

# Automatic measurement of hand dimensions using consumer 3D cameras

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## ABSTRACT

This article describes the metrological characterisation of two prototypes that use the point clouds acquired by consumer 3D cameras for the measurement of the human hand geometrical parameters. The initial part of the work is focused on the general description of algorithms that allow for the derivation of dimensional parameters of the hand. Algorithms were tested on data acquired using Microsoft Kinect v2 and Intel RealSense D400 series sensors. The accuracy of the proposed measurement methods has been evaluated in different tests aiming to identify bias errors deriving from point-cloud inaccuracy and at the identification of the effect of the hand pressure and the wrist flexion/extension. Results evidenced an accuracy better than 1 mm in the identification of the hand's linear dimension and better than 20 cm<sup>3</sup> for hand volume measurements. The relative uncertainty of linear dimensions, areas, and volumes was in the range of 1-10 %. Measurements performed with the Intel RealSense D400 were, on average, more repeatable than those performed with Microsoft Kinect. The uncertainty values limit the use of these devices to applications where the requested accuracy is larger than 5 % (volume measurements), 3 % (area measurements), and 1 mm (hands' linear dimensions and thickness).

Section: RESEARCH PAPER

**Keywords:** hand; Kinect v2; Intel RealSense; NI LabVIEW; diet; calibration; measure.

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## 1. INTRODUCTION

There are several applications in medicine that require knowledge of the dimension of the human hand. Oedema of the hand, resulting in an increase of the hand volume, often accompanies upper-extremity lymphedema, which develops after breast cancer-related surgical interventions [1][2]. In this case, measurement of the hand volume and its changes over time can provide objective measures about the effectiveness of the therapy; however, to date, this measurement is not a part of the routine assessments due to the absence of a readily available method for the estimation of the hand volume. Given the rapid increase in prevalence of obesity [3] and the costs associated therewith [4], the benefits of a low-cost measurement system would also be consistent in the assessment of correct food portions. In fact, food portions have increased their energetic

content from two to eight times in the past 40 years [5], and it has been found that body weight is related to food portion size [6]. Great benefits may be derived from assessing correct food portions using a simple intuitive comparison [7][8], and the size and geometric parameters of the hand can be used for this purpose [9][10]. It could be possible to determine food portions also with a portable reference object (a ball or a cube), but the hand offers difference reference volumes and areas (fist, palm, fingers) and cannot be left at home or forgotten somewhere. Since the anthropometric measurements of the hand vary greatly from person to person (up to 400 % according to [11]), it is necessary to verify the food volume to obtain precise diet indications.

Different measurement methods were proposed for the automatic identification of one or more geometrical parameters of the hand. The different technologies that can be used for the

measurement of the hand shape for biometric identification have been reviewed by Duta [12]. Existing works typically focus on the identification of the hand silhouette (hand shape systems) or on the identification of specific geometric features (hand geometry systems). The measurement chain of both these systems is based on cameras or scanners for capturing a subject's hand image and compares this information with the database records to verify the subject's identity. After the review of Duta was published, several works focused on similar topics. Sanchez-Reillo et al., in their work [13], described a system capable of extracting hand parameters from a 2D colour image. Kumar et al. [14] proposed the extraction, from a single image, the palmprint and the hand geometry. The different hand features are then used to verify the capability of classification on a dataset of 100 users.

The length of fingers is measured in several studies; the most widely used finger parameters are the distal extent of the fingertips and the length of the fingers. In a pilot study, Peters et al. [15] used a device first built by George [16] to identify the distance from the middle fingertip to the index and ring fingertips. The device is based on a sliding calliper with a resolution of 0.5 mm. Manning et al. [17] took photocopies of hands and made measurements based on the photocopies. The uncertainty of the method based on photocopies was evaluated [15] by assessing the measurement reproducibility. Four observers took ten measurements of the hands of four subjects. The observed parameters were the finger lengths of the index, middle, and ring fingers on both hands and from these parameters it was possible to compute the difference in length among fingers. The standard deviation of the length measurement across the fingers and the different subjects was 0.64 mm. The standard deviation of the tip measure was 0.52 mm, very close to the resolution of the instrument based on the calliper.

The hand volume has been measured by Hughes using Archimedes principle [18]: the technique involves the immersion of a hand in a water container placed on an electronic balance, with errors lower than 0.3 %. Mayrovits et al. [19] proposed the estimation of the hand volume using geometric algorithms. The hand's linear dimensions were measured using a calliper. The hand volume was calculated using an elliptical frustum model. The results of the model were compared to volumes determined by water displacement, with errors in the estimation typically lower than  $\pm 30$  ml for hands with volumes between 220 and 600 ml.

