

Automatic human body morphological measurement from 3D scan acquired with low cost devices

A. Villa, A. Carboni, MA. Pascali, M. Magrini

Abstract—In this work we present an algorithm for extracting morphological measurement from 3-D human scans acquired using Kinect v2 devices. The algorithm objective is to provide computation of classical body measures, including height, waist circumference and hip circumference and measures related to the shape, such as area and volume. It is independent from the pose and robust to noise. Exploiting the obtained measures we calculate several indices, such as waist-to-hip ratio and *Barix*.

I. STATE OF THE ART AND PROBLEM MOTIVATION

Body scanners are used for a wide variety of applications. Jones and Rioux [5] divided their applications into:

- Medical: body deformation, orthodontics, orthopaedics, etc.
- Human system engineering: work environment, clothing, human morphology, human motion, etc.
- Virtual reality and communications: 3-D portraits, computer animations of human models.

An overview of several methods to analyze and model the human body is presented in [10]. In [3] the authors propose an approach for automatic estimating geometrical parameters from 3-D human scans independent on pose and robustly against the topological noise.

In this work we present an algorithm which will be implemented in a system for a virtual observer to be used in wellness and fitness centres. The purpose of the algorithm that we describe in this work is to extract relevant geometrical feature and measures for calculating the major indices for body fat estimation.

Obesity is an established risk factor for increased morbidity and mortality. The assessment of obesity is primarily based on the body mass index (BMI); however, studies have shown that body fat distribution and in particular abdominal obesity is closely associated with risk of morbidity and mortality. Hence waist circumference (WC) or the waist-to-hip ratio (WHR), as indicators of abdominal obesity, may be better predictors of risk than BMI for several diseases, including cardiovascular disease [4], [7]. Another index, designed to be a potential replacement to BMI, and called body volume index (BVI) has been proposed [9] to evaluate obesity. It is computed, however, with a closed software solution and is currently being validated.

The necessity of an algorithm that is robust with respect to noise and positions taken by the subject is dictated within the project VIRTUOSO specifications. The fundamental idea behind the whole project is the ability to evaluate the psycho-physical condition of an individual and get directions on the best route to wellness to these suitable, through an analysis of diagnostic signs collected by different techniques and technologies. In this paper, we present an algorithm for automatic extraction of health-related geometrical parameters from body

scans, acquired using Kinect v2. The algorithm is specific for the kind of data provided by this sensor.

II. ALGORITHM DESCRIPTION

This section is divided in two parts, the first one concerns the data that are processed by the algorithm, the second one regards mainly the algorithm itself and its structure. In particular as we mentioned in the previous section data are obtained using a Kinect v2 device.

A. Data type

Kinect is a gesture tracking device developed by Microsoft for gaming purposes. It can detect the tridimensional position of 25 body joints of 1-to-6 human bodies placed in front of it at a rate of 30 FPS. Fig.1 shows which are the body joints captured by the device.

Its first version was based on structured light techniques,

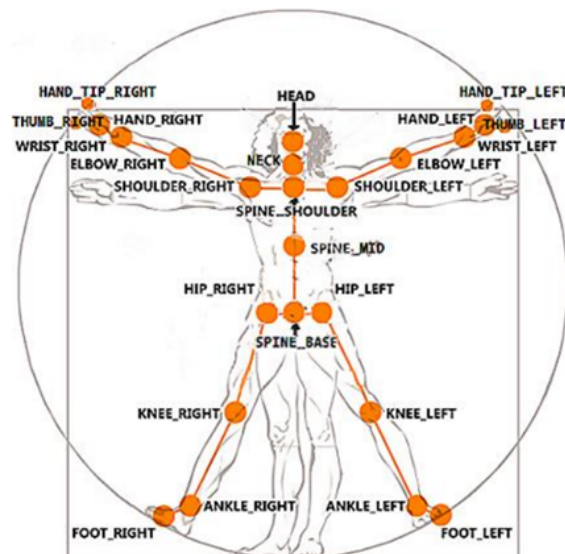


Fig. 1. Body joints types in a skeleton

while the new one (the one we used) is based on time-of-flight techniques. Using the software development kit (SDK) supplied by Microsoft, the developer can access all the data generated by the device. Beside the skeletons, that is the set of body joints coordinates (in meters), the supplied data are: a color image (3x1920x1080 pixels), an infrared image (1x512x424 pixels), and a depth camera image (1x512x424 pixels). The depth image refers to a FOV (field of view) of 70.6x60 degrees, resulting in an average of about 7 x 7 pixels per degree. Additionally, another part of the SDK, called Fusion, can process multiple frames of the depth camera data in order to build a point cloud of the 3D scene in front of the device. In our approach, we used both the skeleton data and the point clouds. The skeletons data are useful for a first segmentation of the human body figure represented in the point cloud.

