# METHODS FOR ASSESSING THE ACCURACY OF HUMAN UPPER LIMB BONES MODELS

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**Abstract:**
*The paper presents two methods for comparing virtual models of the bones which provide different accuracies. The discrete qualitative method and the visual-quantitative method are analyzed and their results are compared in terms of accuracy. Advantages and disadvantages of each method are shown, together with time consuming.*
**Keywords:** *upper limb, model, accuracy*

## 1. INTRODUCTION

The importance of biomechanics is related to solving some practical issues like: prosthesis and orthesis design, elite athletes' performances analysis, orthopaedics, physical rehabilitation, kinematic analysis of human body for robot control, ergonomics. In order to achieve its goals, biomechanics uses the kinematic analysis which describes the geometry of motion. The kinematic analysis provides positions data and displacements of anatomical segments centres of gravity, of joints and of end effectors of anatomical segments.

## 2. STATE OF THE ART

Due to the complexity of the human upper limb, its kinematic modelling is still a challenge for all scientists. In order to better manage the kinematic models, simplifying assumptions are taking into account. Based on the joint morphology, Furnstahl (2009) tried to develop a kinematic model of the upper limb which performs accurately the pronation-supination motion. He was able to reveal the joint sliding motion using tomographical scanning.

The pronation–supination motion of the human upper limb was studied by Weinber (2000) who had as a starting point the kinematic model of Fick, (1904), ignoring the limitations regarding the motion of ulna. This particular motion was studied by Nakamura (1999) and Nojiri (2008) using magnetic resonance. They have developed a kinematic model, similar to the model of Kasten (2002), having 7, which allows the prediction of the forearm fracture related to the amplitude of motion. The results are important to the surgeons for restoring the mobility of the forearm.

Bullock, Borràs and Aaron (2012) conducted a review of kinematic models used to simulate the motion of the upper limb, focusing on simplifying assumptions and on their influence on the final results.

The virtual model of the upper limb presented by Pennestri, Stefanelli, Valentini, and Vita (2007), has 7 degrees of freedom, and the shoulder was considered fixed. The model has four elements corresponding to humerus, ulna, radius and hand. A special attention was paid to modelling the joints whose motion should provide the best natural movements of the upper limb, especially for the arm and forearm. The model includes 24 muscles. The limitations were imposed by ergonomics and by the extreme positions of the upper limb joints. Also, optimization techniques have been used considering the minim trajectory of the effector as objective function. Electromyography experimental tests have revealed the muscle activity.

## 3. BONE MODELLING

Generally, bone modelling is not intended to provide exact geometry of the bone, because the kinematic schemes include segments as kinematic elements. However, the most accurate representation of the bones in the virtual model reduces the data processing time, due to the fact that the software automatically calculates mass-inertial properties.

The geometric model of the human skeleton was taken from the virtual library 3Dlancer being modelled in 3D StudioMax software [http://3dlancer.net/en/3dmodel-human-skeleton-4792.html].

### 3.1. SURFACE DESIGNING

To achieve a realistic model of the bone according to the size and geometric shapes given in literature [Doube 2009, Murray 1999] it was necessary to process the outer surfaces of the bones which were imported into AutoCAD, from 3D StudioMax. The purpose of this conversion is to change the bone superficial model into a solid model whose mass-inertial properties can be automatically determined.

The human upper limb skeleton created in 3D StudioMax is exported as ".dwg" file. The file thus created is opened in AutoCAD and every bone of the human upper limb is saved in a different file (thus, the time computing is decreasing).

The dwg files contain the polyface mesh of each bone (Fig.1a). This model type provides only the outer surface of the bone, without providing any

other information regarding the mass, the inertia moments, etc.

For accurate modelling of the bones we have used an AutoCAD feature referring to redefining the surfaces. This is an automatic and controlled process which changes a rough surface is reshaped, thereby achieving a smooth surface (Fig.1b). The superficial model thus obtained is converted into solid.

The process is applied for all the bones that compose the mechanical structure that models the human upper limb.
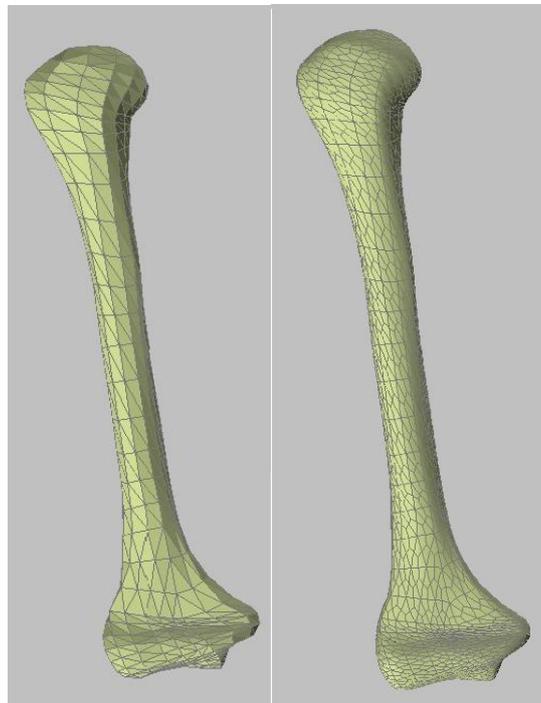


a) Polyface mesh          b) 3D Solid type model
**Figure 1.** Bone model

## 4. COMPARISON OF THE VIRTUAL MODELS OF THE BONES

To evaluate the accuracy of the bones as solid models, we have compared them, considering as reference the surface model (mesh type) and comparing to the 3D solid model of the bone. In order to conduct this study we have used the features provided by other modelling software, namely Catia.