The performance of a biometric system is typically evaluated by verifying the correct classification rates of images; however, as evidenced by Duta in [12], a comparison between the performances of different systems is almost impossible for different reasons. From a metrological point of view, the most important issue is that the different experimental setups used for the acquisition strongly affect the classification capabilities. However, the different works do not focus on the accuracy of the systems used to acquire the images. Furthermore, all the biometric systems are based on 2D hand images, thus preventing their usage in all the applications that require knowledge of the hand thickness or volume. A typical example is dietary applications, which are those for which the systems described in this work were developed. This article proposes the extraction of the following features (hereinafter parameters) necessary for the identification of food portions in a volume diet:

- 1) Volumes
  - a) Hand volume
  - b) Palm volume
- 2) Areas
  - a) Area of the hand
  - b) Area of the palm
  - c) Middle finger area
- 3) Dimensions
  - a) Hand width
  - b) Hand length
  - c) Index, middle and ring fingers width
  - d) Thumb length
  - e) Fingers' length
  - f) Height (thickness) of the fingers, computed at the nails or at the first phalanx

Many of the above parameters have no clear definition, and the presence of soft tissues implies a potentially relevant loading effect in the presence of contact measurement devices, such as the callipers. The main idea of our work is to derive the above listed parameters from point clouds describing the hand dorsum. The accuracy of different parameters is assessed by the metrological characterisation of two consumer 3D cameras. Although in the literature there are several works focused on the identification of metrological performances of 3D cameras [20]-[23] and the classification capabilities of point cloud-based methods for hand silhouette identification, in this work, we focus on the accuracy in the identification of hand geometrical parameters using point clouds acquired by commercial 3D cameras. The article is structured as follows: the measurement method is described in Section 2; experimental results are presented in Section 3 and discussed in Section 4. The study's conclusions are drawn in Section 5.

## 2. MEASUREMENT METHOD

The measurement system described in this work is based on acquiring the point cloud of the hand dorsum with the two 3D vision systems, i.e. Kinect V2 and the Intel RealSense D415 and D435.

### 2.1. Sensors' characteristics

Kinect V2 is a Time-of-Flight (ToF) camera that uses Infrared (IR) emitters and sensors to reconstruct a 3D scene from the elapsed time between the emission of a light ray and its collection after reflection from a target. The metrological qualification of the camera [20] evidenced that the measurement uncertainty increases linearly with the distance between Kinect V2 and the measured point. The repeatability (expressed as standard deviation on the distance of planar objects perpendicular to the optical axis) is 1.2 mm at 1.5 m and 3.3 mm at the maximum distance (4.2 m). Moreover, there is a relationship between the measurement uncertainty and the radial coordinate of the sensor, as the IR light cone of emission is not homogeneous [20][21], and this might affect the volumes, areas, and dimensions of the hand parts. The minimum working distance of Kinect is 0.70 m. In these conditions, the field of view implies an observed area that is much larger than the hand size (a suitable measurement area can be defined by the size of an A4 piece of paper). In order to limit the effects of the different reflectivity of the reference surface and of the human skin, the subject is required to wear black silk gloves and to keep the instrument far from obstacles that may reflect or scatter IR radiation, as described in [23].

Two 3D cameras belonging to the Intel RealSense D400 series were initially tested (D415 and D435). The cameras are

Table 1. Kinect V2 and RealSense D400 characteristics.

Characteristic	Kinect V2	RealSense D415	RealSense D435
Working principle	Time-Of-Flight	Active IR Stereo	Active IR Stereo
Depth range	0.7-4.2 m	0.4-10 m	0.2-10 m
Max depth resolution	512x424	1280x720	1280x720
Max colour resolution	1920x1080	1920x1080	1920x1080
FoV	H: 70°, V: 60°	H: 69°, V: 42°	H: 91°, V: 65°
Max acquisition frequency	30 Hz	90 Hz	90 Hz
Working conditions	Indoor	Indoor/outdoor	Indoor/outdoor

based on stereo vision depth technology and consist of left and right imagers assisted by an IR projector. The latter emits an invisible static IR pattern to improve depth accuracy in scenes with low texture. The 3D scene is reconstructed by correlating points on the left and right images using built-in calibration equations [22]. The Intel RealSense data acquisition program allows for the selection between different settings for the 3D scene reconstruction: following the user manual, all the acquisitions were performed with the ‘short-range’ depth preset (given the fixed camera focal length and the necessity of filling scene with the subject hand) and the automatic exposure computation. The optimal distances for obtaining hand 3D images using RealSense D435 and D415 cameras are 0.4 m and 0.5 m respectively. Distances are slightly larger than the minimum distances: 0.35 m and 0.45 m.