Memeber	Value	Description
AnkleLeft	14	Left ankle
AnkleRight	18	Right ankle
ElbowLeft	5	Left elbow
ElbowRight	9	Right elbow
FootLeft	15	Left foot
FootRight	19	Right foot
HandLeft	7	Left hand
HandRight	11	Right hand
HandTipLeft	21	Tip of the left hand
HandTipRight	23	Tip of the right hand
Head	3	Head
HipLeft	12	Left hip
HipRight	16	Right hip
KneeLeft	13	Left knee
KneeRight	17	Right knee
Neck	2	Neck
ShoulderLeft	4	Left shoulder
ShoulderRight	8	Right shoulder
SpineBase	0	Base of the spine
SpineMid	1	Middle of the spine
SpineShoulder	20	Spine at the shoulder
ThumbLeft	22	Left thumb
ThumbRight	24	Right thumb
WristLeft	6	Left wrist
WristRight	10	Right wrist

TABLE I
IDENTIFICATION OF THE 25 JOINTS POINTS.

B. Structure

We first remove outliers and floor points from the acquired point cloud and then re-mesh models to ensure a uniform quality using the Poisson method [6]. These first steps are implemented using Meshlab scripting [1]. Then we follow subsequently the following steps.

1) *Platform Detection*: A direct analysis of the triangulated mesh is performed on the bottom part in order to find the platform of the system. It is important to know at which level is the top of the platform in order to calculate the total height of the subject.

To perform this task we first find three points on the platform,

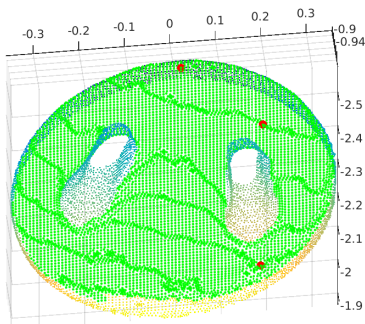


Fig. 2. Detection of the platform: green coloured points are identified to belong to the top of the platform

i.e. red dotted points (fig. 2), using the information of the settings of the system. Then we consider the plane passing

through the three points and we calculate the distance plane-point. If this distance is less than a given parameter we consider the vertex belonging to the top of the platform (fig. 2). The level of the top is calculated as the mean value of the points identified (fig. 2). This step is independent from the other steps and can be performed at the meantime of the others. In the following we discard each point under the level of platform's top.

2) *Extracting skeleton joints points*: With input the .obj file given by the sensor, we calculate the the position of the 25 joint points of the skeleton. We use, for each joint, a sample of fixed cardinality for each point and then we calculate the mean of the sample. In figure 3 there is an example with the skeleton shifted by 0.40m alongside the z -axis and plotted within the 3-D mesh.

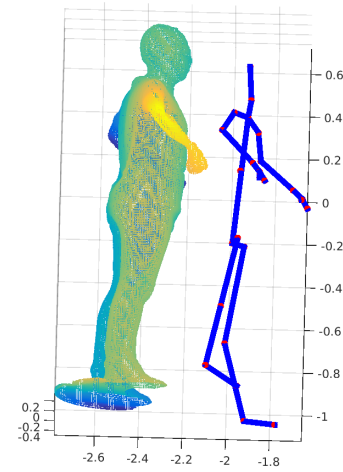


Fig. 3. Skeleton points shifted by 0.40m on the z -axis and plotted within the mesh

