An Automated 3D Scanning Algorithm using Depth Cameras for Door Detection

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***Abstract* – This paper presents an investigation on the characteristics of Microsoft Kinect depth camera for door detection in an indoor environment. Autonomous vehicles usually have to rely on images when navigating indoors due to network limitations of an indoor environment. Locating a door for exit and entryway is one of the problems that need to be tackled when navigating indoors. In this paper, images from a depth camera are captured and used as a tool for detecting doors. The continuously varied ratios and depth differences in the door images have been analysed. An algorithm for door detection was developed using MATLAB. Experiments using different heights and depths of the Kinect sensor have been performed to verify the efficacy of the algorithm for indoor autonomous flying robots like the quadcopter. The algorithm developed is best performed in a clear path of 3.5 meters. The accuracy of the measurement was influenced by the low resolution of the depth images.**

Index Terms – 3D scanning algorithm; Kinect depth camera; door detection

I. INTRODUCTION

Autonomous airborne vehicles can face serious complications for path planning when navigating indoors. This is especially true for door detection, which is a key step for intelligent navigation [1]. Doors are one of the most common landmarks since they show the topological structure of indoor environments [2]. It is crucial for robots to have the intelligence to decide whether to enter or exit from the space through the door from identification of door status, i.e, open, half open or closed [3]. The interior door detection methods can be classified into non-visual and visual-based methods.

A. Non-Visual

Researchers have applied ultrasonic technique and a combination of sonar and video for door detections [2][4]. The result accuracy gets affected because the sound waves can easily get distorted by the door reflection coefficient. Laser distance measuring method for fast door detection is not economical as the need for high-precision motor would result in high cost [5].

B. Visual

Other researchers use the average doorknobs height as a recognition pattern for door detection [6]. However, it has some limitation since there are many different types of door knobs. In [7], Hough Transform is used to extract edge lines from images. However, any square-shaped like objects might be treated as a door due to similar edge numbers. A door detection algorithm based on bottom-edge intensity of door is limited to only closed door detection [8]. Modelling using shape and colour as parameters may not work for door detection since there are too many objects with similar colours. Such technique is also sensitive to variation in light characteristics [9].

Microsoft Kinect is a consumer-grade range sensing technology developed in recent years. It is a low cost range sensor which is an attractive alternative to expensive laser scanners in wide application areas like indoor 3D object detection. Kinect has an RGB camera and an infrared (IR) emitter and camera. They are capable of capturing both coloured image and depth of each pixel in the scene, allowing us to perform tasks which seem impossible using image-only methods [9]. Most of the image processing systems are based only on the colour channels. The image information acquired by Kinect (RGB + depth) has a structure that creates a new way to process images. The Kinect sensor captures depth and colour images simultaneously at a frame rate of about 30fps [10].

In this work, we focus on only using depth images. Kinect depth sensor consists of the IR laser emitter and the IR camera. The IR camera operates at 30 Hz and pushes images with resolution of 1200x960 pixels. These images are presented at 640x480 pixels with 11 bits, which provide 2048 levels of sensitivity. The field of view in the system is 58 degrees horizontal, 45 degrees vertical, 70 degrees diagonal, and the operational range is between 0.8 meters (2.6 ft) and 3.5 meters (11ft).

The depth sensing uses structured light method to measure depth. A known pattern of dots is projected from the IR laser emitter. These dots are recorded by the IR camera and then compared to the known pattern. Any disturbances are known to be variations in the surface and can be detected as its position is either closer or further away. However, some materials do not reflect infrared light well. It is advised to stay about 1.8 meters away from the Kinect camera for better interaction [9].

Unlike ground robots, the unmanned aerial vehicles (UAVs) are free to fly at any height and space. Thus the limit of Kinect depth sensor can be overcome.

II. METHODOLOGY

This section describes our proposed algorithm in detail. Fig. 1 shows the step by step procedure to detect the object of interest. The objective is to detect the door and to know its state in terms of opening angle in indoor environment. Note that we focused on the detection of doors and its status as well as the detection accuracy. Thus, our algorithm will be explained based on passive door detection scenario. In addition, we assumed that the Kinect camera is always perpendicular to the door plane, and the dimension of the door is typical to the Asian region which is 2.0 meters x 0.9 meters.

Unlike the works of other researchers, the proposed algorithm only manipulates the depth information from the Kinect depth sensor without using the RGB image information. The algorithm was developed using the Image Acquisition Toolbox in MATLAB software which supports Kinect for Windows sensor for acquiring images and depth maps. The image was extracted using the depth Kinect sensor connected with a personal computer (PC) with an i5 1.7GHz Intel microprocessor and 5GB of RAM. The image was saved in the .png format.

