Obstacle Detection using a TOF Range Camera for Indoor AGV Navigation

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ABSTRACT— The performance evaluation of an obstacle detection and segmentation algorithm for Automated Guided Vehicle (AGV) navigation in factory-like environments using a 3D real-time range camera is the subject of this paper[1]. Our approach has been tested successfully on British safety standard recommended object sizes and materials placed on the vehicle path. The segmented (mapped) obstacles are then verified using absolute measurements obtained using a relatively accurate 2D scanning laser rangefinder.

Keywords:

Automated Guided Vehicle, 3D range camera, 2D Laser Rangefinder, Obstacle Detection and Segmentation.

1. INTRODUCTION

Obstacle detection and mapping are crucial for autonomous indoor driving. This is especially true for Automated Guided Vehicle (AGV) navigation in factory-like environments where safety of personnel and that of the AGV itself is of utmost importance. This paper describes the performance of an obstacle detection and segmentation algorithm using a 3D real-time range camera.

The 3D range image camera is based on the Time-Of-Flight (TOF) principle [8] and is capable of simultaneously producing intensity images and range information of targets in indoor environments. This range camera is extremely appealing for obstacle detection in industrial applications as it will be relatively inexpensive as compared to similar sensors and can deliver range and intensity images at a rate of 30 Hz with an active range of 7.5 m.

Since obstacle detection plays a basic function for autonomous driving, there has been much research on many different types of sensors, such as sonar [11], color/gray level cameras [2], FLIR (Forward Looking InfraRed) cameras [10], and stereo cameras [9], [1], [12], [6]. Most of the vision approaches are not applicable to indoor scenes due to lack of texture in the environment. Other researchers have proposed LADAR (Laser Detection And Ranging) sensors for detecting obstacles [4], [3], [5]. However, one dimension LADAR which has been used in AGV industry is not suitable for the 3D world of factory environments.

Our proposed approach to obstacle detection uses a low cost, 3D real-time range camera. First, we calibrate the camera with respect to the AGV so that we can convert the range values to 3D point clouds in the AGV coordinate frame. Second, we segment the objects which have high intensity and whose elevation values are above the floor of the operating environment on the AGV path. The segmented 3D points of the obstacles are then projected and accumulated into the floor surface-plane. The algorithm utilizes the intensity and 3D structure of range data from the camera and does not rely on the texture of the environment. The segmented (mapped) obstacles are verified using absolute measurements obtained using a relatively accurate 2D scanning laser rangefinder. Our approach has been tested successfully on British safety standard recommended object sizes and materials placed on the vehicle path. In this paper, the AGV remained stationary as the measurements were collected.

The U.S. American Society of Mechanical Engineers (ASME) B56.5 standard [13] was recently upgraded[2] to allow non-contact safety sensors as opposed to contact sensors such as bumpers on AGVs. Ideally, the U.S. standard can be upgraded further similar to the British safety standard requirements [14]. The British safety standard of industrial driverless trucks/robots requires that (a) sensors shall operate at least over the full width of the vehicle and load in every direction of travel, (b) sensors shall generate a signal enabling the vehicle to be stopped by the braking system under specified floor condition before contact between the rigid parts of the vehicle and/or load and a person, (c) sensors shall detect parts of a persons body as close as possible to the floor but at least the

[1]Commercial equipment and materials are identified in this paper in order to adequately specify certain procedures. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

[2]not cited here as the upgrade was not published prior to the date of this paper.

“test apparatus shall be detected”, (d) the activation of such sensors shall not cause injury to persons, and (e) reflective characteristics of test apparatus for personnel detection means which work without physical contact shall be representative of human clothing. We anticipate the work described in this paper and the continuing research efforts to lay the groundwork towards further upgrade of the U.S. safety standards for AGVs in factory-like environments.

The paper is structured as follows: Section 2 describes an obstacle detection and segmentation algorithm using range camera images. Section 3 provides the experimental results when the proposed algorithm is employed for detection and segmentation of British standard test apparatus. Section 4 concludes the paper and indicates future research areas that are under investigation.

2. OBSTACLE DETECTION AND SEGMENTATION

In this section, we describe an algorithm to detect and segment obstacles in the path of the AGV using a solid-state Time-Of-Flight (TOF) range camera. The 3D range camera shown in Figure 1 is a compact, robust and cost effective solid state device capable of producing 3D images in real-time. The camera has a field-of-view of 42° (horizontal) × 46° (vertical) and is capable of producing range images of 160×124 pixels. For a brief overview of the characteristics and operating principles of the camera, see [8]. Approximately sized British standard test obstacles, shown in Figure 2, were placed on the travel path.

