Comparison of the Resolution of 3-D Sensors

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***Abstract*—This is a survey of the resolution of data gathered by different 3D-imaging devices. The sensors covered in this paper consist of the Asus Xtion Pro Live [1], Microsoft Kinect [2], Microsoft Kinect with Nyko Zoom Lens [3], and Hokuyo URG-04LX Laser Range Finder [4]. The results of this survey suggest that the Asus and Kinect (both with and without the Zoom Lens) possess similar capabilities, and are well-suited to near real-time applications, while the Hokuyo URG-04LX Laser Range Finder is able to detect smaller features than both the Kinect and the Asus, but is only viable for non-real-time applications.**

I. Introduction

This survey was conducted with the goal of deciding upon the 3D-imaging platform for the Autoponics project [5] being conducted at the Solid State Depot (SSD) in Boulder, Colorado [6]. Autoponics is a method of growing plants in which robots and other computerized machinery perform all aspects of plant food production: seeding, growing, harvesting, and processing. The Autoponics project at SSD is using the Robot Operating System (ROS) [7] framework for reading data and controlling system operations. Therefore, the ideal 3D imaging device should have two important properties: it must be supported by ROS, and it must have a sufficiently high resolution to gather useful and reliable data. Specifically, the point cloud data produced by the device must be of sufficient resolution such that it can be used to produce a 3D model used for path planning and end-effector manipulation (i.e. harvesting parts of a plant). All of the devices tested in this survey are supported by ROS, and thus the ability to distinguish plants and their component features becomes the most important factor.

The sensor package (which includes the imaging device) of the Autoponics system is mounted on a vertically-oriented cartesian robot, and so we will refer to a coordinate system throughout this paper with respect to the orientation of this vertical cartestian robot. Let us define the coordinate system such that the sensor is at the origin, pointed directly towards the positive Z-axis, which is parallel to the ground and orthogonal to the vertical XY-plane. The depth data is translated into Z-coordinates, and the resulting point clouds generated by the sensors create the basis for a varying surface that extends in the X- and Y-directions.

Although the experiment is conducted in a similar manner for every device, it is important to note the differences in the purpose of each image sensor, as it may explain some of the results. The Microsoft Kinect was originally created as a enhanced gaming device for the Xbox platform. The primary purpose of the Kinect is to distinguish people and their gestures. Also, since it is a mass market device, the cost of the sensor is relatively cheap at approximately $150. Another mass market device is the Asus Xtion Pro which costs about $190. The Xtion Pro was built with the purpose of sensing human movement for the PC platform. Since they are built to enhance an interactive experience, both the Kinect and Xtion Pro are real-time systems. The third image sensor used in the experiment is the Hokuyo URG-04LX Laser Range Finder. The URG-04LX has significant differences in function and purpose to the previous systems; which helps explain its price tag of almost $1,200. The URG-04LX is intended for use in indoor robot navigation and obstacle avoidance. It delivers a line of depth data in real-time, but creating 3D point clouds from this data requires post-processing, described below, and introduces enough latency that it is not considered a real-time system.

The remainder of this paper is as follows: Materials, Methods, Results, Discussion, Conclusion.

II. Materials

The experiment conducted in this survey consists of the various pieces seen in Figure 1. The three main components of the experimental setup are the 3D imaging devices, visual

Fig. 1: The test setup from the perspective of a sensor. In the foreground is the Microsoft Kinect with the Nyko Zoom Lens. Beyond it is the visual target and the backdrop.

target, and the white cardboard backdrop behind the target. All three are placed on a flat eight-foot table.

The visual target (Figure 2) is a one-foot by one-foot square of inch-thick acrylic, laminated with an opaque brown material so as to eliminate the factor of transparency from the experimental variables. The features of the target are laser-cut holes that increase in size from right to left and from bottom to top. The diameter of the holes are 0.25 cm, 0.50 cm, 0.75 cm, 1 cm, 2 cm, 3 cm, 4 cm, 6 cm, 8 cm, and 10 cm.

The Xtion Pro and the Kinect were tested without modification. Both of these devices use structured light to cast a grid of infrared points onto the environment. Because the light is distributed in two dimensions, each frame of the sensor data produces a complete point cloud. The Hokuyo Laser Range Finder differs in that it creates a 1D line of points at different depths, or a slice of a point cloud. To generate a full 3D point cloud from this data, we orient the laser such that it produces slices parrallel to the YZ-plane and take a series of slices by incrementing the X-position of the laser. The full point cloud is produced by programming a ROS node that stitches the slices together by inserting an X-coordinate into each YZ laser scan. The laser is mounted to a carriage on a Makerslide [8] rail, as shown in Figure 3. A stepper motor, also mounted to the carriage, controls a belt drive to move the carriage along the rail, and continually publishes its position to a ROS message topic. The stitching node reads both the position and laser scan topics, inserts the X-coordinates, buffers the modified laser scans, and then displays a collection of slices simultaneously in the ROS Visualizer (RVIZ) [9] to create the full 3D point cloud.