3) *Slicing the triangulated mesh*: A fundamental passage in the algorithm is the slicing of the triangulated mesh, i.e. calculate an approximation of the intersection between the mesh and a given plane. We present below a pseudo code for performing this action. The input arguments are the normal direction to the plane and a point belonging to the plane, the output is a list of paths that approximate the intersection. In figure 4 there is an example of slicing at the hips. We provide here a simplification of the Matlab code:

```

1 function [paths]=CutPlane(v,f,P,vec,par,max
2 )
3 % return the list of edges cutted by a
4 plane
5 % perpendicular to the xy plane and to v
6 and
7 % passing from a given point P
8 mlineproj=-vec(1)/vec(2);
9 clineproj=P(2)-mlineproj*P(1);
10 % distance of the y coordinate of the first
11 vertex
12 % for every face.
13 yd=v(f(:,1),2)-mlineproj*v(f(:,1),1)-
14 clineproj;
15 % taking face that are close to the plane
16 dFB=abs(yd)<max;

```

```

12 UpTri=f(dFB,:);
13 % fining face cutted by the plane
14 UpF=sum(v(f(dFB,1),:)).* repmat(vec,sum(dFB
    ,1),2)-sum(P.*vec);
15 UpS=sum(v(f(dFB,2),:)).* repmat(vec,sum(dFB
    ,1),2)-sum(P.*vec);
16 UpT=sum(v(f(dFB,3),:)).* repmat(vec,sum(dFB
    ,1),2)-sum(P.*vec);
17 isUpF=UpF>0;
18 isUpS=UpS>0;
19 isUpT=UpT>0;
20 BUp=(isUpF+isUpS+isUpT)==2;
21 UpTri=UpTri(BUp,:);
22 % BUp is a logical matrix with 0 indicating
23 % the low vertex
24 BUpT=[isUpF(BUp),isUpS(BUp),isUpT(BUp)];
25 % reshape the BUpT and the UpTri matrices
26 % into a colum vector take the up vertex
27 % and the reshaping it into a nUpFaces x 2
28 reUpTri=reshape(UpTri',1,[]);
29 reBinUpTri=reshape(BUpT',1,[]);
30 UpVrtx=reshape(reUpTri(reBinUpTri),2,[]);
31 % creating paths using the up edges
32 [paths]=nConnected(UpVrtx);
33 % gluing close paths
34 paths=GluingCut_v02(v,paths,par);
35 end

```

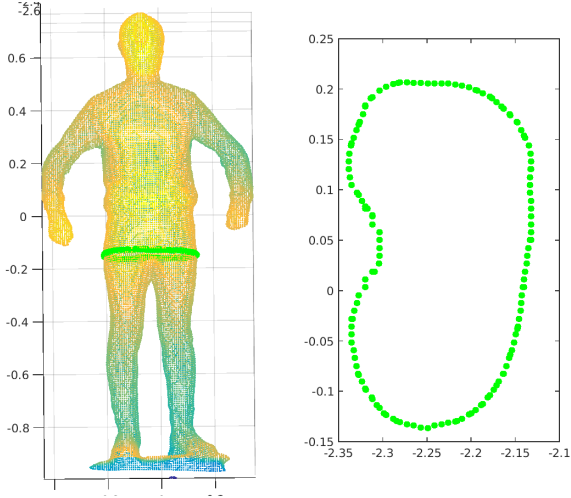


Fig. 4. Slicing with minimal length value at the hips level. On the right the projection of the intersection onto the given plane

After the first slice we let the plane vary of an angle $\pm\theta$ with respect the xz -plane and we take the slicing with minimal length value.

We use the joint of the skeleton in order to select the relevant paths. This action assume that the joints are contained in the convex hull, i.e. the minimal convex set which contains all the points of the path. For this reason we can use the Jordan curve theorem. In particular its application (fig. 5), in this case consists in calculating the number of intersection points between a ray starting from the joint and a given path: if the intersection number, counted with the multiplicity, is odd the the point is internal otherwise the point is external to the curve.

