Development of an Automated Tabletop Kinect-based 3D Scanner for the PSHS Fab Lab

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ABSTRACT

The Philippine Science High School - Main Campus (PSHS-MC) Fabrication Lab lacks a 3D scanner. Industrial 3D scanning systems are powerful and automated but are too large and expensive for the lab. This research developed an inexpensive, fully-automated, and user-friendly 3D scanning system that can be operated on a tabletop. The system utilizes the depth-sensing capabilities of the Microsoft Kinect v2. The proponents designed hardware mechanisms for elevating the Kinect while fully rotating an object of interest. A custom 3D scanning program was developed and integrated with the hardware. The researchers pre-selected 15 objects-of-interest of varying size and shape. Scans for each of the 15 objects were performed using the system with a uniform 6-slice setting. The total scan times ranged from 10 to 15 minutes. The resulting scans were compared to the original 3D models of the objects through visual inspection. The developed system was able to produce viable 360-degree point cloud and mesh files that can be further edited through 3rd party software. With this system, users of the PSHS-MC Fabrication Lab may scan objects for their research and fabrication projects.

Keywords: 3D Scanning, Kinect

INTRODUCTION

3D scanning, the analysis of objects or environments to digitally construct 3D models, has various applications in fields such as animation, cultural heritage documentation, and 3D printing (Boehler & Marbs 2002). In Philippine Science High School - Main Campus (PSHS-MC), numerous research and design projects may require 3D scanning for object reconstruction and replication. However, the school's fabrication lab lacks a 3D scanner to address this need.

There are 3D scanning systems currently available in the market. However, all manifest a trade-off between performance or automation and affordability.

This project aimed to develop an inexpensive, automated, and user-friendly 3D scanning system for PSHS-MC. The system will be utilizing the Kinect V2, an affordable 3D sensor. Kinect has been used in various reconstruction projects such as that of Tong et al. (2012) and Kinect-Fusion (Izadi et al. 2011).

The development of an automated, inexpensive, and satisfactory 3D scanning system for the PSHS Fabrication Lab enables both student and teacher makers to efficiently replicate real-life objects. The 3D scanning system reduces the work needed to construct or refine models of real-life objects using computer-aided software (CAD) before 3D printing. A 3D scanning system is particularly helpful for research and maker projects related to fields such as biomedical engineering (Dombroski et al. 2014) and environmental science (Bassett et al. 2015).

METHODOLOGY

System design considerations

The researchers took into account the remaining space in the PSHS Fabrication Lab, user-friendliness, efficiency and the Kinect's optimal operating conditions during the design phase. Autodesk Fusion 360 was used to design the turntable and the base of the system. Inkscape was used to design the elevating platform where the Kinect would be placed. Figure 1 shows the schematic of the system altogether.

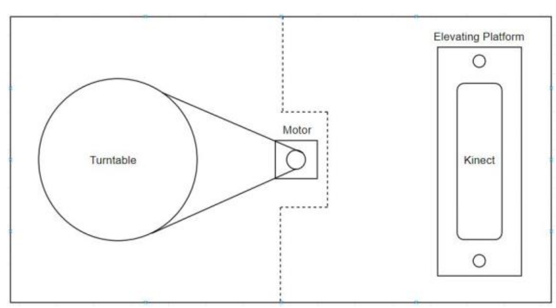

Figure 1. Schematic of the hardware design

Construction of the 3D scanning hardware

The tabletop system was designed to move the Kinect sensor up and down while rotating the object being scanned. Medium Density Fiber (MDF) boards were cut using a Computer Numerical Control (CNC) machine to form an elevating platform for the Kinect and a turntable for the object of interest. The elevating platform is mounted on two stepper motors that are programmed to move the Kinect up and down. The mechanism is similar to that of a Cartesian 3D Printer system (Chaitanya et al. 2016). The rotating turntable has a belt conveyor system run by a stepper motor. The motors were automated using an Arduino UNO microcontroller.

Development of the 3D scanning software

A Kinect V2-compatible 3D scanning program was developed using the Point Cloud Library (PCL) (Rusu & Cousins 2011). Using point cloud version of Kinect Fusion (Tsukasa 2013), the program creates a point cloud of the scene for every position of the turntable. PCL's outlier removal and cropping functions are used to clean and extract the target object's point cloud from that of the scene. Finally, transformations and multiple iterations of the Iterative Closest Point (ICP) algorithm are applied to the collection of point clouds to form a complete point cloud of the object of interest. Using PCL, the user is given the choice to convert the final point cloud into a mesh file of their preferred type (i.e. .stl, .obj, .ply).

Integration of hardware and software

The 3D scanning software was designed to operate in unison with the hardware of the system. The developed program is able to communicate with the microcontroller, allowing the user to control the whole system from the scanning program alone. The dimensions and relative positions of the turntable and elevating platform were fixed to automate the filtering of the scene point cloud into the object point cloud. The turntable also rotates to known angles to automate and speed up the point cloud transformations and ICP algorithm.

