

Virtual Mock-Up of Shoulder Articulation for an Aided Surgery System

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Abstract

The aim of the work described in this paper is to provide a light and easy-handling shoulder model for surgeons in order to ease the preoperative and peroperative work when substituting the articulation by prosthesis. The digital mock-up of shoulder is simplified according to the criteria of the surgeon. The simplification allows an easy manipulation of the model for a virtual operation. This paper describes the chosen method to obtain a virtual mock-up useful for preoperative simulation.

1 - Introduction

The context of this work is related to the operation of the replacement of shoulder articulation by a prosthesis. The substitution of the articulations of the knee and the hip by prostheses is a procedure which succeeds well. On the other hand, the case of the prosthesis of shoulder is much less obvious. The main cause of failure of the positioning of the prosthesis is related to the anatomy of the shoulder [1]. The visual field of the surgeon is very limited during the operation because a small incision is carried out on the patient to limit the damage to surrounding tissues. Consequently, only the sleeve of the scapula and the humeral head are exposed. The goal of this work is the development of a virtual reality system in order to simplify the preoperative and peroperative work for surgeons when substituting the shoulder articulation by prosthesis. To reach this goal, different steps have been identified:

- modeling the bones of human shoulder from available medical images of the patient;
- simulation of the operation from this model (preoperative virtual surgery);
- designing of a real-time augmented reality system for peroperative work.

The Fig. 1 describes the proposed method to reach the presented goal.

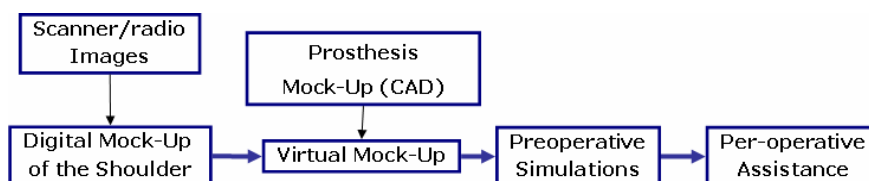


Fig.1. Towards a computer-aided surgery system for the shoulder prosthesis placement.

2 - Digital mock-up

2.1 - Comparison of different techniques for shoulder modeling

With respect to the final application (computer-assisted surgery), different criteria are necessary in order to determine the best possible modelling method:

- parameterizable surface, which allows us to adapt the surface to the morphological characteristics of the patient,
- parameter type, because a surface ruled by physical parameters consents to deform the model

morphologically which is not the case with mathematical parameters,

- logical operators, because the surface has to allow logical operations to ease the subsequent virtual surgery.

Different techniques from the literature have been implemented and evaluated [2-12]. The Table 1 resumes the obtained results according to the mentioned criteria.

Table 1. Comparison of the methods.

Implemented methods	Surface/Volume?	Parameters	Kind of parameters	Operators (intersection, subtraction, union)
RBF	Surface	Yes	Mathematical	Possible
Kohonen	Surface	Yes	Mathematical	Possible
Skeleton	Surface	No	-	Impossible
Snakes	Surface	No	-	Impossible
Subdivision	Surface	No	-	Possible
Marching cubes	Volume or Surface	No	-	Impossible
Simple-form	Surface	Yes	Morphological	Possible

RBF, Kohonen maps and simple-form modeling methods are parametric representations. Nevertheless, for RBF and Kohonen maps, the parameters are purely mathematics and do not represent any anatomical information (such as the diameter of the humeral head or the length of the humerus). Moreover, it seems quite difficult to determine anatomical information by combining the mathematical parameters of these representations. All the other methods are non-parametric so that the shape and size of the reconstruction can hardly be adapted to the patient morphology unless a morphing algorithm is applied.

The chosen modelling method is the simple-form one. In that model, the bones of the shoulder are represented by simple forms, such as quadrics, planes and so on, that can be handled with a very few parameters. It has been already stated that the data provided by the surgeon are sufficient to parameterize this kind of model. Furthermore, logical operations as subtraction or intersections can be easily computed on quadrics and planes so that the drilling and cutting can be simulated on the model and a virtual operation can be considered.

