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COMPARISON BETWEEN 3D LASER SCANNING AND COMPUTED TOMOGRAPHY ON THE MODELLING OF HEAD SURFACE

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Abstract

The measurement of people physical parameters and proportions constitutes an important field of science, the anthropometry, since it is related to the characterization of the human size and constitution; it allows improving the design and sizing of systems and devices to human use.

To enable these measurements, different direct and indirect methodologies may be used depending on the particular aim of a specific study and on the eventual availability of data sources that can be used also for this purpose.

Because of this relevance, the present work intends to assess the influence of different acquisition and reconstruction methods in the modelling of a 3D head surface.

In order to assess the significance of the differences between acquisition and reconstruction methods a set of measurements between several anatomic references of a physical phantom were carried out. Statistical evaluation using the Friedman test for non-parametrical pared samples was considered.

We found, so far, no statistically significant differences between the several methods considered for acquisition and reconstruction.

INTRODUCTION

The measurement of people physical parameters and proportions constitutes an important field of science, as it enables to the understanding of anthropological information associated to human remains, a better acquaintance of our ancestors' heritage and, not least importantly, the improvement in design and sizing of systems and devices to human use.

Nowadays several approaches, ranging from low cost scanners to professional scanners, exist to reconstruct a precise 3D model of a human body. This problem is especially complex in non-rigid applications and to use these models in such applications, approaches to extract anthropometric data from human body scans are required. The extracted measures build the basis for further processing and thus automatic and reliable approaches are important. The literature proposes semi-automatic and automatic approaches like detecting landmarks and in its precise localization, although other methods recurring to new developed algorithms and prior data enable the modelling 3D surface without recurring to landmarks as done by Anguelov et al [1].

Within the methods to access surfaces one can use Scanners or Computed Tomography (CT) technique, being CT the gold standard, as it constitutes currently the main imaging technique to access surface for radiotherapy. Illustrating this we may refer the work developed by Gopan and Wu[2], and by Morton [3], who focused on the accuracy issues related to this imaging technique. The evaluation of spatial resolution of the applied imaging systems is essential for accurate and precise measurements. The advent of more complex imaging systems has posed an increasing challenge in our ability to assess their performance, including spatial resolution. Richard et al. [4]addressed the problem associated to iterative and statistical reconstructions which can exhibit nonlinear signal characteristics, which can affect system resolution properties differently than with standard reconstruction algorithms, and acquisition techniques.

Contrarily to CT, made of a sequence of bi-dimensional images, 3D Laser Scanning (3DLS) provide a three-dimensional sampling of an object, namely of the human body, characterizing it by a dense set of points in the 3D space, usually known as point's cloud. The topology of these points can be represented, for instance, through the constitution of a polygonal mesh or via parametric surfaces. It is noteworthy that the measurements obtained represent the human body at a certain time and that various scans may lead to slightly different results, as pointed by Paquet and Rioux[5].

Recent advances in three-dimensional scanning technology have enabled the generation of high-density point data sets to describe the surfaces of real objects (Bernardo and Loja [6][7]), including animate objects such as the human body. This means that it is now possible to produce computer-based models that describe in detail the topology and the geometry of an actual human body. Such models can be used to perform fast and accurate automatic measurements. However, such measurements cannot be made on raw point data, as very often the point's cloud is noisy and contains undesired information. To minimize these problems Douros et al. [8]proposed an algorithm to analyze the data and from it infer the topology (and subsequently the geometry), taking into consideration that skin surface presents further challenges, such as more accurate reconstruction algorithms.

With the present study the authors propose to evaluate and compare the CT images of craniofacial anthropometry of the PIXY phantom and the points cloud obtained via 3D laser scanning. These features are further compared to caliper measurements.

1. METHODOLOGY

As mentioned, the main aim of the present work is the comparison of different anthropometric head measurements by using different data acquisition sources, in order to assess from their significance so one can establish a viable departing point to an automated design of head devices.