The sensors’ characteristics are summarised in Table 1. Kinect V2 has a smaller depth measurement range with respect to RealSense cameras. The Kinect V2 resolution and sampling rate are lower than those of the Real Sense cameras, and its minimum focusing distance is larger. The Kinect V2 Field of View (FoV) is similar to that of the D415 and smaller than that of the D435. The smaller FoV of the D415 camera makes it more suitable for measuring small objects and was consequently chosen for the identification of the hand size. Preliminary tests evidenced that RealSense cameras are less sensitive to lighting conditions and are not affected by obstacles close to the target, although the light reflection on the plane that supports the hand often leads to disturbances on the point cloud.

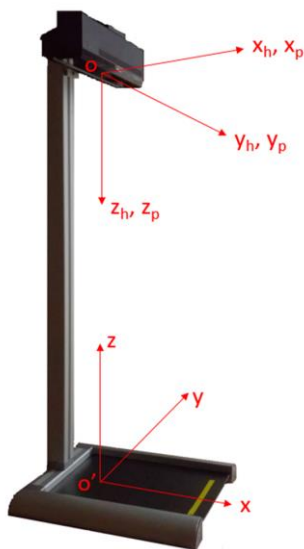


Figure 1. Scheme of the plane and image reference systems.

## 2.2. Measurement procedure

The geometry of the hand is obtained by subtracting the 3D image of the plane that is supporting the hand from the 3D image of the hand laying on the plane. With reference to the coordinated axes of Figure 1, the measurement process consists, therefore, of the identification of two point clouds:

1. The point cloud of the reference plane, with coordinates  $[X_p]$ ,  $[Y_p]$ ,  $[Z_p]$ ;
2. The point cloud of the hand lying on the reference plane, with coordinates  $[X_h]$ ,  $[Y_h]$ ,  $[Z_h]$ ;

The point cloud to be analysed, whose coordinates are  $[X]$ ,  $[Y]$ ,  $[Z]$ , is defined by:

$$\begin{aligned} [X] &= [X_h] - [X_p] \\ [Y] &= [Y_h] - [Y_p] \\ [Z] &= [Z_h] - [Z_p] \end{aligned} \quad (1)$$

## 2.3. Algorithms

Fit-for-purpose algorithms were implemented in LabVIEW 2017 in order to recognise the main parts of the hand and to compute the parameters listed in section 1. The automation of the measurement process allows for the reduction of the variability due to the observer; although, the lack of a standardised model for the identification of specific hand parameters might introduce a discrepancy between different measurement algorithms. The dimensions, areas, and volumes of the hand were computed with the algorithms that are extensively described in [23]: the different hand features are identified using simple image processing algorithms that are based on the extraction of the hand silhouette identified from the binarized 2D image of the hand by detecting the borders of the hand. The flowchart of the method is shown in Figure 2. Multiple point clouds of the hand are acquired by the sensor. A temporal average is used to derive the point cloud for analysis. The reference plane is subtracted from the observed scene, as described in section 2.2. The image is binarized to obtain the hand area; a particle filter was used to delete measurement

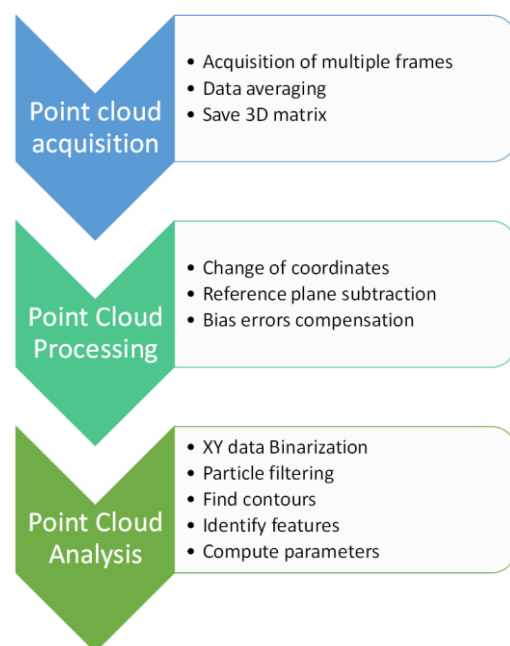


Figure 2. Flowchart of the analytical method for 3D point clouds.

artefacts. Conventional image processing algorithms (image derivatives or contours extraction starting from the binary image) were used to identify the hand features parameters described in Section 2.1 [23].