Fig. 1. The TOF 3D range image camera. The camera simultaneously generates intensity images and range information of targets in its field-of-view at a rate of 30 Hz with an active range of 7.5 m.

The obstacle detection and segmentation algorithm combines intensity and range images from the range camera to detect the obstacles and estimate the distance to the obstacles. The steps of the algorithm are illustrated for a sample image from the camera:

1) First, a patch data with high intensity values (i.e., the intensity value is greater than 20) in the front of the robot are used to fit a plane for estimating the floor surface as shown in Figure 3(a).
2) Second, the left and right edges of 3D robot paths are projected to the range and intensity images such that only obstacles on the path can be considered as shown in Figure 3(b).
3) Third, all the intensity pixels inside of the left and right edges are used to hypothesize the potential obstacle. If the intensity value of the pixel is greater than half of the average of the intensity in the image then the pixel is considered as a potential obstacle as shown in Figure 3(c).
4) Fourth, each potential obstacle pixel in the range image is used to find the distance to the floor plane when the distance to the floor is greater than some threshold as shown in Figure 3(d). The threshold is dependent on the traversability of the robot.

(a)

(b)

Fig. 2. Experimental setup. (a) and (b) depict the experimental setups that are described in this paper. See Section 3 for further details.

Potential obstacles in the world model can be accumulated as the AGV drives; Figure 4 shows an obstacle map representation that is part of the world model. The obstacles map is shown at 10 cm grid resolution. Nearly all the obstacles are found, but at the cost of false positives from the reflected objects. To increase the accuracy of our