To this purpose, one has considered the head of a physical phantom (PIXY) [9]and performed a set of direct and indirect measurements methods. The first method considered a direct, manual measurement, by using a Rosscraft caliper with the scale of 0-180mm and a precision of 0.1 mm mainly utilized in nutrition.

Two other approaches were carried by considering the data acquired via 3D laser scanning (3DLS) and via computerized tomography (CT).

To perform the 3D laser scanning of the phantom head, one has used a NextEngine system, which settings involved a medium range acquisition and a number of ten sectors with a density of 850 points per square inch. The system precision is 0.005 inch. With the 3D point cloud acquired, a subsequent mesh was generated in order to yield the surface reconstruction. This reconstruction stage was carried out automatically by the same system.

The two computed tomography were performed using a system Philips Gemini TF 16 with two different slices' thickness (1 mm and 2mm) while keeping other acquisition parameters constant: 20 mAs, 120kVp, pitch of 0.938, 512x512 pixel matrix, rotation speed of 0.5s per rotation. It is important to say that these settings are the usually considered in a normal planning CT, in the Nuclear Medicine scientific area.

The CT images were next used to build the 3D head mesh, by using two alternative image processing applications, ImageJ and Osyrix. The meshes were also obtained by different members of the research team.

1.1. 3D Reconstructions

The meshes built, were subsequently imported layer by layer, to a trial version of Geomagic Design, and converted into solid entities, enabling to obtain the required measurements. Figure 1 illustrates the solids corresponding to the 3DLS and CT acquisition methods.

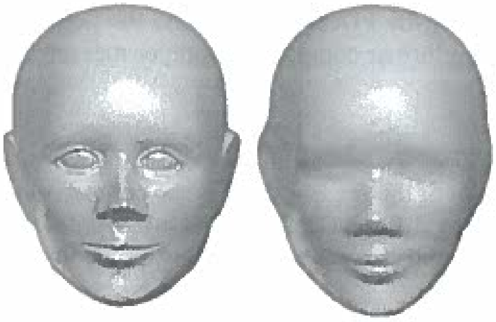

Figure 1: Solid representation of 3DLS (left) and CT (right) data.

From Figure 1 it is possible to conclude that for the settings used, there exists an evident difference on the level of detail obtained using 3DLS and CT.

The measurements carried out to characterize the anthropometry features of the physical phantom head, were based on the set of measurements carried out by Yokota [10]. The results obtained are presented in Table 1.

Table 1: Identification of craniofacial measurements [10].

Measure ID	**Designation**	**Definition**
1. BIGONIAL	Bigonial breadth	Straight-line between the right and left gonion on the jaw
2. BIOCBRMH	Biocular breadth	Distance between the right and left ectoorbitale
3. BIZBDTH	Bizygomatic breadth	Maximum horizontal breadth between zygomatic arches
4. CHINPROJ	Chin projection	XYZ coordinates between right tragion and mentona
5. HEADBRTH	Head breadth	Maximum horizontal breadth of the head
6. HEADLGTH	Head length	Maximum distance between the glabella and back of the head
7. LIPLGTH	Lip length	Distance between the right and left cheilion on the corner of the mouth
8. MENSUBNH	Menton–subnasal	Distance between the menton and the subnasal
9. NOSEBRTH	Nose breadth	Distance between the right and left alare
10. RTRAGX	Right tragion X	Distance between right tragion and back of the head plane
11. SBNSSELH	Subnasal-sellion length	Distance between the subnasal and sellion
12. SELLIONZ	Sellion Z	Distance between sellion and top of the head plane
13. SELTRAG	Facial projection	Distance in XYZ coordinates between sellion and right tragion

A better illustration of these measurements' meaning is shown in Figure 2 that presents a schematic representation extracted from Yokota[10] although in the present case, the physical phantom doesn't possess that much detail.

