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Metrological evaluation of KinectFusion and its comparison with Microsoft Kinect sensor

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ABSTRACT

In recent years the use of low cost sensors like Microsoft Kinect in the engineering field is growing day by day. Its use as a measurement device, capable of generating geometric data in close-range environment has been already validated. KinectFusion is a software that is able to capture a complete dataset of a 3D scene reconstruction using the Microsoft Kinect depth sensor at a very low cost. In this work, a metrological geometric verification of the KinectFusion implementation is performed using a standard artefact which consists of five delrin spheres and seven aluminum cubes. Accuracy and precision tests at different resolutions and ranges were performed to assess the metrological behavior of KinectFusion and compare it with the Microsoft Kinect depth sensor. The analysis reveals that both approaches yield a decrease in precision and accuracy with increasing range between sensor and object. Measurement of the length between the centers of the spheres was used for accuracy assessment. Taking into account the farthest sphere, an increasing trend of the accuracy with the distance was obtained for KinectFusion dataset, independently of the 3D model resolution and the range. By contrast, this trend is not shown for Kinect depth sensor dataset. KinectFusion precision results are better than the obtained with Kinect stand alone sensor. Besides that, precision values for KinectFusion are proportional to the resolution of the 3D model. KinectFusion algorithm provides a suitable 3D model of the scene that can be used for engineering applications where accuracy requirements are not very strict.

1. Introduction

Originally developed for the entertainment market, Microsoft Kinect sensor has become a foremost depth sensor for the development of many new engineering applications. The ability to capture the scene at a very low cost, compared with professional LiDAR sensors, helped the engineers to start the development of new applications over a huge different areas, such as robot and medical instrumentation [1–3], people recognition and tracking [4–6] and gestures detection [7,8]. One of the best capabilities of the Kinect sensor is to capture the scene and create a 3D point cloud which represents the shape of the scanned object. A point cloud acquired from a single snapshot is not complete and, in consequence, more shoots are needed for the creation of a complete 3D model. The main drawback of this technique lies on the need to perform a registration of the data which, in some cases, becomes a costly work. Here is where the KinectFusion [9,10] algorithm comes on handy. KinectFusion is a method for real-time capture of dense 3D geometry of the physical

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environment using a Microsoft Kinect depth sensor. Users can obtain a complete 3D model of the scene with a good quality for short range environment.

Previous metrological study of the Microsoft Kinect and similar sensors, based on a reference metrological artefact, has corroborated that these sensors are suitable for measuring objects at short ranges when accuracy is not an strict requirement [11]. Meister et al. [12] studied the use of the KinectFusion system to acquire ground truth volumetric objects at a fixed range and resolution and show the potential of the system against commercial LiDAR measurement systems.

The aim of this work is to assess the KinectFusion results at different resolutions and ranges, and to study the reliability of the system for engineering applications. The study was performed with the help of a reference standard artefact and a Microsoft Kinect sensor. The metrological evaluation consists of verifying the 3D models generated by the KinectFusion implementation at the available resolutions of the 3D model, with varying ranges from the artefact. Also a comparison with the standalone Kinect sensor was performed to determine the difference between both systems.

The manuscript is organized as follows: the materials used for the study are described in the next section. In Section 3 the different steps followed to accomplish the metrological evaluation and the metric indicators of the assessment are presented. The results of the evaluation are presented and discussed in Section 4. Finally, Section 5 presents the conclusions of the work.

2. Materials

In order to perform the metrological assessment of the KinectFusion results compared to the raw results of the Kinect sensor, the authors have followed an analogous methodology to previous evaluations [11]. The main elements of this work are a reference standard artefact, a Microsoft Kinect sensor and the KinectFusion implementation in the Kinect for Windows SDK [13] by Microsoft.

2.1. Reference standard artefact

The reference standard artefact is composed by five delrin spheres and an aluminum block body with seven cubes of different dimensions. The aluminum blocks were built by a precise CNC machine. The reference standard artefact is shown in Fig. 1. The nominal diameter of the spheres is 100 mm and the edge of the cubes range between 100 mm and 10 mm The main geometric characteristics are described in Tables 1–3. The reference standard artefact is portable in order to allow the comparison with different laser scanners that present different technical characteristics. The calibration of the artefact was performed by AIMEN Technological Centre (Vigo, Spain) which is ENAC accredited for dimensional measurements according the ISO 17025:2005. The calibration procedure used a precision coordinate measurement machine. The machine is a Mitutoyo Euroc Apex 12010. It works in a laboratory under environmental controlled conditions of temperature (20 ± 2 °C) and relative humidity (50 ± 10 %). The uncertainty limits of the machine and procedure cannot provide values lower that those shown in the Table 3. These values do not indicate any trend with the direction.

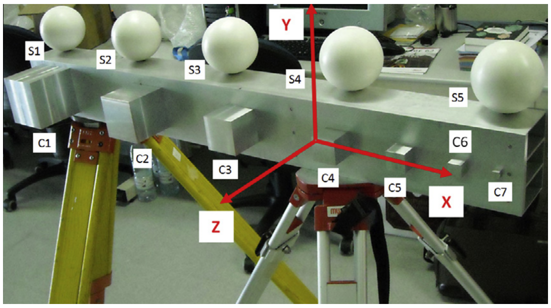

Fig. 1. Standard artefact.

Table 1
Length L_{ss} between the center of the spheres S1 to S5. ΔL_{ss} represents the standard deviation in length measurements.

Spheres	L_{ss} (m)	ΔL_{ss} (m)
S1-S2	0.2502	0.00008
S1-S3	0.50014	0.00007
S1-S4	0.75017	0.00014
S1-S5	1.00039	0.00006

Table 2
Diameter D_{ss} and standard deviation ΔD_{ss} of the spheres from the standard artefact.

Spheres	D_{ss} (mm)	ΔD_{ss} (mm)
S1	99.964	0.045
S2	99.958	0.042
S3	99.967	0.039
S4	99.956	0.051
S5	99.992	0.027

This artefact [14–16] was previously used for metrological studies of terrestrial and mobile LiDAR and photogrammetric systems. These studies show as the distance between centers of spheres could be used to obtain the accuracy data and the standard deviation of the sphere and plane fittings could establish the precision (repeatability) in the measurements. Accuracy and precision results are in agreement with those provided by the technical specification of the manufacturer of the systems. Important influences between resolution and range are observed.

2.2. Microsoft Kinect sensor

Microsoft released the Microsoft Kinect sensor (Fig. 2) for the Xbox 360 video game console on November 2010. This sensing device is intended to be used to control the Xbox console and their games via gestures, movement and spoken commands, instead of using the special game controller. Due to the wide range of applications that users were giving to the sensor, Microsoft released the Windows