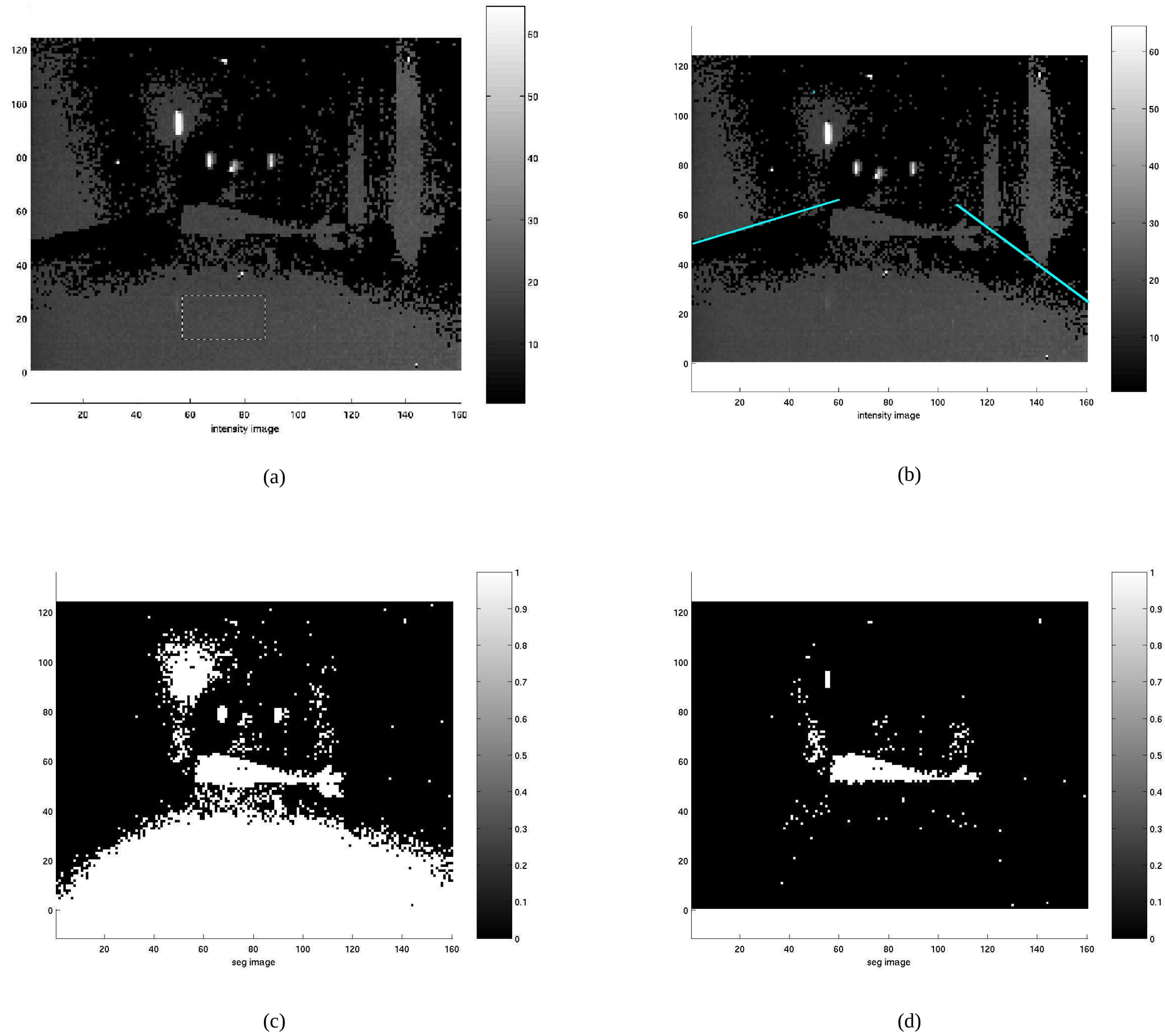

Fig. 3. Obstacle segmentation algorithm illustration.

obstacle detection, the obstacles in the map and information obtained from an added color camera may be temporally integrated. Such integration has proven to be a very useful cue for obstacle detection [7].

3. EXPERIMENTAL SETUP AND RESULTS

The experiments were conducted under two scenarios as stated within the British Standard:

1) A test apparatus with a diameter of 200 mm and a length of 600 mm placed at right angles on the path of the AGV. The actuating force on this test apparatus shall not exceed 750 N.

2) A test apparatus with a diameter of 70 mm and a height of 400 mm set vertically within the path of the AGV. The actuating force on this test apparatus shall not exceed 250 N.

Figures 2(a) and (b) show the experimental setup for the two aforementioned scenarios. The center of the camera lens was centered approximately horizontal and vertical on the apparatus for all measurements. The scanning laser rangefinder was offset from the camera by 0 mm vertically, 250 mm horizontally, and to the left of the camera as viewed from the camera to the test apparatus. The range camera was used to detect known test apparatus mounted on a stand and moved to different locations with respect to the camera.

The obstacle detection and segmentation algorithm was tested on the British standard test apparatus as described in [14], and was evaluated against *ground truth*. A single-line scanning laser rangefinder, shown in Figure 5, mounted beside the range camera, was used to simultaneously verify the distance to the test apparatus for each data set and served as ground truth. The rangefinder produces 401 data

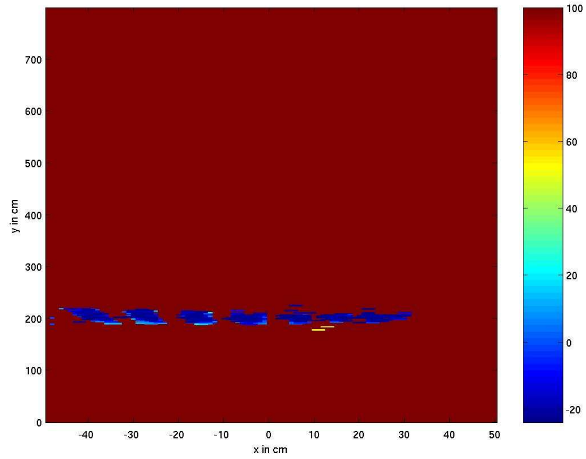

Fig. 4. Obstacle map.

Fig. 5. Experimental setup of the AGV, the scanning laser rangefinder, and the range camera.

points over a 100° semi-circular region in front of the robot.

The obstacle detection and segmentation algorithm was tested on British standard test apparatus which were placed in 0.5 meter to 7.5 m distances to the sensor. Table 1 shows the performance of the range camera for measuring the distance to the test apparatus placed at several distances from the range camera. As can be seen, the accuracy (mean) of the range decreases as the distance of the apparatus placed in front of the range camera is increased.

In Figure 6, the test apparatus was placed at a distance of 2.5 m from the range camera. Each object in the test apparatus was clearly detected even though the range camera was also sensitive to the reflectors on the wall of the hallway. The resultant intensity, range, and segmented images are shown in Figures 6(a), (b) and (c), respectively. The ground truth provided by the scanning laser rangefinder is shown in Figure 6(d) and has been rotated to show a top-down view.