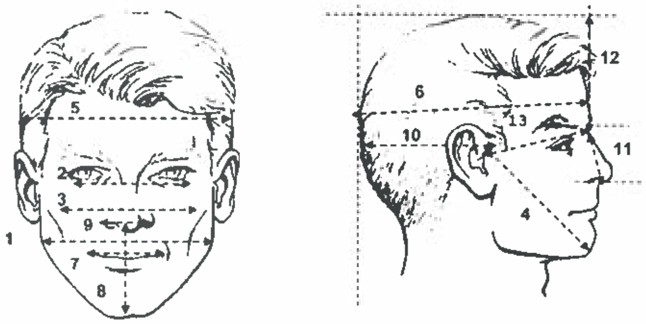

Figure 2: Schematic representation of craniofacial measurements. (Source: Yokota [10][10]).

To guarantee the maximum accuracy and consistency among the different phantom head reconstructions, all the four meshes were aligned, considering an approach based on the minimum global deviation among meshes. After this alignment, and after the selection of the points of interest, the measures were taken at each active layer, corresponding to a specific head model.

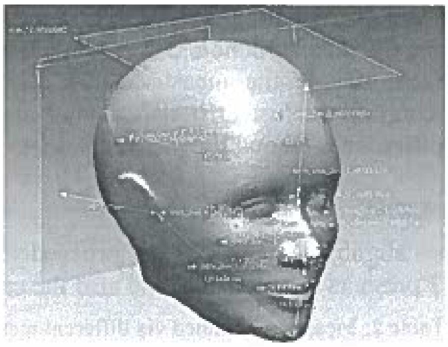

Figure 3: Measures extraction in 3DLS model.

This procedure allowed obtaining model by model the required measures. Figure 3 illustrates the extraction of some measures in the 3DLS model.

In the preliminary comparison of the measurements carried out to characterize the anthropometry features of the physical phantom head, one has calculated different relative deviations. These relative deviations were plotted using radar charts.

1.2. Statistical assessment of the models

As at that moment it wasn't intended to assume a single mesh as the golden standard, then one has assumed that the CT 1mm and 3DLS may assume that role.

Statistical inferential models were also applied in the comparison of the measurements executed in the different acquisitions (1 mm or 2 mm slices thickness), and of the different imaging reconstruction applied methods, and also in the comparison of these with the physical measurements obtained with calliper. In order to execute further inferential statistical evaluation, it is necessary to investigate previously the distribution of the sample and classify that distribution as a normal on non-normal one. Due to the small size of the sample it is necessary to apply Shapiro-Wilk test to enable classifying the distribution of the samples obtained. Furthermore, in a subsequent phase, to evaluate if there were any statistical significant differences between the measurements collected of the same landmarks (when the phantom is reconstructed and/or acquired with different settings) is was applied Friedman for the multiple comparisons.

All statistical analysis was performed using Statistical Package for the Social Sciences (SPSS v.24) software. For all the groups included in the study, a significance level of 5% was used [11].

2. RESULTS AND DISCUSSION

In order to simplify the designation of the different reconstructions performed, the following acronyms and corresponding meaning were used: CTImg1 – ImageJ CT reconstruction, 1 mm slice; CTImg2 – ImageJ CT reconstruction, 2 mm slice; CTOsx1 – Osyrix CT reconstruction, 1 mm slice; CTOsx2 – Osyrix CT reconstruction, 2 mm slice; 3DLS – 3D Laser scanning.

The results here summarized include the measurements carried out using the different methodologies, their deviations and the further statistical analysis to understand whether there are statistically significant differences among the methodologies.

2.1. Craniofacial measurements

After the preliminary meshes alignment stage, one has proceeded to the measurements, which task was developed. Table 2 presents these results, and also the calliper direct measures.

Table 2: Measures obtained via different methods.