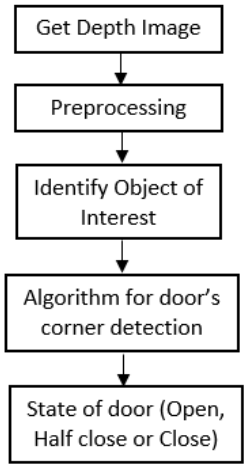


Fig. 1. Step by step procedure to detect the object

In depth images, the edge of the door is usually viewed as vertical straight line edges with depth difference between the left and right sides. Based on these characteristics, the door edge can be determined. According to [10], the random error of depth measurement increases with increasing distance to the sensor, resulting in missing holes. Our algorithm manipulates the missing holes for door detection. The large number of pixels of missing holes is what our measurement is based on. Fig. 2 shows the conceptual idea of our algorithm and the technique used. The major area of 0 pixels tells us that a door was detected. Different total amount of pixels 0 indicate status of door opened at different angle. The algorithm builds upon a number of iteration codes and the output is the coordinate of the corner point of the black hole. Fig. 3 illustrates the flowchart of the proposed algorithm.

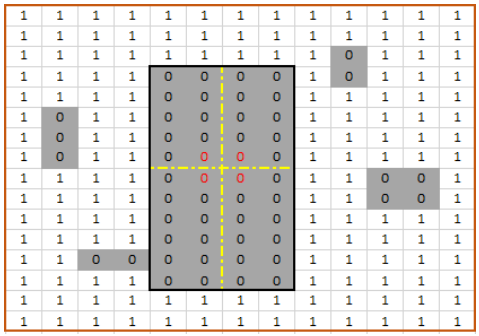


Fig. 2 Technique used for algorithm

Step 1: Get Depth Image

In Kinect, depth image is generated through receiving infrared structured light. The size of the depth image here is 320x240 pixels and the value of each pixel represents the distance from that point in real world to the Kinect camera plane. Fig. 4 and Fig. 5 show two examples of different raw depth images captured by the Kinect camera. In areas of occlusion region, smooth surface and distance exceeding its range, depth information is missing. The missing parts of the depth information are estimated.

Step 2: Image preprocessing & identifying objects of interest

Preprocessing was done to make the object of interest to be in the center of the image. Here the object of interest is the largest black colour portion which is the 0 pixel.

Step 3: Detecting door corner coordinate

An iteration programming loop is applied at this point. The object of interest was divided into four parts. Top left, top right, bottom left and bottom right. The loop iterates upwards and sideways. The loop will stop when a pixel other than 0 is detected. Finally the four corner coordinates will be displayed. The coordinates are top left (X_{TL}, Y_{TL}), top right (X_{TR}, Y_{TR}), bottom left (X_{BL}, Y_{BL}) and bottom right (X_{BR}, Y_{BR}). Thus, the formulas below are used to calculate the door's width and length:

i) The door Width, $W = X_{TR} - X_{TL}$

ii) The door Length, $L = Y_{BL} - Y_{TL}$

Step 4 Data analysis

The ratio of W/L is an important information showing that the object detected is a door while telling us the state of door.

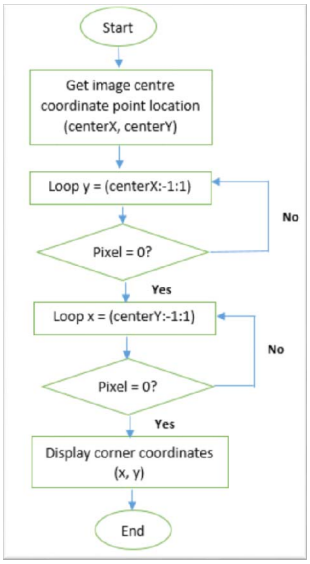
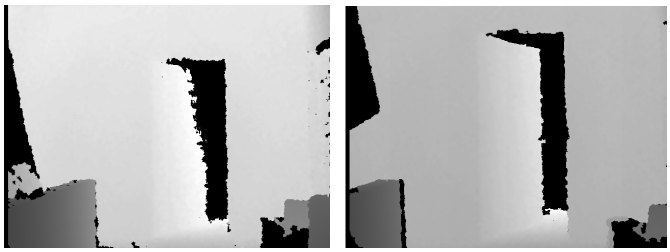


Fig. 3. Flowchart of the proposed algorithm



(a) (b)

Fig. 4. Raw Depth Image (1.0 m height outside of room) (a)3.4 m view range from door (b) 3.0 m view range from door

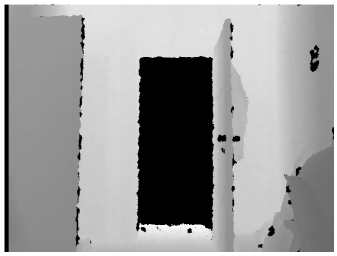


Fig. 5.Raw Depth Image (3.3 m x 1.0 m inside room, 90°)

