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# Metrological comparison between Kinect I and Kinect II sensors

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ABSTRACT

This work shows a metrological comparison between Kinect I and Kinect II laser scanners. The comparison is made using a standard artefact based on 5 spheres and 7 cubes. Accuracy and precision tests are done for different ranges and changing the inclination angle between each sensor and the artefact. Results at 1 m range show similar precision in both cases with values between 2 mm and 6 mm. However, at 2 m range values of Kinect I increase up to 12 mm in some cases, while Kinect II keeps all results below 8 mm. Accuracy is also better for Kinect II at 1 m and 2 m range, with values always lower than −5 mm. Accuracy for Kinect I reaches −12 mm at 1 m range and −25 mm at 2 m range. Precision study shows a decrease of precision with range according a second order polynomial equation for Kinect I, while Kinect II shows a much more stable data. Measurement range of Kinect II is limited to 4 m, while Kinect I can obtain data up to 6 m.


## 1. Introduction

3D modelling of the environment is something that is becoming more widespread with applicability in fields such as civil engineering [1], quality control in industry [2], robotics [3], cultural heritage [4], mining [5], or the entertainment industry [6]. In recent years, laser scanners have become widely used systems for the performance of 3D models of the environment. Depending on the type of application parameters such as range, accuracy or measurement rate are fundamental for choosing one laser scanning system over the other.

Applications in civil engineering, mining, and environmental science (e.g. surveying of a riverbank, a quarry, or a road slope) require long range (hundreds of meters) with accuracies typically around 1 cm. Architecture and cultural heritage (facades of historical buildings) require intermediate range of some tens of meters with accuracies better than 5 mm. Quality control in automotive or aerospace industry requires short range (sometimes lower than 1 m), high accuracies (0.1 mm or even better) and high measurement rate. Most of the systems used for quality control are embedded in production lines, therefore there is a need for synchronization with the manufacturing of the parts. Autonomous robots use laser scanners to map the environment, obstacle detection, and navigation-aid. They typically need medium range (30 m maximum) and low accuracy (between 3 cm and 5 cm) systems. However, since being part of a real-time control system, they need high scanning rate. Entertainment industry has more recently contributed to the development of such systems well-known as gaming sensors. They seek low-cost systems with low–intermediate ranges (between 1 m and 5 m; to work in a domestic room) and high measurement rate (to map quickly the player's movements and transmit them to the videogame). In addition, although the accuracy begins being low, the greater demands of the players, who

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**Fig. 1.** Kinect I laser scanner with highlighting of IR illuminator, RGB camera and IR sensor (top), and Kinect II laser scanner with RGB camera, IR sensor and IR illuminator (bottom).

want the response of the avatars accurately synchronized with their movements, is pushing the improvement of accuracy of the laser scanners.

Asus and Microsoft were two of the most popular laser scanning systems for the entertainment industry with the Xtion and Kinect systems. Kinect sold more than 24 million systems whole over the world. Both systems consist of low-cost triangulation laser scanners that have become very popular during the last couple of years. Due to the great community of potential developers working with these systems, many new applications have been developed that extend the potential of the systems to other fields different to entertainment. Some examples are indoor robotics, face recognition, virtual learning, and forensic science [7–12].

Recently, Microsoft has released Kinect II. It is based on a time-of-flight technology instead of triangulation-based former scanner. According the technical specifications, Kinect II improves Kinect I with higher camera resolution, depth resolution and frame rate [13]. However, there are not official data about the metrological characteristics of the depth measurements (i.e. accuracy and precision). These data could be very valuable for users to determine the real possibilities of the systems in many applications.

The aim of this work is to use a previously calibrated standard artefact to perform a metrological comparison between Kinect I and Kinect II sensors. Section 2 of the manuscript depicts the materials and methods used for the comparison and Section 3 the results and discussion. Conclusions are exhibited in Section 4.

## 2. Materials and methods

### *2.1. Laser scanners Kinect I and Kinect II*

Main differences between Kinect I and Kinect II sensors (Fig. 1) are described in Table 1 [13]. The ranging technology of the Kinect II sensor uses a novel image system that indirectly measures the time it takes for laser pulses to travel from the IR illuminator to the image sensor after returning from the target surface. This technology divides a pixel in a half and then they are turned on or off alternatively (180° out of phase between them). The light source is pulsed in phase with the first pixel of each couple. The returned light is absorbed by the half pixel turned on and rejected by the half pixel turned off. That means that when the distance between the system and the target is increased the total amount of light absorbed by the first pixel will decrease slightly, while the second pixel increase slightly. When the target is out of range, the light photons arrive later than second halves pixels are turned on. The photons are detected by first pixels, although in another cycle.