#### 2.4. Calibration

Tests have been performed by comparing the lengths, distances, and volumes measured with the 3D cameras with the standard measurement systems; more than 50 subjects participated in the experiments, which were performed in accordance with the Politecnico ethical guidelines.

##### 2.4.1. Thickness

The hand thickness measured by the 3D cameras was compared to that which was measured by a triangulation laser sensor Micro-epsilon optoNCDT 1402, with a measurement range of 50 mm and a resolution of 5  $\mu\text{m}$  [23]. The results reported in this work refer to the thickness measured at the centre of the middle fingernail; the finger represents a challenging position for measuring the thickness, given that small pressure variations at the fingertip result in a large variation of the measured height. However, similar experiments were performed also in different hand positions and provided similar results. The thickness of different subjects' right hands (18 for the RealSense, 33 for the Kinect) was measured; given that tests were performed in different time periods, the subjects were not the same, thus preventing a direct comparison between the two measurement systems (described for a single subject in Section 2.4.4).

##### 2.4.2. Volume

The reference volume of the hand was computed by immersing the hands of different subjects (33 for the RealSense, 30 for the Kinect) in water using a graduated beaker according to the procedure described by [18]. The resolution of the graduated scale was 10 ml. Furthermore, in this case, since the tests were performed in different experimental sessions, the subjects were not the same.

##### 2.4.3. Disturbances

A third series of tests were performed to investigate the effect of disturbances. The quantities that may worsen the measurements' reproducibility are the position of the forearm (i.e. the wrist flexion/extension) and the pressure between the hand and the supporting surface. Both these factors, because of the compliance of the hand soft tissues, modify the local height of the hand and consequently might vary the hand volume. Tests were performed with a single subject under reproducibility conditions: the hand volume has been measured with the Kinect V2 and RealSense D415 cameras upon varying:

- the elbow extension (i.e. the forearm angle with respect to the horizontal plane); the wrist extension angles were  $-10^\circ$ ,  $0^\circ$ ,  $10^\circ$ ,  $20^\circ$ ,  $30^\circ$ ; a total of 40 measurements were performed;
- the hand pressure against the reference plane (0 kPa, 1.30 kPa, 1.94 kPa, 2.65 kPa, 3.31 kPa, 3.97 kPa).

The setups for the identification of the effects of the forearm orientation and of the hand pressure are shown in Figure 3. Tests were performed both with the Kinect V2 and RealSense D415. Wrist extension was controlled by positioning supports of different heights below the elbow. The extension  $\alpha$  has been computed as the arctangent of the support height  $h$  divided by the forearm length  $w$ :

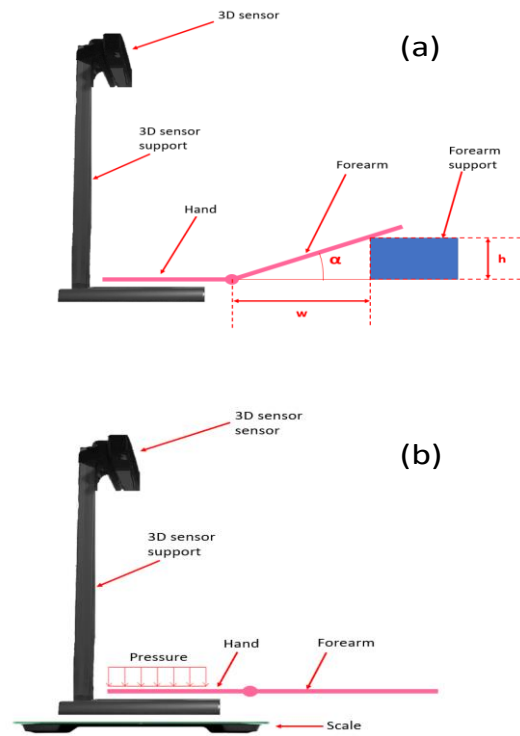


Figure 3. Scheme of the setup for the identification of the disturbances generated by the forearm angle (a) and hand pressure against the surface (b).

$$\alpha = \arctan(h/w) \quad (2)$$

The hand contact pressure was obtained by dividing the net force measured by the scale (difference between the force measured by the balance  $F$  and the device weight  $W$ ) by the hand area measured by the proposed 3D measurement system  $A$ .

$$p = \frac{F - W}{A} \quad (3)$$

Given that the contact area is smaller than the total hand area (because of the palm concave shape), the reported values are an overestimation of the actual hand pressure; however, reporting pressure data allows for a comparison of the measurement results with possible forthcoming studies.