To export the file type "dwg" from AutoCAD to CATIA, we have had to use Inventor Fusion for opening the files and save them with the extension "IGES". Then we saved them with the extension "CATPart". IGES, meaning Initial Graphics Exchange Specification defines a neutral data format for transferring digital information as circuit diagram, surfaces, solids, between CAD systems. [http://en.wikipedia.org/wiki/IGES].

This file format conversion process is applied to both files that contain bones as polyface mesh entities (the original version of the bone) and those that contain bones as 3D solid entities (redesigned version of the bone).

### 4.1. Discrete-qualitative method for comparing virtual models of bones

The method is based on comparing cross-sections contours. To this end, it is necessary to activate Digital Mockup> DMU Navigator module and create a file "CatProduct" where are listed as existing components (Insert> Existing Component) the files containing the initial and refined bone. We perform random cross-sections and measure the distance between the two contours. The relative position of the two shapes provides two systems of highlighting the distances. Thus, the green dimensions measure the distance (deviation) from the redesigned bone contours when it is included in the original bone contour and the red dimensions indicate the distance between the redesigned contours bone when it is outside the original contour.

Three cross-sections of the humerus bone, two sections near the ends and one about midway between the two extremities are shown in fig. 2. It may be noted that for none of the three cross-sections the maximum distance between the two contours does not exceed 1.00 mm.
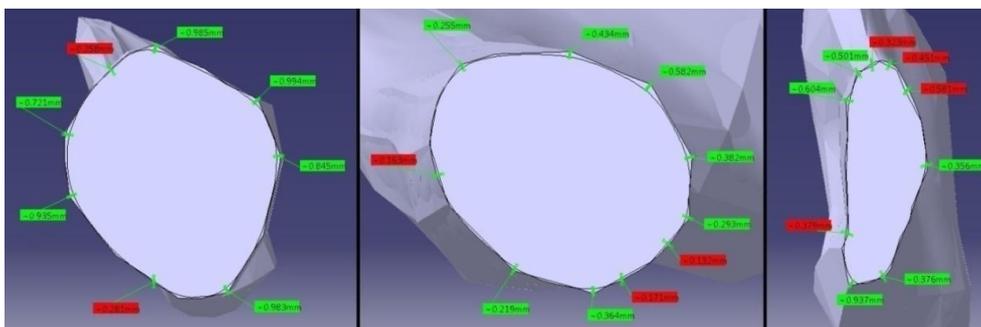
**Figure 2.** Cross-sections in both superficial and solid models

Similar metrics were made for the other bones of the arm, and we get the following maximum values of the deviation between the two shapes (Table 1, Fig. 3):

**Table 1**. Maximum values of deviation between the two models

| Bone | Maximum deviation [mm] |
|---|---|
| Ulna | 0.89 |
| Radius | 0.68 |
| Scapula | 1.05 |
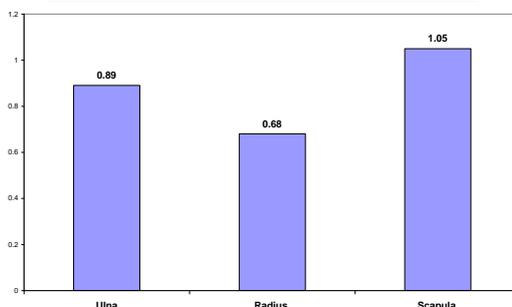


Fig.3. Maximum values of deviation between the two models

### 4.2. Visual - quantitative method for comparing virtual models of bones

This is an automated method that allows comparison of bones using Digital Mockup> DMU Space Analysis module. This module allows highlighting the subtracted and added volume from/to the original bone using cubes in order to get the redesigned bone (Fig. 4).
The cube side 0.2 mm and in Fig. 4 the removed volume is red, while the added volume is green. The percentage differences for volume and aria of the redesigned bones are shown in Table 2.