**Table 1**
Technical specifications of Kinect I and Kinect II laser scanners.

| | Kinect I | Kinect II |
|---|---|---|
| Field of view ($H \times V$) | $57.5^\circ \times 43.5^\circ$ | $70^\circ \times 60^\circ$ |
| Camera resolution ($H \times V$) | 640 × 480 @ 30 fps | 1920 × 1080 @ 30 fps (15 fps with low luminance) |
| Depth resolution ($H \times V$) | 320 × 240 | 512 × 424 |
| Maximum depth range | 6 m | 4.5 m |
| Minimum depth range | 40 cm | 50 cm |
| Depth technology | Triangulation between near infrared camera and near infrared laser source (structured-light) | Indirect time of flight |
| Tilt motor | Yes | No |
| USB standard | 2.0 | 3.0 |
| Supported OS | Win 7, Win 8 | Win 8 |

Kinect II takes a first measurement with low resolution estimation, high pixel exposure time, and no ambiguities in distance. The second measurement is then taken with high precision, using the first estimate to eliminate any ambiguities.

Kinect II has built in ambient light rejection, where each pixel individually detects when that pixel is over saturated with incoming ambient light and it resets the pixel in the middle of an exposure. On the contrary, Kinect I does not provide ambient light rejection.

### 2.2. Metrological comparison

Metrological comparison between Kinect I and Kinect II was done by using a standard artefact developed at University of Vigo [14–16]. This artefact (Fig. 2) consists of five delrin spheres of nominal diameter 100 mm equidistantly assembled on an aluminium block and seven cubes of edge dimensions 100 mm, 80 mm, 60 mm, 40 mm, 30 mm, 20 mm, and 10 mm. The artefact was calibrated in an ENAC accredited laboratory according ISO 17025:2005 using a coordinate measurement machine. Calibration is yearly updated and no significant changes have appreciated to work with laser scanning systems with precisions above mm. Metrological characteristics of the artefact are shown in the bibliography, in the same way that the results obtained by the sensor Kinect I. These results will be used in the present work to compare with the data obtained with Kinect II.

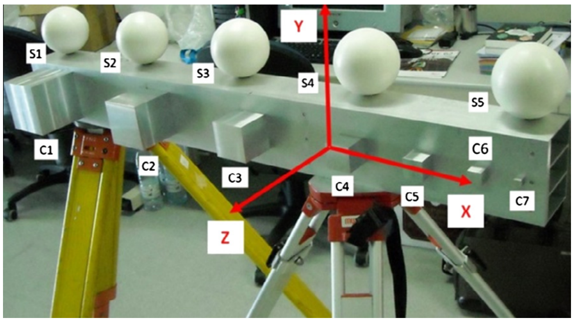


**Fig. 2.** Standard artefact used for metrological comparison between Kinect I and Kinect II.

The metrological evaluation performed with Kinect II sensor follows the procedure used with the same standard artefact and Kinect I [6]. It basically consists of placing the artefact and the Kinect sensor on two surveying tripods and performing six complete measurements at 1 m and 2 m range, with 45°, 90° (coincident with $Z$ axis in Fig. 1), and 135° angles between artefact and sensor (Fig. 3). Depth measurements were also made at 90° angle, from 1 to 4 m. For ranges higher than 4 m Kinect II appears out of range. Kinect II data are stored using the Microsoft Kinect SDK for range measurements. The whole data acquisition was done indoors where the illumination consisted of fluorescence tubes. Example of the point cloud is show in Fig. 4.