##### 2.4.4. System comparison

The final analyses were performed to compare the results of measurements performed with the Kinect and RealSense cameras. Different parameters of the hands of a single subject

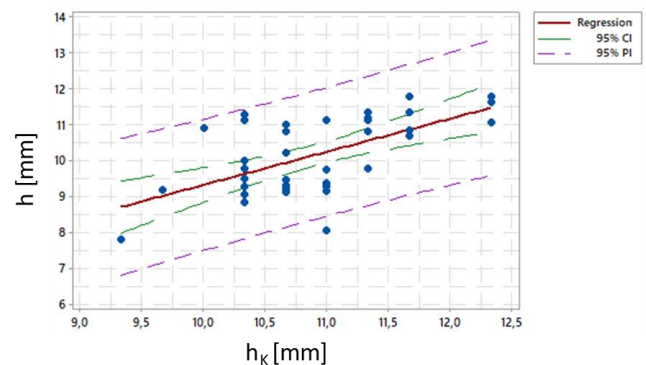


Figure 4. Correlation between the height of the hand measured by the laser sensor and the height of the hand measured by RealSense D415.

were automatically extracted from 30 repeated measurements by means of the computation algorithms described in [23]. The compatibility of measurements was verified through the hypothesis testing about the equality of the means using Minitab.

### 3. RESULTS

#### 3.1. Hand thickness calibration

The fingers' thickness ranged between 9 and 12 mm. The Root Mean Square (RMS) of the difference between the height measured with the Kinect and the height measured by the laser is 1.1 mm. This value is compatible with the Kinect resolution (1 mm) and with the instrument uncertainty identified in [20], which was 1 mm when the measurand was placed at 0.75 m from the sensor. As shown in Figure 4, hand thickness  $h$  can be determined starting from the thickness measured by the Kinect  $h_K$  using the following linear regression model:

$$h = 0.93 \cdot h_K \quad (4)$$

The standard error of the estimate is 0.85 mm. The  $R^2$  value is 36.8 %; such a low value reasonably derives from the large variability of the measurand (uncontrolled pressure of the fingers) and to the limited variation of the fingers' thickness in comparison with the Kinect resolution.

The first order term of the regression model is between 0.9 and 0.95 with a 95 % confidence level. The distribution of residuals and the probability plot of standardised residuals evidenced the validity of the proposed regression model [25]-[28].

The same calibration was performed for the RealSense camera. The RMS of the difference between the height measured with the RealSense and the height measured by the laser is 1.1 mm. This value is compatible with the expected resolution for RealSense D415 at a 0.5 m distance and is equal to the value obtained with the Kinect. As shown in Figure 5, similar to what was performed with the Kinect, the finger thickness  $h$  was fitted by a linear regression model starting from the thickness measured by the RealSense  $h_{RS}$ :

$$h = 3.53 + 0.62 \cdot h_{RS} \quad (5)$$

The standard error of the estimate is 0.88 mm.  $R^2$  is also low in this case (47.7 %). The distribution of residuals and their probability distribution evidenced the validity of the regression model.

#### 3.2. Volume calibration

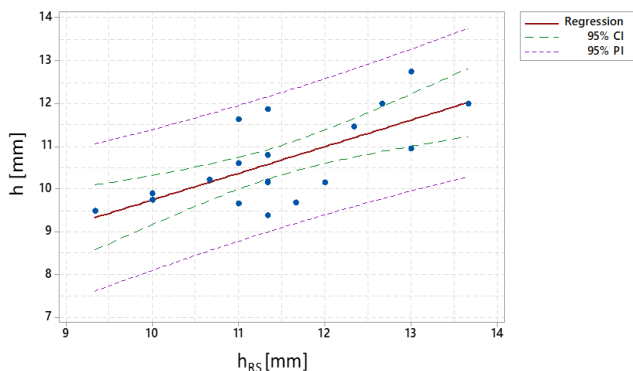


Figure 5. Correlation between the height of the hand measured by the laser sensor and the height of the hand measured by Kinect V2.

