a condition that results in unreliable range measurement. Hence, any computations based on such pixels are erroneous. To handle such scenario, we perform localized search around identified corners such that nearest pixel that falls on inner surface of the object are selected.

4.5 Dimension Measurement

As discussed earlier, the dimension measurement now reduced to problem of computing Euclidean distance between range values corresponding to detected corners. While Euclidean distance between corner pairs (1, 2) or (7, 8) yield object height, corner pair (4, 8) offers width measurement and corner pair (1, 4) used for object depth measurement.

5 RESULTS AND DISCUSSIONS

In addition to testing under normal condition, we conducted several other experiments to assess the performance under difficult conditions of background and lighting. Figure 3 presents sample results along with measurement error under normal condition. Rest of this section discusses sensitivity of method to different operating parameters.



PARAMETER	ACTUAL (in m)	MEASURED (in m)	ERROR
HEIGHT	0.34	0.32305	0.01695
WIDTH	0.55	0.579384	-0.29384
DEPTH	0.55	0.548208	0.001792

PARAMETER	ACTUAL (in m)	MEASURED (in m)	ERROR
HEIGHT	0.41	0.361635	0.048365
WIDTH	0.4	0.391544	0.008456
DEPTH	0.205	0.189064	0.015936

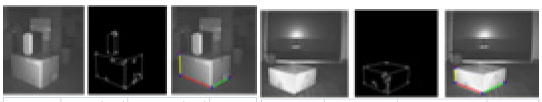
Figure 3: Experimental results – normal conditions.

5.1 Integration Time

Objects at different distances require different integration (exposure) time to compute range. For instance, experiments indicate the measurement error for object at far distance is almost stable when integration time set between 300 and 1000 microsecond. Our adaptive method of setting integration time described in section 4.1 ensures accurate results irrespective of object distance.

5.2 Background Complexity

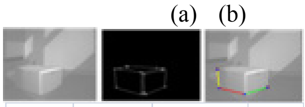
As shown in Figure 4 (a), despite the presence of other objects, algorithm successfully segments the target and measures its dimension. In addition, we conducted experiments testing performance against high reflecting background which tends to saturate pixels faster and thus necessitating appropriate integration time selection. With adaptive integration time setting procedure, such scenario has been successfully handled as shown in Figure 4 (b).



PARAMETER	ACTUAL (in m)	MEASURED (in m)	ERROR
HEIGHT	0.295	0.278583	0.016417
WIDTH	0.365	0.358162	0.006838
DEPTH	0.545	0.544632	0.000368

PARAMETER	ACTUAL (in m)	MEASURED (in m)	ERROR
HEIGHT	0.205	0.18461	0.02039
WIDTH	0.405	0.399843	0.005157
DEPTH	0.4	0.423643	-0.023643

(a) (b)



PARAMETER	ACTUAL (in m)	MEASURED (in m)	ERROR
HEIGHT	0.305	0.316303	-0.011303
WIDTH	0.39	0.425641	-0.035641
DEPTH	0.395	0.413984	-0.018984

(c)

Figure 4: Results with complex conditions (a) multiple objects (b) reflecting background (c) bright background.

Figure 4 (c) shows the performance of algorithm when target object is placed under bright light. As evident, the proposed method is insensitive to bright background lighting condition. It is due to the fact that algorithm uses amplitude image to extract object edges and corners. Any processing based on intensity image (which is sensitive to background lighting) under such condition would have resulted in inaccurate edges and corners.

6 CONCLUSIONS

A new algorithm for measuring 3D object geometry was presented in this paper. We presented the proposed approach with quantitative and qualitative analysis with appropriate illustrations under normal and challenging conditions. Ability of the proposed approach to dynamically set integration time makes it robust under difficult operating conditions. In addition to using geometrical characteristics of target effectively, the developed method exploits different information sources (intensity image, amplitude image and range image) in ensuring accurate dimension measurement.

REFERENCES

Dorrington, A. A., Carnegie, D. A. and Cree, M. J., 2006. “Toward 1-mm depth precision with a solid state full-field range imaging system,” *.Proc. SPIE, Vol. 6068 – Sensors, Cameras, and Systems for Scientific/Industrial Applications VIII, part of the IS&T/SPIE Symposium on Electronic Imaging, San Jose, CA, USA, pp. 60680K1–60680K10.*

Cui Y., S. Schuon, D. Chan, S. Thrun, and C. Theobalt, 2010 “3d shape scanning with a time-of-flight camera,” *in IEEE CVPR 10, pp. 1173–1180.*

Distante C., G. Diraco, and A. Leone, 2010, “Active range imaging dataset for indoor surveillance,” *Annals of the BMVA, London, vol. 3, pp. 1–16.*

Bostelman R., P. Russo, J. Albus, T. Hong, and R. Madhavan, 2006, “Applications of a 3d range camera towards healthcare mobility aids,” *IEEEInternational Conference on Networking, Sensing and Control (ICNSC’06), pp. 416–421.*

Chiabrando F., R. Chiabrando, D. Piatti, and F. Rinaudo, 2009, “Sensors for 3d imaging: Metric evaluation and calibration of a ccd/cmos time-of-flight camera,” *Sensors, vol. 9.*

Sobers L X Francis, Sreenatha G Anavatti, Matthew Garratt, 2011, “Reconstructing the geometry of an object using 3D TOF Camera”, *Merging Fields Of Computational Intelligence And Sensor Technology (CompSens), 2011 IEEE Workshop On*