4) *Best Fitting Geometrical Ellipse*: Identified the path at the hips level, we analyse the geometrical properties in order

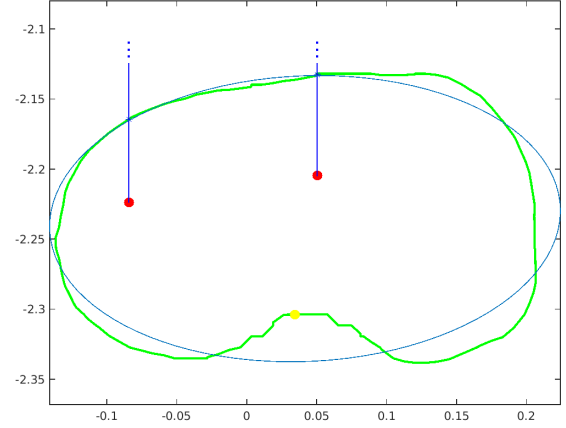


Fig. 5. With the Jordan curve theorem relevants components of the section are selected. The blu line is the ellipse that minimize the sum of the squares of the distances, and the yellow dot is the vertex that is internal and reach the maximum distance from the best geometrical fitting ellipse.

to find the best candidate for the hip circum and for the crotch. In particular we perform a least square method for finding the best ellipse that minimize the geometrical distance of the given section (fig. 5) using the method described in [2].

This part of the algorithm will return the algebraic form, $aX^2 + bXY + cY^2 + dX + eY + f = 0$, of the ellipse that minimize the sum of the squares of the distances to the given points. In the meanwhile we calculate maximum distance of internal points, i.e. the points $P = (x_P, y_P)$ that satisfies $F(x_P, y_P) < 0$, at each approximation. If this distance, reached the best fit, is greater than a given threshold.

5) *Hips and Crotch*: Given the ellipse with best geometrical fit, we confront the maximal internal distance with a given parameter. Two cases are possible: the maximal internal distance is equal or exceed the given threshold or it is less then the threshold. In the first case an upper cut is done, then we

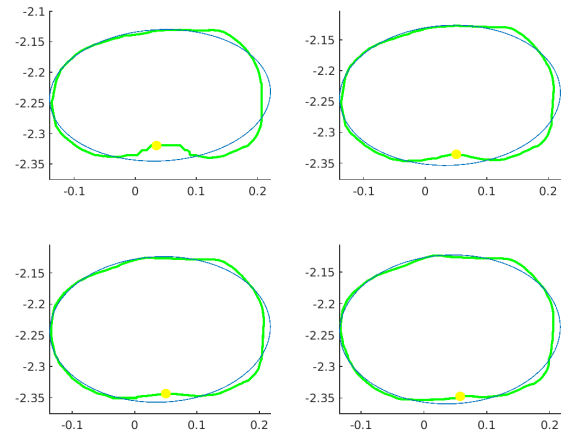


Fig. 6. Section at the hips level: blue line represent the best geometrical ellipse fitting the point of the section. Yellow dot is the internal point with maximal distance to the ellipse. The slicing will stop when this distance is less than a give threeshold.

select the components this section that are closer with respect the Euclidean distance to the preceding selected components. We re run the part of the algorithm for finding the best fitting ellipse. We will stop until the maximal internal distance is less than the given parameter. The second case is specular to the first one: a lower cut is done and we stop when the maximal internal distance is greater than the given parameter.

We establish the crotch level in relation to the hip level, for example in fig. 7 we use $crotchlevel = hiplevel - 0.06m$. As for calculating the hips circum we approximate the section path with the ellipse that minimize the geometrical distance. We take as crotch the vertex which maximize the distance from the ellipse and is internal to it.

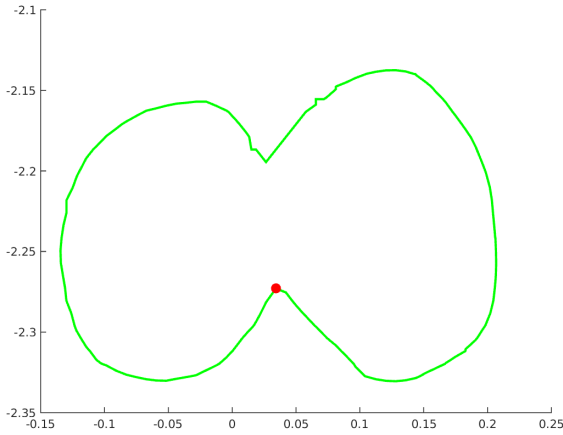


Fig. 7. The red dot represent the crotch: it is internal point which maximize the distance from the ageometrical approximant ellipse. This part of the algorithm is similar to the part for calculating the hips circum.