The results of the calibration of Kinect are shown in Figure 6. Hand volumes ranged between 180 and 500 cm<sup>3</sup>. The RMS of the difference between the volume measured with the Kinect V2 and the volume measured by the beaker is 35 cm<sup>3</sup>. The hand volume  $V$  (in cm<sup>3</sup>) can be estimated starting from the volume  $V_K$  measured by the Kinect using the following quadratic regression model:

$$V = 48.44 + 0.63 \cdot V_K + 0.00095 \cdot V_K^2 \quad (6)$$

The standard error of estimate is 17 cm<sup>3</sup>. The  $R^2$  value is 96.7 %, evidencing a better correlation with respect to the thickness data presented in the previous paragraphs. The distribution of residuals and the probability plot of standardised residuals evidenced the validity of the quadratic regression model; conversely, the adoption of a linear model led to a parabolic distribution of residual versus fits.

A similar regression operation was performed with the RealSense camera, and the results are shown in Figure 7. The RMS of the difference between the volume measured with the RealSense D415 and the reference volume was 64 cm<sup>3</sup>. To increase the accuracy of the volume results, data were modelled with a linear regression model:

$$V = 33.71 + 0.75 \cdot V_{RS} \quad (7)$$

The standard error of estimate was 16 cm<sup>3</sup>, i.e. comparable to the value of 17 cm<sup>3</sup> obtained with Kinect.  $R^2$  was 95.2 %, and the analysis of the residuals evidenced the validity of the linear model.

#### 3.3. Influencing quantities

The results (Figure 8 and Figure 9) evidenced the necessity of controlling both the forearm position and the contact pressure.

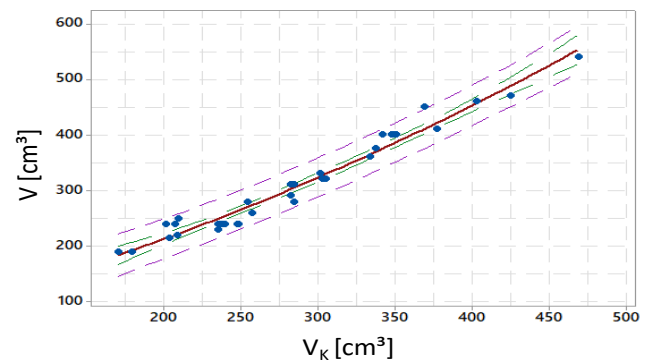


Figure 6. Correlation between the hand volume measured by the Kinect camera and the one measured with the reference system.

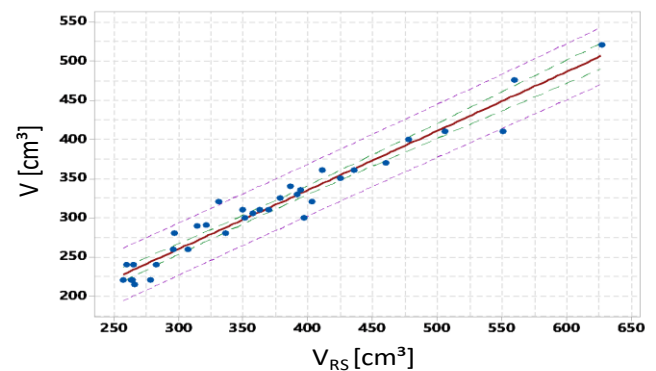


Figure 7. Correlation between the hand volume measured by the RealSense camera and the one measured with the reference system.

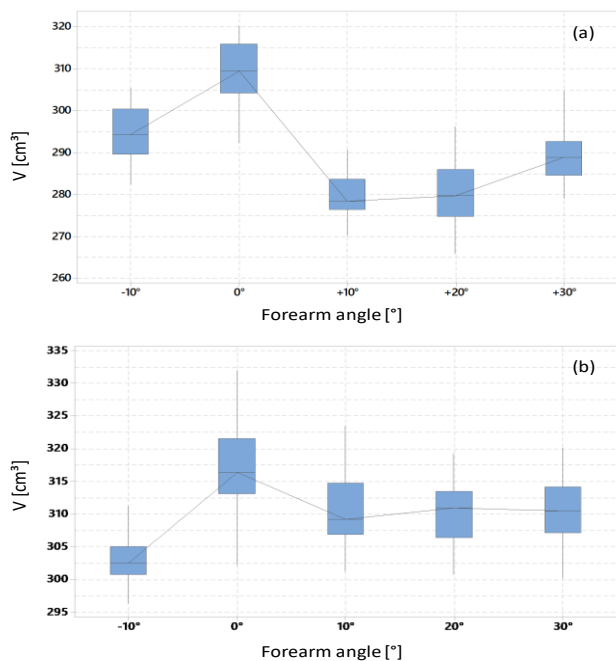


Figure 8. Boxplot of the hand volume measured by Kinect V2 (a) and RealSense D415 (b) upon varying the forearm angle. Data refer to two different groups of people.