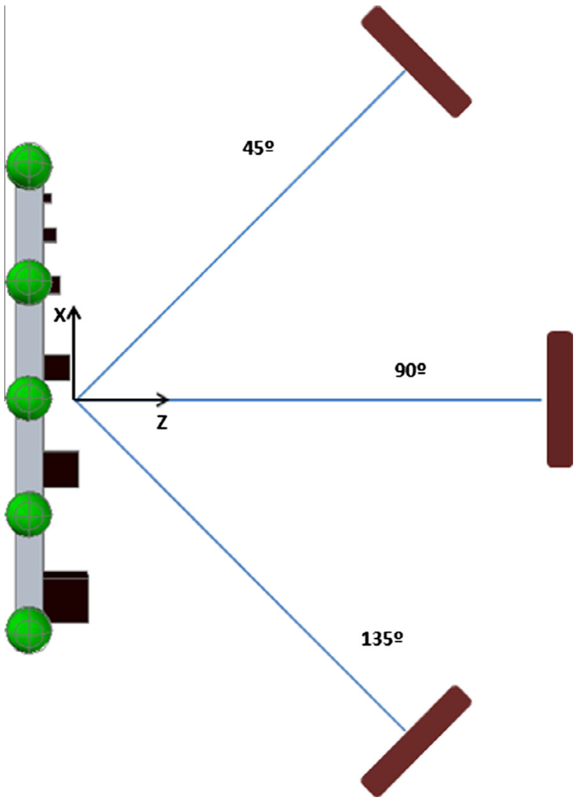


**Fig. 3.** Scheme of data acquisition.

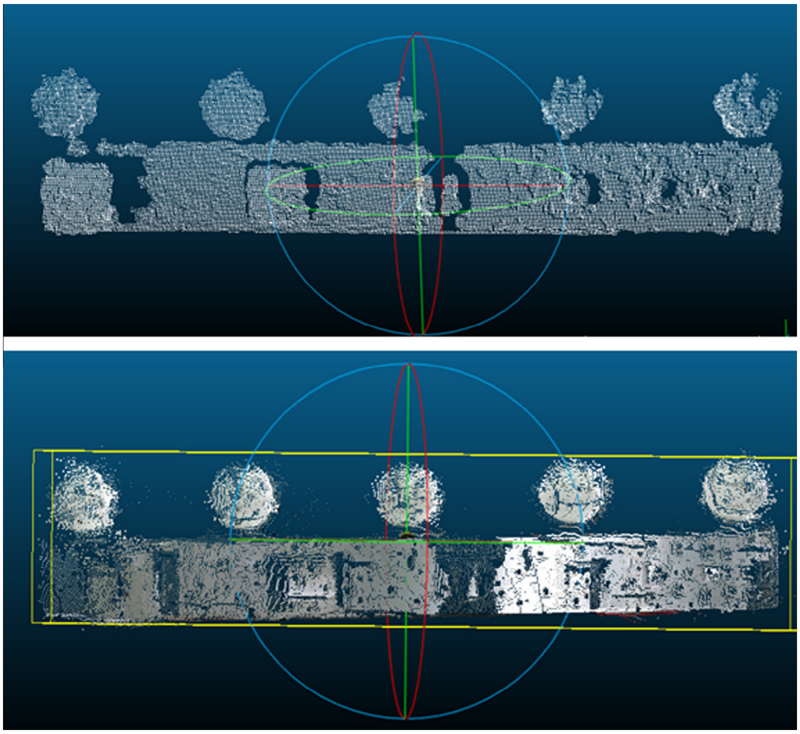

**Fig. 4.** Point cloud from standard artefact obtained with Kinect I laser scanner (top) and Kinect II laser scanner (bottom).

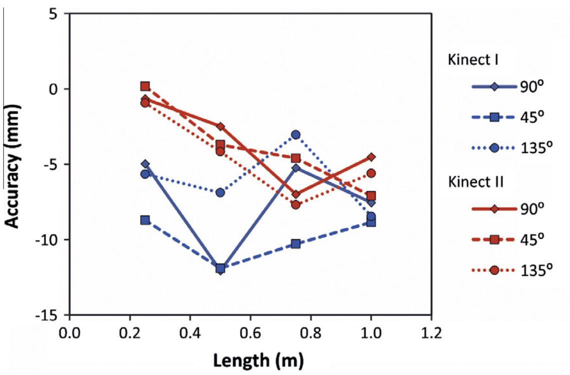


**Fig. 5.** Accuracy for 1 m range.

Accuracy *acc* is calculated as the difference between the distance values obtained for the standard artifact $D_i^{SA}$ and the Kinect I $D_i^{\text{Kinect I}}$ (Eq. (1)) or II $D_i^{\text{Kinect II}}$ (Eq. (2)). Eqs. (3)–(5) show as the distance values are obtained from the center of each sphere $(x_{i+1}, y_{i+1}, z_{i+1})$ in relation with sphere 1 $(x_1, y_1, z_1)$; $i$ values range from 1 to 4. The coordinates from the center of the spheres are obtained in all cases using a least square fitting algorithm, taking into account the data from the coordinate measurement machine (standard artifact data) or the data from the point clouds (Kinect I or II).