In Figure 7, the test apparatus is a mannequin leg placed on the floor with an approximate diameter of 200 mm and a length of 600 mm. This test apparatus is more challenging for the algorithm because the entire object is close to the floor. As can be seen, the legs are detected, but at the cost of detecting reflectors. Since some reflectors (see Figure 7(c)) are at a distance of more than 7.5 m, these are modulated by the non-ambiguity distance range of the camera. This deficiency can be eliminated by using two different modulation frequencies (such as 10 MHz and 20 MHz) where the detected objects would be coarsely represented at a more appropriate distance. The control algorithm can then intelligently delete them.

4. CONCLUSIONS AND FURTHER WORK

An obstacle detection and segmentation algorithm for Automated Guided Vehicle (AGV) navigation in factory-like environments using a novel 3D range camera was described in this paper. The range camera is highly attractive for obstacle detection in industrial applications as it will be relatively cheap and can deliver range and intensity images in real-time. The performance of the algorithm was evaluated by comparing it with ground truth provided by a single-line scanning laser rangefinder.

We envisage the extension of the work detailed in this paper in the following areas:

• We believe that the range camera can be used for moving obstacle detection from a moving AGV. The detection of moving obstacles in the factory floor is a next critical step for AGV navigation in such dynamic environments. Additionally, this sensor can be combined with a color camera for detecting and tracking obstacles over long distances.

• We also believe that the range camera discussed in this paper holds good potential to be used in outdoor environments. Towards this, we have taken and analyzed some outdoor data and the preliminary results show good promise in using this sensor for outdoor forest environments. Some prospective applications include mapping factory environments (“lights-out”) manufacturing, and even for use in space due to its compactness.

5. REFERENCES

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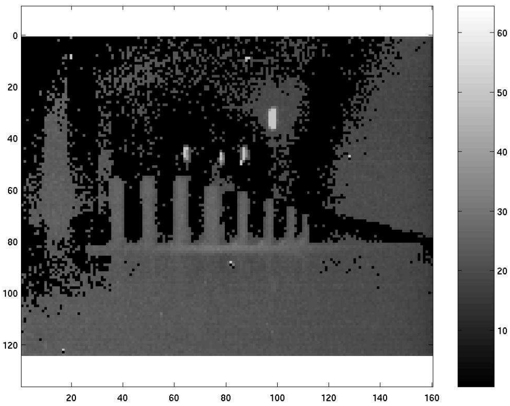
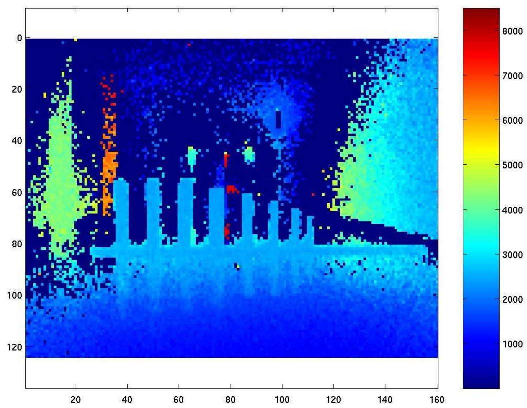
Table 1
Quantitative Comparison of Performance

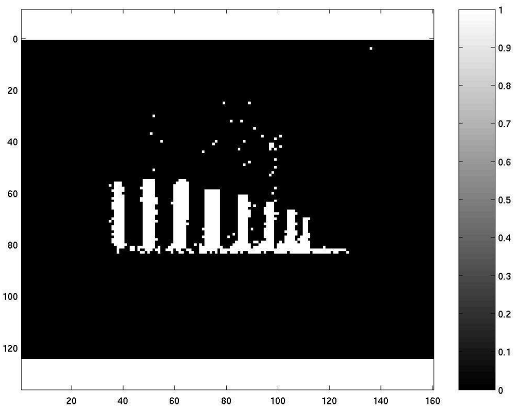
Nominal Obst. Dist. [cm]	**3D Range Camera Mean [cm]**	**2D Rangefinder Mean [cm]**
64	64	65
111	111	111
160	161	161
210	204	210
259	249	259
310	284	310