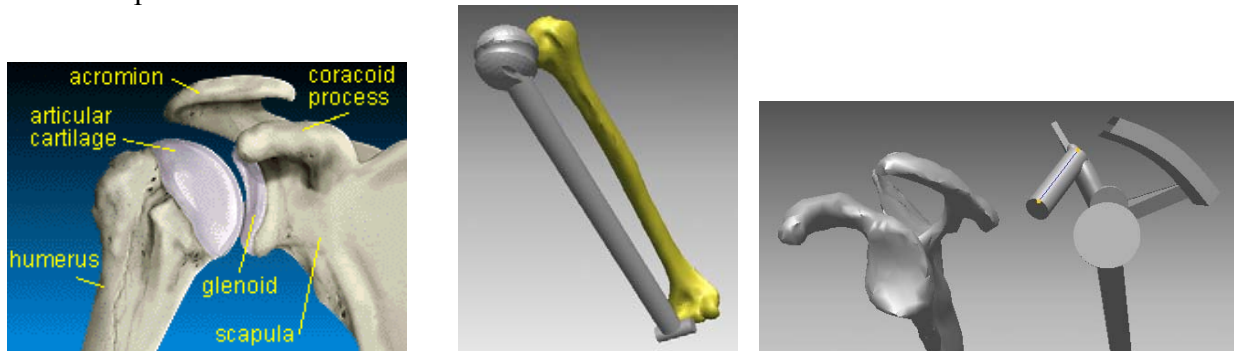


Fig.2. Anatomical description of left shoulder articulation and simple-form model developed.

It is important to notice that the model is used in the context of the replacement of the bones articulation by a prosthesis articulation. In our case, the inverse prosthesis which is the DUOCENTRIC prosthesis is installed. Then, for the application, it is not necessary to perform a fine model of a real shoulder articulation. The simple-form model is sufficient for the application.

The simple-form model proposed is composed of quadrics, boxes and Dupin supercyclides for the links between different forms. For instance, the humerus is mainly made of a sphere and a cylinder [13]. A Dupin supercyclid is added to ensure the continuity and completeness of the model and the bicipital groove is modelled by carving a cylinder into the humeral head. The scapula is composed of planes, ellipsoids, cylinders and so on. The complete model will be detailed and the link between relevant parameters and simple form parameters that legitimates our choice will be stated.

Then, only 9 parameters are necessary to compute a model adapted to the morphology of the patient. In accordance with orthopaedists [14], the parameters of interest described in the Table 2 have been chosen.

Table 2. Parameters of the simple-form model.

Ray of the humeral diaphysis
Ray of the humeral head
Position of the bicipital groove with respect to the centre of the humeral head
Maximal distance between the epiphysis and the greater tuberosity of humerus
Height and width of the glenoid cavity
Position of the coracoid with respect to the centre of the glenoid cavity
Lateralisation of the acromion
Position of the axillary border with respect to the horizontal plane
Position of the acromion with respect to the inferior border of the glenoid cavity

2.2 - Extraction of the parameters of the simple-form model

The goal of the system is to provide a full system to extract parameters of the chosen model in a simple way. More precisely, the system has to be able to extract parameters from radiological images. For that, a procedure is studied by the surgeons to make the useful radiological images. To validate the method of extraction, a system has been developed to extract parameters from scanner images.

The proposed approach consists in the automatic (or sometimes supervised) extraction of relevant parameters from various medical images (CT slices, X-ray images, radiological images). A first experimentation has been performed based on scanner images. The different steps of the image processing algorithm are:

- conversion from colour to gray-level;
- binarization to extract the bones from medical images;
- filtering;
- morphological operations in order to reject irrelevant regions and to differentiate the scapula from the humerus.

These steps are obviously adapted to the kind of images (threshold, prior knowledge on the relative positioning of the scapula/humerus, etc.) and parameters to extract. The Fig. 3 depicts an example for the extraction of the diameter of the humeral head from scanner images. The selected image is chosen according to the biggest diameter of humeral head. The different steps of image processing have been implemented to be automatic.

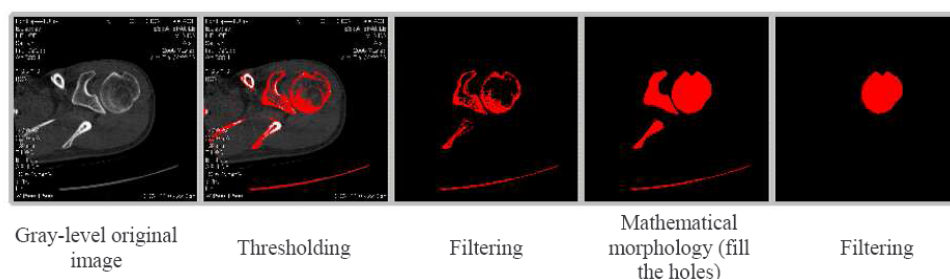


Fig.3. Image processing method for the extraction of the diameter of the humeral head.

2.3 - Integration of the prosthesis in the model

The computer assisted design (CAD) model of the prosthesis is integrated in the shoulder simple-form model as illustrated in the Fig. 4. The assembly of the different parts is performed for preoperative simulation.