$$acc_i^{\text{Kinect I}} = D_i^{SA} - D_i^{\text{Kinect I}} \quad (1)$$

$$acc_i^{\text{Kinect II}} = D_i^{SA} - D_i^{\text{Kinect II}} \quad (2)$$

$$D_i^{SA} = \sqrt{(x_{i+1}^{SA} - x_1^{SA})^2 + (y_{i+1}^{SA} - y_1^{SA})^2 + (z_{i+1}^{SA} - z_1^{SA})^2} \quad (3)$$

$$D_i^{\text{Kinect I}} = \sqrt{(x_{i+1}^{\text{Kinect I}} - x_1^{\text{Kinect I}})^2 + (y_{i+1}^{\text{Kinect I}} - y_1^{\text{Kinect I}})^2 + (z_{i+1}^{\text{Kinect I}} - z_1^{\text{Kinect I}})^2} \quad (4)$$

$$D_i^{\text{Kinect II}} = \sqrt{(x_{i+1}^{\text{Kinect II}} - x_1^{\text{Kinect II}})^2 + (y_{i+1}^{\text{Kinect II}} - y_1^{\text{Kinect II}})^2 + (z_{i+1}^{\text{Kinect II}} - z_1^{\text{Kinect II}})^2} \quad (5)$$

Precision of Kinect II is evaluated using the standard deviation of least square algorithm applied to the fitting of the spheres and the top face of the largest cube of the artifact (100 mm edge) [6,7,14,17–19]. In particular, the procedure for estimating precision included: the same measurement procedure, the same observer, the same measuring instrument, used under the same conditions, the same location, and repeated measurements from the same measurand. To this end, Eq. (6) shows a quantitative parameterization of the results based on the standard deviation of fitting residuals $d_i$, where $N$ depicts the number of points from the cloud that are used for the fitting. Low precision will be indicative of a noisy point cloud that produces large $d_i$ values.

$$prec = \sqrt{\frac{\sum_{i=1}^{N} d_i^2}{N-1}} \quad (6)$$

## 3. Results and discussion

Figs. 5 and 6 show the accuracy results for Kinect I and Kinect II sensors for ranges of 1 m and 2 m, with angles

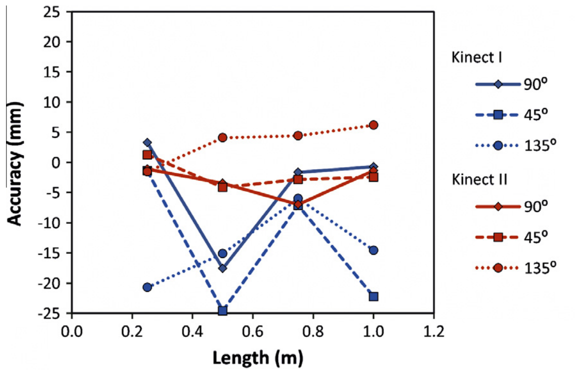


**Fig. 6.** Accuracy for 2 m range.

between the laser scanners and the standard artifact of 45°, 90°, and 135°. Kinect I depicts accuracy values ranging between −2 mm and −12 mm for 1 m range and between 4 mm and −25 mm for 2 m range. A clear decreasing of accuracy with range is shown. Kinect II shows accuracy values between 0.1 mm and −7.5 mm for 1 m range and between 5 mm and −7 mm for 2 m range. The accuracy decreasing with range is much less pronounced. Accuracy values of Kinect II clearly improve the values obtained for Kinect I at 2 m range. In both cases there is not a trend between the accuracy and the angle between the sensor and the standard artifact.

Fig. 7 depicts the precision results for 1 m range and Fig. 8 the results for 2 m range. Both sensors show a decreasing of precision with the increasing of range, although it is much more prominent in sensor Kinect I. Results for 1 m range are very similar for both sensors. The precision values range between 1.5 mm and 6 mm. However, for 2 m range, Kinect II clearly improves the Kinect I data. Kinect II shows precisions values lower than 8 mm, while Kinect I shows values over 10 mm in many cases.

The incidence angle does not affect the obtained results, as well as it does not influence precision or accuracy values.