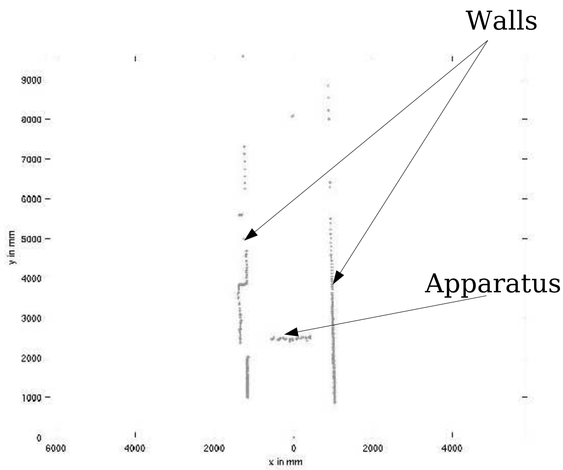
(a) Intensity Image



(b) Range Image

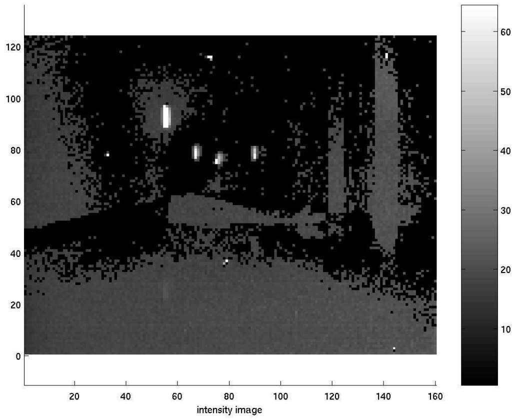


(c) Segmented Image

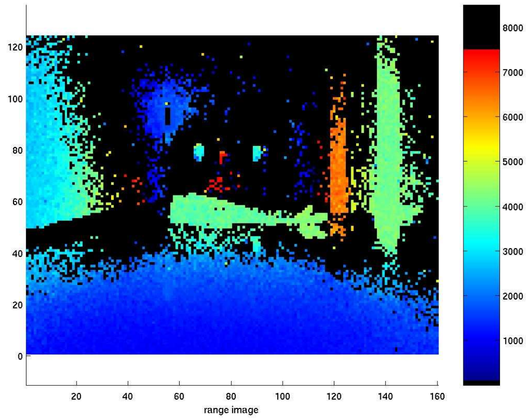


(d) Ground Truth

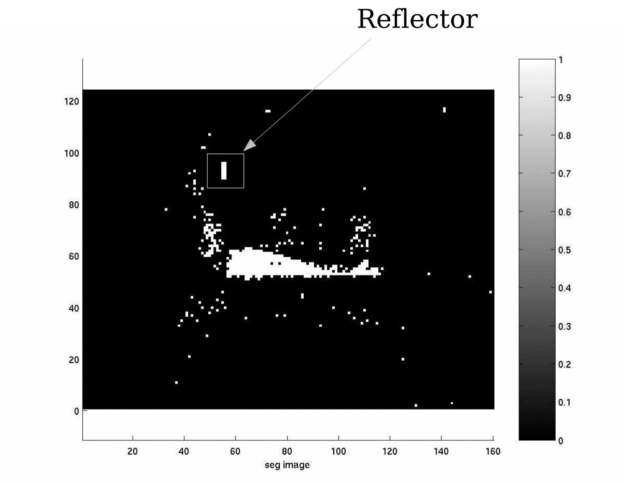
Fig. 6. Results of the obstacle detection and segmentation algorithm for the experimental setup shown in Figure 2(a). The resultant intensity, range, and segmented images are shown in (a), (b) and (c), respectively. The ground truth provided by the scanning laser rangefinder is shown in (d) and has been rotated to show a top-down view.



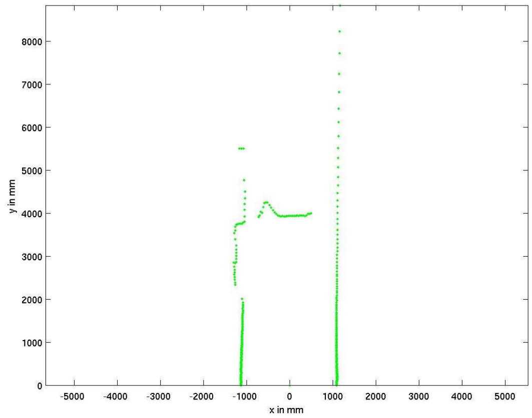
(a) Intensity Image



(b) Range Image



(c) Segmented Image



(d) Ground Truth

Fig. 7. Results of the obstacle detection and segmentation algorithm for the experimental setup shown in Figure 2(b). The resultant intensity, range, and segmented images are shown in (a), (b) and (c), respectively. The ground truth provided by the scanning laser rangefinder is shown in (d) and has been rotated to show a top-down view.

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