6) *Underarm Points*: For the underarm points we first vertically translate the points of the skeleton corresponding to right and left shoulders, then we slice the upper part of the torso. As illustrated in fig. 8, each red line correspond to a single slice. From every section we consider the two lateral part, green line in fig. 8, and we calculate both the area and the length. We there is a sensible decrease of these two measures we calculate the underarm as the vertex of the section which the absolute values of the difference between its x -coordinate and the x -coordinate of the corresponding shoulder point is maximal. This action is performed both for the left and for the right side of the upper torso.

7) *Torso Surface and Volume*: Given the hip circum and the the underarm circum, we proceed to cut into n different pieces the part of the mesh between these two circles. We will divide the segment from the mid point of the under arm to the mid point of the hips into n pieces of equal length. The plane for the cutting is then the plane that pass trough these points and which angle vary uniformly from the angle of the hip plane to the angle of the underarm plane. This procedure is well illustrated in fig. 9. At each cut level we calculate the length and the area of the section.

We are able to approximate the volume and the surface for each single slice. We use the surface area and the volume

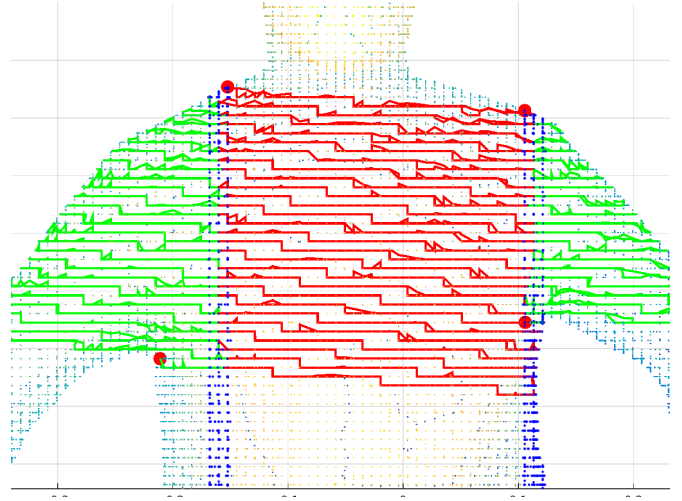


Fig. 8. The red dots corrspod to shoulders and arms. The shoulders are obtained by vertically translate the corresponding points of the skeleton, the underarms are identified after a variation of the lenght and area of the lateral parts of the torso sections

of the truncated cone with bases equal to the ellipse with area and perimeter with the obtained measures for the section and apothem the mean of the distances between vertices of two corresponding (i.e. vertices that minimize the euclidean distance) consecutive cuts.

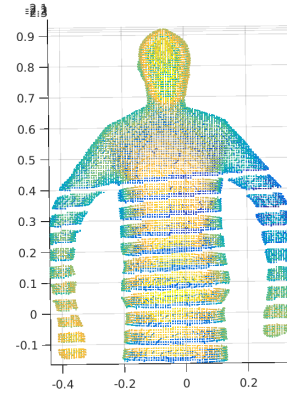


Fig. 9. Slicing of the bust. For each single slice we calculate surface area and volume.

8) *Neck Circum*: We perform slicing in the neighbourhoods of the neck joints, from the bottom to the top. We stop when the eccentricity of the ellipse with best geometrical fit is close to one. Then we let the angle of the cutting plane varying of $\pm \delta$ and we select the components which minimize the area.

III. DATA ANALYSIS

With the given measures we are able to automatic extract most of the index related to human wellness. In particular we

focus on the *Barix* [8] and of the waist-to-hip ratio.

The formula for the *Barix* is given by:

$$\text{Barix} = \frac{\text{Torso Height} * \text{Torso Surface Area}}{\text{Torso Volume}}$$

The formula for the waist-to-hip (WHR) ratio is given by:

$$\text{WHR} = \frac{\text{Waist Length}}{\text{Hip Length}}$$

People in healthy condition seem to have two peaks and a regular pattern, instead people with adiposity in excess has a more irregular behaviour. For such reason we could use the graph given by area-height in order to localize the adiposity in excess. For example in fig. 10 is present a peak at the level of the waist.