The wrist extension (Figure 8) affects the hand volume in a complex manner. The volume is maximum when the wrist is in neutral position, i.e. when the forearm is parallel to the plane supporting the hand palm. In the presence of elbow flexion or extension, the measured volume decreases, reasonably because of the change in pressure distribution on the hand palm and fingers. Results also evidence that Kinect V2 seems more sensitive to the elbow angle with than RealSense D415; however, given that the tests were performed by different subjects, it is not possible to conclude that the bias is generated by an instrumental effect.

The effect of pressure is summarised in Figure 9; the increase in contact pressure results in a decrease of measured volume because of an average reduction of the hand thickness deriving from the compression of the hand soft tissues. The trends measured by the two measurement systems are comparable, although the volume reductions measured by the Kinect (Figure 9 a) are, on average, larger than those measured by RealSense. The reduction of volume in correspondence to a pressure of 1.48 kPa is 13.8 % for Kinect and 9.5 % for RealSense; similar differences occur at higher pressures.

### 3.4. Systems comparison

The comparison between the hand's parameters extracted in 30 repeated measurements from the two 3D cameras are shown in Table 2. Data show that the differences between the average measurements obtained with the Kinect V2 and the RealSense range between 1 % (hand area, flat fist volume) and 16 % (index finger thickness).

In most cases (6 out of 9), the hypothesis testing about the equality of the means of the measurements performed by the two measurement systems lead to a rejection of the null hypothesis  $\mu_k = \mu_{RS}$ . The most critical measurement was the thickness of the index: the difference between the two measurement systems was large in percentage (16 %) but was comparable to the resolution of the two measurement systems (2 mm). Measurements of the Kinect were performed wearing a silk glove because of the

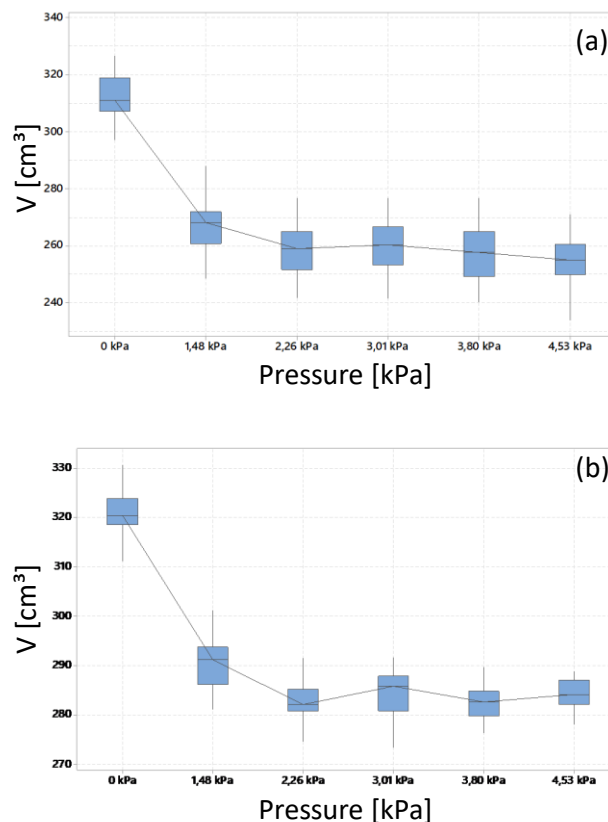


Figure 9. Boxplot of the hand volume measured by Kinect V2 (a) and the RealSense D415 (b) upon varying the pressure between the hand and the supporting surface. Data refer to two different groups of people.

necessity of keeping the sensor as close as possible to the hand (to grant a decent resolution) and to avoid saturation problems in specific hand areas. This did not lead to a systematic overestimation of hand dimensions/areas/volumes.