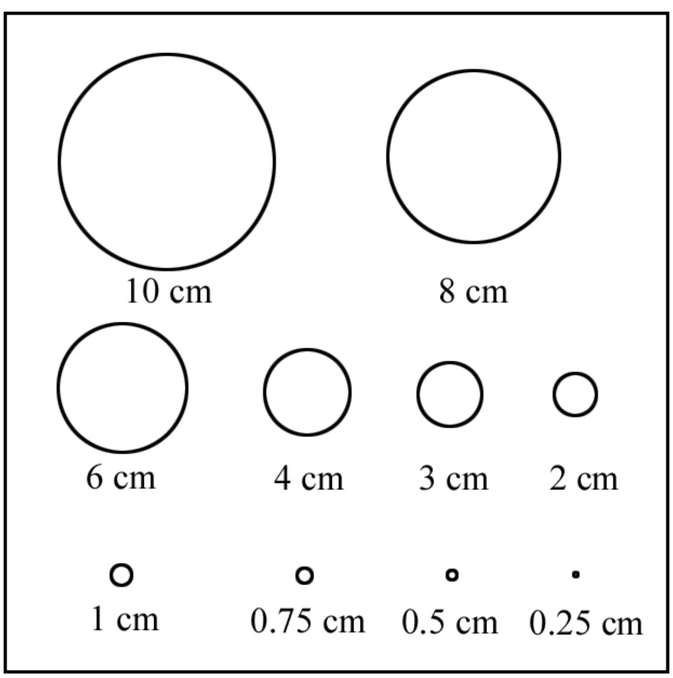

Fig. 2: Diagram of the visual target

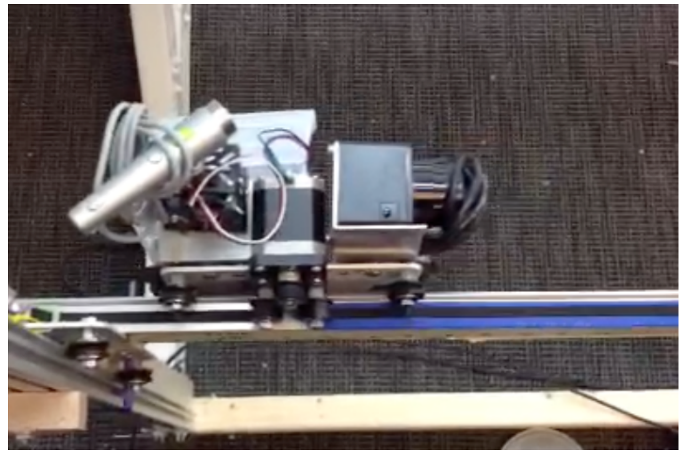

Fig. 3: Picture of the X-Carriage on the Makerslide. The Hokuyo laser scanner (right, black and square) is mounted next to the stepper motor (center, black). Also visible is the IPEVO Document Camera (left, long and silver), which was unused in these tests.

III. Methods

We test two different types of resolution in this survey, the XY-resolution and the Z-resolution, at increasing distances between the sensor and the target. The XY-resolution demonstrates the minimum size of detectable features at given distances. In this paper, we will call this the *linear* resolution. It is a function of the angular resolution of the device and the distance, given by

$$L = D * \tan A$$

where L is the linear resolution, A is the angular resolution of the sensor, and D is the distance between the sensor and the target. The Z-resolution demonstrates the minimum consistently detectable difference in depth of different features, and we will use the term *depth* resolution when discussing it.

A. Linear Resolution Test

The sensor was placed at one end of the table and the white backdrop at the other. We gradually moved the target from 10 cm from the sensor to 250 cm, taking screenshots and noting the distance each time a feature (the holes) was no longer consistently visible. Figure 4 shows a screenshot from this test.

B. Depth Resolution Test

In this test, the sensor was again stationary at one end of the table. The target is placed at increasing distances from the sensor, from 50 cm to 210 cm at 10 cm increments. At each distance, we placed the backdrop immediately behind the target and slowly increased the distance between the backdrop and the visual target until we could visibly differentiate between the backdrop and the features of the target. The depth data was mapped to the color spectrum, rather than simply gray-scale, making the difference more noticeable.

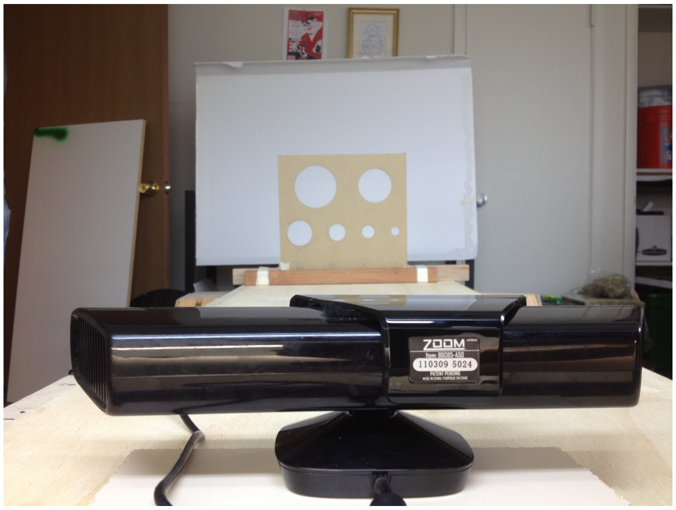

Fig. 4: An example screenshot from the linear resolution test, using the Asus Xtion Pro at 60 cm from the target.

IV. Results

A. Linear Resolution Test

B. Depth Resolution Test

V. Discussion

VI. Conclusion

The conclusion goes here.

Acknowledgment

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