The accuracy/precision ratio is for all cases approximately between 1 and 2. This result correlates with that

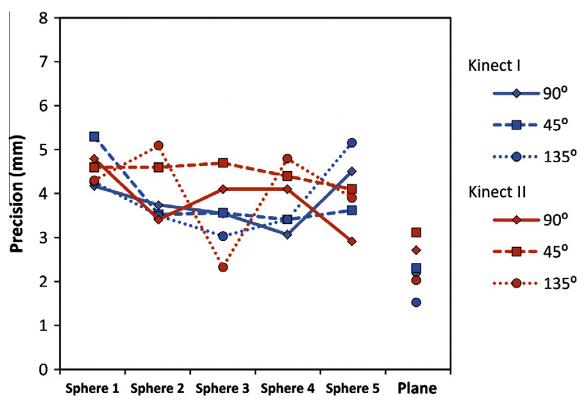


**Fig. 7.** Precision for 1 m range.

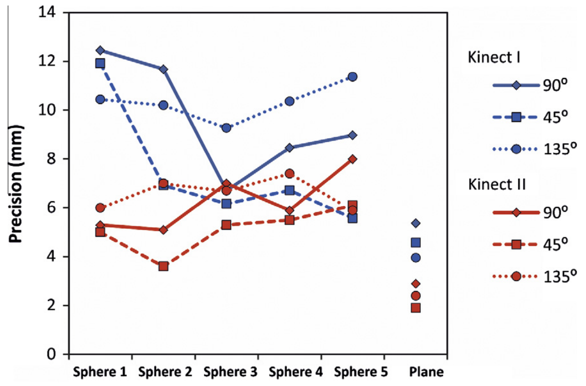


**Fig. 8.** Precision for 2 m range.

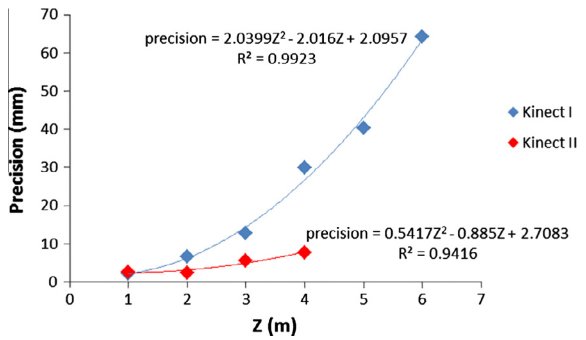


**Fig. 9.** Precision trend with range.

obtained for commercial systems (i.e. Faro Focus 3D [20]) with precision values between 0.6 and 2.2 mm and accuracy of 2 mm. In this case the ratio depicts values between 0.9 and 3.3.

Fig. 9 exhibits the precision as a function of range for the laser scanners Kinect I and II. Precision was obtained from the standard deviation of the least squares plane fitting to the top face of the largest cube (90° angle). Precision data for 1 m and 2 m range come from those depicted for the planes in Figs. 7 and 8. Precision data for 3 m and larger ranges are specifically calculated to this part.

Kinect I shows a measurement range between 1 m and 6 m, while Kinect II shows it between 1 m and 4 m, both in agreement with the technical specifications. Kinect I shows a precision decreasing in agreement with a second order polynomial [17], while Kinect II does not show this clear mathematical behavior. Precision for Kinect II appears much more stable with the increasing of range inside the measurement window. This fact could be quantified with the fitter second order polynomial that shows a lower $Z^2$ coefficient for Kinect II (0.54 vs. 2.04 in Kinect I).

## 4. Conclusion

This works shows the comparison between Kinect I and Kinect II laser scanners using a standard artefact. The comparison evaluates the accuracy and precision at angles of 45°, 90° and 135° and distances of 1 m and 2 m. Precision was also evaluated for larger ranges up to 6 m for Kinect I and 4 m for Kinect II.

Results at 1 m range show similar precision values in both laser scanners; however at 2 m range values of Kinect II improve the results of Kinect I. Accuracy shows a similar pattern, although even for 1 m range values for Kinect II appear slightly better.

Precision was tested until the range limit of the sensors. Precision obtained for Kinect I sensor decreases following a second order polynomial equation, while Kinect II fits a more stable behaviour. Decreasing of precision with range for Kinect II is less appreciable. Range limit of Kinect II appears at 4 m, while Kinect I achieves 6 m.

The metrological comparison performed in this work concludes that Kinect II could be useful for the same technical applications as Kinect I (robotics, quality control of low-tolerance parts, or indoor mapping), improving accuracy and precision. It must also be noted the stability of measurements with range that could be very valuable for many uses, the same way the better performance in outdoor environments.

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