## 4. DISCUSSION

The results presented in this work evidence the accuracy limitations of the use of commercial 3D cameras for the identification of hands' geometrical parameters. Both the calibrations versus the golden standard and the comparison between two different measurement systems evidenced accuracy limitations that are in the order of millimetres for the hand thickness, of a few  $\text{cm}^2$  in area measurements, and  $20 \text{ cm}^3$  for volume measurements. The volume measurements were affected by the wrist extension and by the hand pressure against the surface; consequently, in order to increase the measurement reproducibility, it is necessary to perform all the measurements with a neutral wrist extension (and lateral deviation) and by controlling the hand pressure. The possibility of compensating the disturbances given by these factors seems limited and deserves future investigations.

The adoption of the fit-to-purpose calibration procedure allowed reducing the measurement uncertainty of both the systems. The Kinect V2 thickness calibration improved the accuracy of the measurement system, reducing the RMS of the errors from 1.1 mm to 0.8 mm; for the same system, the volume calibration reduced the standard uncertainty from  $35 \text{ cm}^3$  below  $20 \text{ cm}^3$ . The RealSense D415 volume calibration lowered the RMS of errors from  $64 \text{ cm}^3$  to  $16 \text{ cm}^3$  for hand volume and from 1.1mm to 0.9 mm for thickness. These values are tolerable for

Table 2. Kinect V2 and RealSense D400 comparison concerning the measurements performed with the two measurement systems on 30 repeated measures of the same subject.

	Microsoft Kinect			Intel RealSense			95% CI difference			
	Mean	St. Dev	COV	Mean	St. Dev	COV	Difference (%)	min	max	P value
Hand volume in cm <sup>3</sup>	311	15	5%	317	10	3%	-2%	-13.5	-0.3	5%
Fist volume in cm <sup>3</sup>	322	16	5%	327	10	3%	-1%	-10.8	2.8	24%
Flat fist volume in cm <sup>3</sup>	344	16	5%	346	10.1	3%	-1%	-9.0	5.0	56%
Hand area in cm <sup>2</sup>	137	4	3%	146	4	3%	-7%	-10.9	-7.0	0%
Hand without thumb area in cm <sup>2</sup>	118	3.8	3%	123	2.9	2%	-5%	-6.8	-3.3	0%
Index thickness in cm	1.2	0.1	8%	1.0	0.1	9%	16%	0.1	0.2	0%
Middle finger width in cm	2.0	0.2	9%	1.8	0.1	3%	9%	0.1	0.3	0%
Hand width in cm	8.4	0.1	2%	8.0	0.2	3%	6%	0.4	0.6	0%
Hand length in cm	17.4	0.4	2%	18.2	0.2	1%	-5%	-0.9	-0.6	0%

the identification of the food portions and are lower than the values reported in the literature for measurements based on the Archimedes principle (around 30 ml). The possibility of using more accurate sensors or scanning both sides of the hand is currently under evaluation and will be the topic of forthcoming studies.

The comparison between the two measurement systems evidenced that the Intel RealSense D 415 camera allows for the acquisition of more repeatable results (average COV 3 %) with respect to the Kinect V2 (average COV 5 %), thanks to the higher resolution and to the lower measurement distance. The main limitation in the use of the Kinect V2 was related to the necessity of wearing black gloves and keeping the system far away from obstacles that could cause IR reflection. These limitations were not present when using RealSense D415 sensor, which reconstruct the 3D scene with an active IR stereo vision camera instead of the ToF principle of the Kinect.

## 5. CONCLUSIONS

This work described the characterisation of an automated system that can be used to determine the volume, silhouette, and other geometrical parameters of the hand, starting from the point cloud acquired with commercial 3D cameras. This automated system is composed of Kinect V2 or Intel RealSense D415 sensors, which acquire a point cloud that is analysed using purposely developed algorithms tests performed with the Microsoft Kinect v2 and Intel RealSense D415. We evidenced metrological performances comparable to those currently used in the literature (for instance, measuring the hand volume by using a graduated beaker or using a calliper for dimensions). The main limitation of the systems based on the acquisition of the point cloud derives from the presence of disturbances that can have a strong influence on the final results. Measurements performed with the Kinect V2 were unreliable when not wearing gloves with optical properties similar to those of the reference plane; stereoscopic cameras did not evidence similar limitations. The accuracy of the measurement systems was increased by direct calibration, adopting a regression model for the compensation of the hand thickness and volume bias error, obtaining an accuracy lower than 1 mm for height and lower than 20 cm<sup>3</sup> for volume. Area measurements did not require any compensation, being the in-plane measurement free from bias component. Further efforts will be focused on the accuracy in

the identification of the silhouette of the hand starting from 3D images.

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