Measure ID	Caliper [mm]	CTImg1 [mm]	CTimg2 [mm]	CTOsx1 [mm]	CTOsx2 [mm]	3DLS [mm]
1. BIGONIAL	110	116.18	112.77	113.54	114.99	116.85
2. BIOCBRMH	85	86.57	86.64	86.71	86.71	86.69
3. BIZBDTH	100	104.11	100.78	109.84	103.04	106.34
4. CHINPROJ	130	132.65	133.57	132.51	131.67	132.30
5. HEADBRTH	110	146.17	140.95	144.78	145.46	145.45
6. HEADLGTH	170	179.45	177.16	177.67	178.40	178.14
7. LIPLGTH	55	54.46	54.66	54.48	54.49	54.51
8. MENSUBNH	50	54.85	54.05	55.19	55.59	55.11
9. NOSEBRTH	36	36.22	33.47	35.94	35.43	35.51
10. RTRAGX	85	99.85	99.78	99.80	99.98	99.93
11. SBNSSELH	50	50.45	50.33	50.36	50.73	50.72
12. SELLIONZ	120	85.69	85.73	85.70	85.68	85.69
13. SELTRAG	75	102.76	102.96	102.99	101.97	102.30

In Table 2, it is clear that ID measures 3 and 5 are the ones where the values obtained are more dissimilar. To allow a better perception of the relative deviations among different methods using different reference reconstructions, Figures 4-6 allow us to understand those deviations when considering different reference models. The relative deviations, when one considers the CTImg1 model as reference is presented in Figure 4.

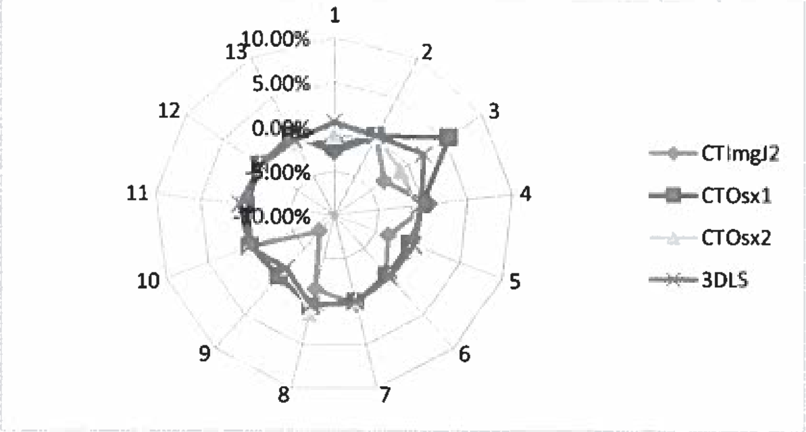

Figure 4: Relative deviations using CTImg1 as the reference measurement model.

In addition, the measures ID 3, 5 and 9 show the greater deviations than all the others. The CTImg2 and CTOsx1 models are the ones where the major values occur, when the golden standard is considered to be the CTImg1. Contrarily, the CTOsx2 and the 3DLS are the ones that perform more accordingly the standard, with minor deviations for the latter one.

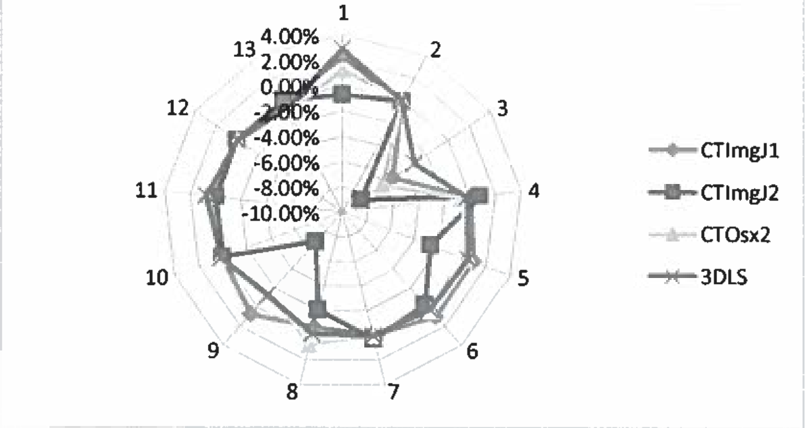

Figure 5: Relative deviations using CTOsx1 as the reference measurement model.