**Table 2**. Percentage differences for volume and aria of the redesigned bones

| Bone | Volume [%] | Aria [%] |
|---|---|---|
| scapula | 93.69 | 93.89 |
| humerus | 98.48 | 96.09 |
| radius | 95.40 | 98.55 |
| ulna | 94.78 | 95.33 |
| carpal | 98.23 | 99.28 |
| metacarpal + phalanges | 96.05 | 94.62 |

It is found that the best results in this method to estimate the accuracy of modelling for lateral area are obtained for the carpal bones (99.28%) and the radius (98.55%), while the worst results were recorded for the scapula (93.89%). Regarding the comparison of volumes, we found that the humerus record best modelling accuracy (98.48%), followed by carpal bones (98.23%). The worst results were recorded for the virtual model of the scapula (93.69%) and ulna (94.78%).
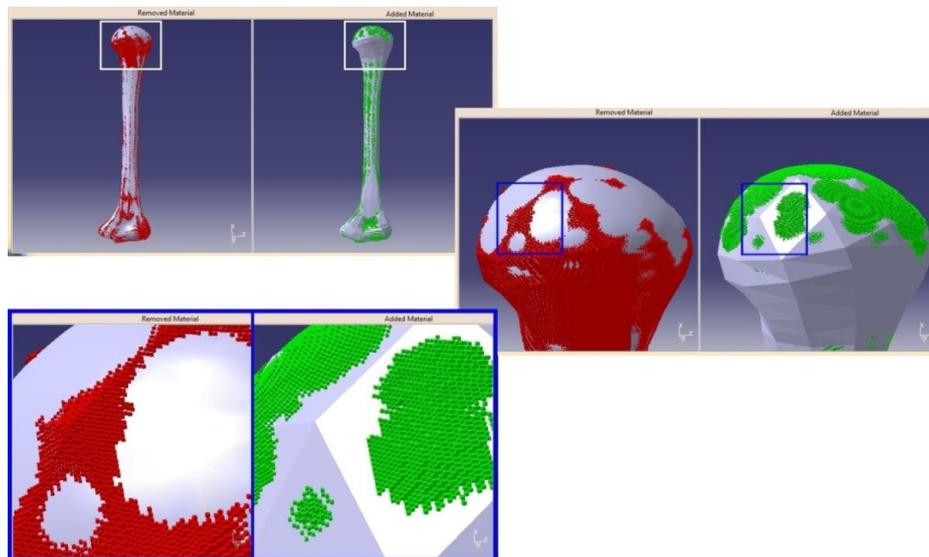
**Figure 4.** Visual-quantitative method

## 5. CONCLUSION

In conclusion, the two methods that we have proposed, namely the discrete qualitative method, and the visual-quantitative method for comparing virtual models of the bones, provide different accuracies. The latter is the most powerful because it provides more accurate information about the solid model. The first method is time and resource consuming, as it requires numerous cross-sections, due to the complexity of the geometric shapes of the bone and, each time, two cross-sections must be superimposed in order to compare their aria. The second method is much faster and more accurate, allowing comparison of the two outer surfaces of patterns, and comparing the volume, meaning that a double-precision to estimate the accuracy of reshaping the superficial model into the solid model.

## REFERENCES

1. Furnstahl P., Schweizer A., Nagy L., Szekely G., Harders M., (2009), *A morphological approach to the simulation of forearm motion,* Computer Vision Laboratory, ETH Zurich, Zurich, Switzerland Department of Orthopedic Surgery, Balgrist University Hospital, Zurich, Switzerland.
2. Weinberg A.M., Pietsch I.T., Helm M.B., Hesselbach J., Tscherne H., (2000), *A new kinematic model of pro- and supination of the human forearm*, Journal of Biomechanics 33 487-491.
3. Fick, R., (1904), *Handbuch der anatomie und der mechanik unter Ber¨*, ucksichtigung der bewegenden Muskeln. Fischer Verlag.
4. Nakamura T., Yabe Y., Horiuchi Y., Yamazaki N., (1999), *In vivo motion analysis of forearm rotation utilizing magnetic resonance imaging*," Clin Biomech, vol. 14, no. 5, pp. 315–320, June 1999.
5. Kousei Nojiri, Nobutomo Matsunaga, Shigeyasu Kawaji, (2008), *Modeling of pro-supination for forearm skeleton based on MRI*, Proceedings of the 17th World Congress The International Federation of Automatic Control Seoul, Korea, July 6-11, ISBN 978-1-1234-7890, p. 14676-14772.
6. Kasten P., Krefft M., Hesselbach J., Weinberg A., (2002), *Computer simulation of forearm rotation in angular deformities: a new therapeutic approach*," Injury, vol. 33, no. 9, pp. 807–813, November 2002.
7. Bullock I.M., Borràs J., Dollar A.M., (2012), *Assessing assumptions in kinematic hand models: A review*, The Fourth IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics, Roma, Italy. June 24-27, 2012, ISBN 978 – 1 - 4577 - 1200.
8. Pennestri E., Stefanelli R., Valentini P.P., Vita L., (2007), *Virtual musculo-skeletal model for the biomechanical analysis of the upper limb*, Journal of Biomechanics 40, p.1350–1361.
9. http://3dlancer.net/en/3dmodel-human-skeleton-4792.html].
10. Doube M., Conroy A.W., Christiansen P., Hutchinson J. R., Shefelbine S., (2009), *Three-Dimensional Geometric Analysis of Felid Limb Bone Allometry*, PLoS One 4(4), doi: 10.1371/journal.pone.0004742.
11. Murray I.A., (1999), *Determining upper limb kinematics and dynamics during everyday tasks*, teza doctorat Newcastle University library. http://en.wikipedia.org/wiki/IGES