Data Analysis

The system's scanning capability was tested by performing scans on each of 15 identified objects-of-interest. The system's performance was evaluated through visual inspections and comparisons with the actual objects.

RESULTS

Specifications of the system

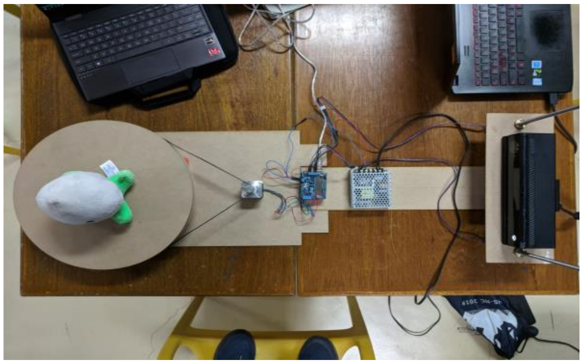

Figure 2. Final 3D scanner

The final system is laid out in Figure 2. It is composed of an Arduino UNO microcontroller board stacked with two Adafruit Motorshield V2 to control the NEMA 17 stepper motors as shown in Figure 2. The motors are powered by a power brick with an output of 5V and 7.0A. One of the motors is used to rotate the turntable via a timing belt. The other two motors are used to elevate the Kinect up and down.

The scan starts with the Kinect going up and down and then the turntable rotates 60 degrees by default. The average duration to fully scan an object is 5 minutes.

Performance of the system

For the default 6-slice scan setting, the full scan times range from 5 to 6 minutes. However, the user may also opt to change the number of slices depending on the object being scanned.

Two processing pipelines were developed. The first pipeline uses a standalone program to scan and generate output in the form of point clouds (.pcd) as seen in Figure 3 and mesh files (.stl, .obj, .ply). The point cloud generation is based on PCLFusion. This pipeline also includes an optional smoothing algorithm. The effects of mesh smoothing can is shown in Figure 4.

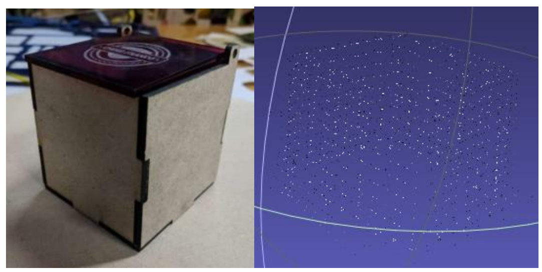

Figure 3. Object vs. point cloud

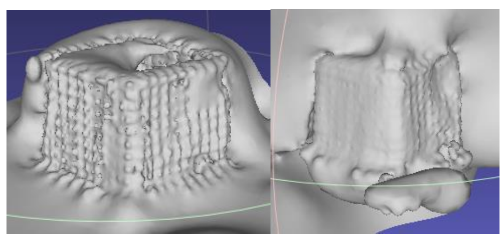

Figure 4. Mesh vs. smoothed mesh (pipeline 1)

The second processing pipeline uses Kinect Fusion to generate mesh files then a separate mesh merging program must be run on the mesh files. The program outputs mesh files in .stl, .obj and .ply formats. An example of this pipeline's output in shown in Figure 5.

Figure 5. Object vs. merged mesh (pipeline 2)

DISCUSSION

As shown in Figures 3 to 5, the developed 3D Scanning system was able to produce scans of tabletop objects in point cloud and mesh formats. The integration of the hardware and software allows users to control the whole system from the scanning program alone. As shown in figure 2, the target object just needs to be placed on the turntable while the motors control the rotation of the object and the elevation of the Kinect. This minimizes manual actions needed in performing scans, contributing to the automation and user-friendliness of the system.

While the 3D scanning system is comparable to established community-made and industrial scanning systems, it still has numerous limitations brought about by budget, allotted time for development, its hardware, and its software. The Kinect has an optimal operating range from 0.5 to 5 meters, and the resolution of the distance measurements decreases with distance (≤1 mm at 0.5 m and ~75 mm at 5 m) (Mankoff & Russo 2013). The Kinect only has a depth frame resolution of 512x424 pixels. This is enough to produce quality scans but may not be enough to compete with the high-resolution professional 3D scanners. The Kinect's infrared time-of-flight approach to gathering 3d data may also cause errors due to how infrared light interacts with some surfaces such as transparent or IR absorbing materials.

The default settings for processing were based on the recommendations from PCL. With multiple variables that can be changed for each scan, general settings that would provide the optimal results for different objects could not be determined. Finding the optimal settings for producing the desired scan quality is therefore left to the user.

SUMMARY AND CONCLUSION

In this work, a 3D scanner based on the Kinect v2 sensor, a popular low-cost depth camera is presented. The scanner is able to obtain shape and color data for reconstructions. The scanner was tested on 3D printed objects in the PSHS-MC Fabrication Lab and was able to meet its goals of being viable, low-cost and user-friendly.

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