Considering now the CTOsx1 as the reference model, the relative deviations presented by the different models, are represented in Figure 5.

Figure 5, shows again the CTImg2 model as being the one where the major deviation values occur, and this happens especially for the ID measures 3, 5 and 9. The approach that provides a closer set of measurements when compared to the CTOsx1 reference is the 3DLS model.

Finally and considering the laser scanning results, Figure 6 depicts the deviations presented by the different CT reconstructions taking the 3DLS as the standard.

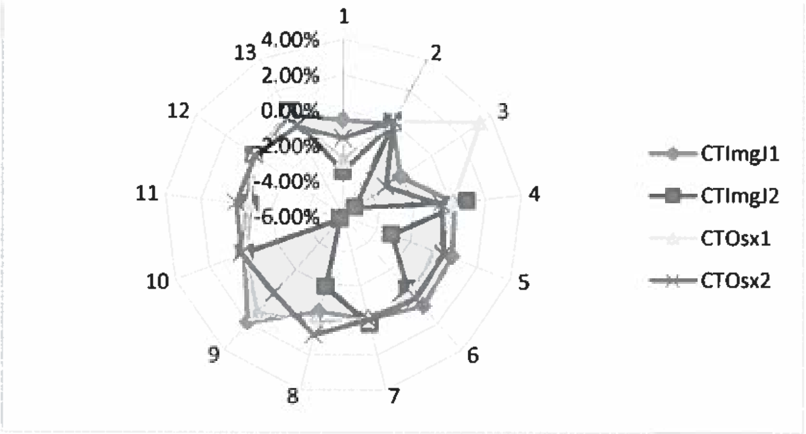

Figure 6: Relative deviations using 3DLS as the reference measurement model.

This last deviations' comparison presented in Figure 6, demonstrates the CTImg1 to be the one that is globally closer to the 3DLS standard. The CTOsx1 is also closer if one excludes the measures 3 and 9.

2.2. Statistical assessment results

After the comparison of landmarks measurements between the different acquisition and reconstructed methods by Friedman test, including all the reconstructed imaging for all methods and thickness of the slices, the different acquisition methodology such as CT and laser technology and comparing this with physical measurements there were found significantly statistical differences ($p=0.000$).

These differences were probably due to the different level of precision and accuracy that were obtained of all the other techniques when compared with the physical measurements obtained with calliper. Although it is possible to be certain about the reference points for measurements executed in all the reconstructed images, and all were measured in the same software, the same is not possible when doing the physical measurements, and this can introduce some inaccuracies.

After the comparison of all the reconstructed images measurements, there were not found any statistically significant differences, in the together comparison of the methods, allowing us to

conclude that al methods from a statistical point of view can be used as suitable for the reconstruction process (p=0.414), even when it is not applied the same thickness of slices in the acquisition protocol of CT (1mm and 2 mm), and when the acquisition technique is different (CT and 3DLS).
When maintaining the thickness of the slices and comparing the CT with 3DLS there were not verified statistically significant differences, neither for the comparison of CT slices acquired with 1 mm neither in the comparison between CTImg1, CTOsx1 and 3DLS (p=0.981); neither in the comparison of CTImg2, CTOsx2 and 3DLS (p=0.232). Despite the non-existence of statically significant differences the results show a greater concordance between 3DLS and the both reconstruction models when the CT was acquired with 1 mm slices, this can be due to the effect of the increase of the slices thickness in the degradation of the imaging spatial resolution and overall quality of the CT imaging [12].
It is also possible to conclude that even in lower spatial resolution CT acquisition, statistically significant differences are not observed when one uses different reconstruction methods.

3. CONCLUSIONS

There are no statistically significant differences between the several methods of acquisition and reconstruction considered in this work.
Therefore, and from a statistical point of view, all models used, can be considered as suitable for the reconstruction process and subsequent measurement and head anthropometry characterization.

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