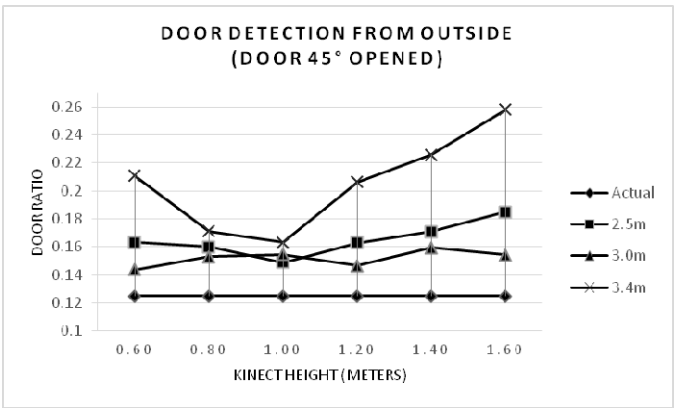
III. RESULTS & DISCUSSION

We determined the accuracy of our algorithm by performing several experiments in a typical indoor environment, using the scenario where a door was fully opened at 90 degrees, as showed in Fig. 5. The result data was compared with the real dimension ratio of the door. Next, we determined the effects of varying the height of the Kinect Camera and its distance to the door using our algorithm. The analysis of result was carried out and the best height and distance result given was determined. The findings can be divided into two categories that are the results obtained from the door detection from outside the room and door detection from inside the room. The Kinect sensor was set up on different heights, keeping the camera plane vertical to the ground. The results consistently show that there is a direct relationship between door detection and the distance of the Kinect Camera to the door.

A. Door detection from outside the room

The experiment was conducted under two scenarios, the door open at 90° and 45°. The results were compared to the actual door ratio. The distance from door at 3.4 meters provides the best results as shown in Fig.6 (a). The performance decreases with the decrease of distance from the door. However, at 3.4 meters distance from the door, the results are unpromising as shown in Fig.6 (b). This is because the distance is close to 3.5 meters, which is the limit of the Kinect depth sensor. The depth image does not detect a perfect rectangular door as shown in Fig.4 (a).

(a)



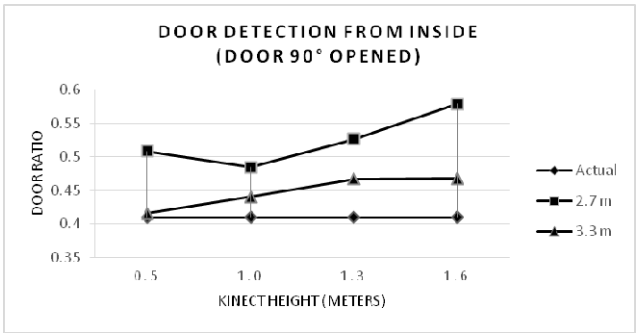
(b)

Fig. 6. Graph showing results of door ratio compared to actual ratio outside the room (a) 90° open (b) 45° open

B. Door detection from inside the room

Three scenarios were used in the study: door opening of 90°, 40°, and 35° angles. The results were compared to the actual door ratio as shown in Fig. 7. Generally the range distance of

3.3 meters shows more promising results as compared to the range distance of 2.7 meters. As for the variations in height, 1.0 meters height of the Kinect sensor from the ground shows the best performance compared to others.



(a)

(b)

(c)

Fig.7. Graph showing results of door ratio compared to actual ratio inside the room (a) 90° open (b) 40° open (c) 35° open

Therefore, using the proposed algorithm, the corners were recognized accurately. However there are a few constraints. Firstly, the view range of the camera is restricted by the Kinect sensor. (distance: 0.6~4 meters, horizontal angle: 57 degree). Doors which are too close or too far will result in undetectable corners, and this will result in some control and tracking problem for the moving UAV. This algorithm will not work on irregularly shaped doors. Furthermore, doors with closed status cannot be detected with this algorithm. Although the detection accuracy has been given with good performance in traditional test environments, more tests should be performed to prove its robustness. Future work can be done to test at different angle views of the camera.

III. CONCLUSION

The door or corner detection is an important step in indoor navigation for unmanned robot patrolling. The Kinect depth image is manipulated using our algorithm with good performance. This algorithm is best performed in a clear path at a distance of 3.5 meters. The view range is restricted by the Kinect sensor. The suitable view range for this algorithm using Kinect is around 3.3 meters. The accuracy of the measurement was influenced by the low resolution of the depth images. Future work can be done to consider adaptation to different scenarios. Additionally, work can be done to adapt the active door detection scenario for the purpose of real-time detection.

ACKNOWLEDGMENT

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