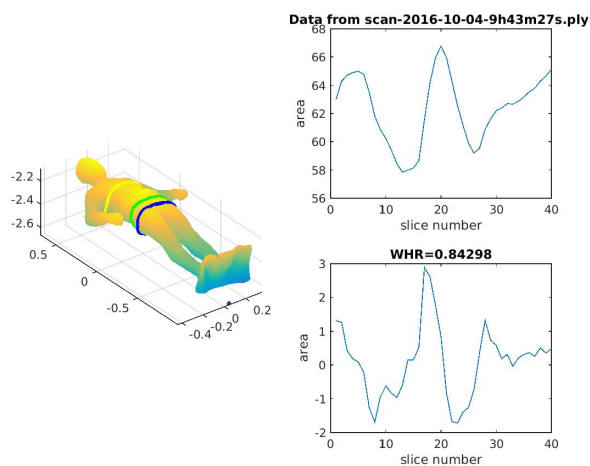


Fig. 10. Bust length variation and its derivative chart.

IV. FUTURE WORK

The algorithm as to work within a system constitute by a Kinect v2 sensor, a calculator and a monitor. Package compatible with Microsoft Systems have to be create. Moreover the algorithm must be robust to noise and should detect wrong position, such as akimbo. After a data collection, experiments on more data will be conduct in order to verify our hypothesis.

V. ACKNOWLEDGEMENTS

This research was fully supported by Regione Sardegna under the research project VIRTUOSO - Un osservatore sanitario virtuale per la prevenzione di malattie cardio-metaboliche nella pratica di attivit fitness & wellness nei centri turistici - A virtual health observer for the prevention of cardio-metabolic activity in the practice of fitness & wellness in tourist centres . We thank our colleagues Francesca Denoth, Massimo Martinelli and Marco Righi, who provided insight and expertise that greatly assisted the research.

Finally, we thank Davide Moroni for helpful comments to this manuscript.

REFERENCES

- [1] Paolo Cignoni, Massimiliano Corsini, and Guido Ranzuglia. Meshlab: an open-source 3d mesh processing system. *Ercim news*, 73(45-46):6, 2008.
- [2] Walter Gander, Gene H Golub, and Rolf Strebler. Least-squares fitting of circles and ellipses. *BIT Numerical Mathematics*, 34(4):558–578, 1994.
- [3] Andrea Giachetti, Christian Lovato, Francesco Piscitelli, Chiara Milanese, and Carlo Zancanaro. Robust automatic measurement of 3D scanned models for the human body fat estimation. *IEEE J. Biomed. Heal. Informatics*, 19(2):660–666, mar 2015.
- [4] Rachel Huxley, S Mendis, E Zheleznyakov, S Reddy, and J Chan. Body mass index, waist circumference and waist: hip ratio as predictors of cardiovascular risk: a review of the literature. *European journal of clinical nutrition*, 64(1):16–22, 2010.
- [5] Peter R.M. Jones and Marc Rioux. Three-dimensional surface anthropometry: Applications to the human body. *Opt. Lasers Eng.*, 28(2):89–117, 1997.
- [6] Michael Kazhdan, Matthew Bolitho, and Hugues Hoppe. Poisson surface reconstruction. In *Proceedings of the fourth Eurographics symposium on Geometry processing*, volume 7, 2006.
- [7] Tobias Pischon, H Boeing, K Hoffmann, M Bergmann, MB Schulze, K Overvad, YT Van Der Schouw, E Spencer, KGM Moons, A Tjønneland, et al. General and abdominal adiposity and risk of death in europe. *New England Journal of Medicine*, 359(20):2105–2120, 2008.
- [8] David B Stefan and David A Gilbert. Method for determining a subject's degree of adiposity, October 6 2009. US Patent 7,599,537.
- [9] Abd Tahrani, Kristien Boelaert, Richard Barnes, Suzanne Palin, Annmarie Field, Helen Redmayne, Lisa Aytok, and Asad Rahim. Body volume index: time to replace body mass index? 2008.
- [10] Naoufel Werghi. Segmentation and modeling of full human body shape from 3-d scan data: A survey. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, 37(6):1122–1136, 2007.