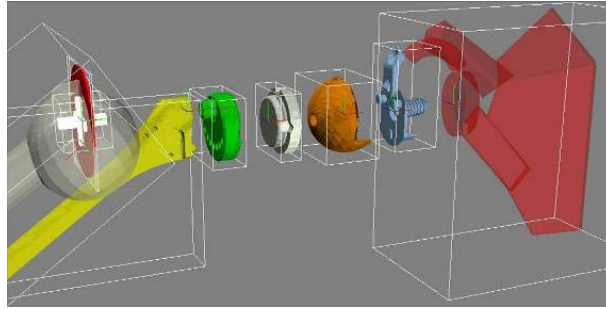


Fig.4. Digital mock-up of the shoulder articulation with integration of prosthesis.

Due to the simple form model of the shoulder, cutting or drilling operations can be simulated easily with logical operators.

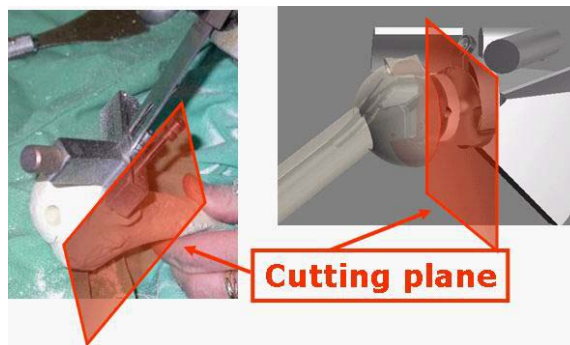


Fig.5. Simulation of bone cutting operation

3 - Pre operative simulation

The digital mock-up of the shoulder articulation with the CAD model of the prosthesis is used to perform a simulation of the surgery operation. A collision detection algorithm between the prosthesis and bones is added in order to measure the mobility of the articulation with respect to the position of the prosthesis and the morphology of the patient. The optimal positioning of the prosthesis can also be deduced from that. Logical operations as subtraction or intersection can be easily computed on this simple model so that the drilling and cutting can be simulated on the model and a virtual operation can be considered with real time performance in a PC calculator.

According to the placement of the prosthesis in the bones, the movements of prosthesis articulation can be performed by the simulation process as shown in the following figures for abduction and adduction movements.

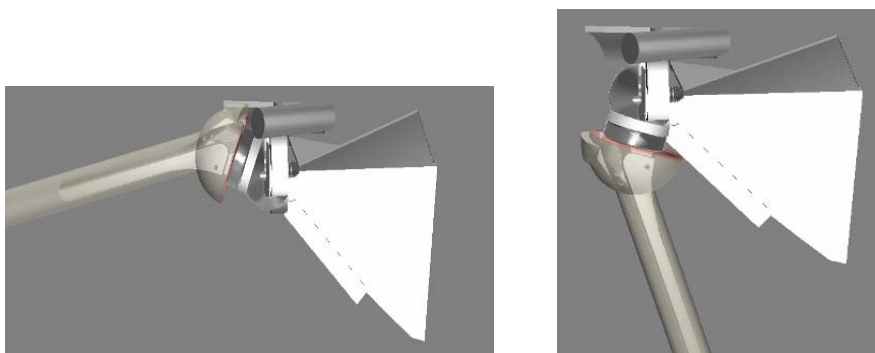


Fig.6. Simulation of shoulder movement with the prosthesis.

In function of the relative position of the prosthesis in the bones, the surgeon can verify the mobility and the feasibility of the operation.

4 - Conclusion and future works

The paper presents a guided tool for the plan of prosthesis surgical operation. The chosen method consists in using a model of shoulder specifically designed for the application of the replacement of shoulder articulation by prosthesis. The model is based on the use of simple forms and has been validated by the surgeon. Then, unnecessary details of the articulation for this application, which are strongly dependant of the patient, are not represented. The model is adapted for each patient because of its parameters which can be extracted from scanner images or radiological images. The use of only radiological images constitutes an interest. The model is very light and can be manipulated very easily. Virtual surgery can be performed interactively.

As a future work, the 3D model and virtual surgery system will be integrated into a real-time augmented reality device which will consist in the spatial positioning of the patient (bones) and surgeon (tools), the registration of the simple model and the real bones of the patient and the development of an ergonomic control interface.

References

- [1] A. Cavaille, "Résultat d'une Prothèse d'Epaule Compatible avec une Destruction Totale de la Coiffe des Rotateurs", Thèse de Doctorat, Université de Dijon, France, 1993.
- [2] W. Maurel, D. Thalmann, « Human shoulder modeling including scapulo-thoracic constraint and joint sinus cones », *Computers&Graphics* 24 (2000), pp. 203-218.
- [3] F. Boudjemaï, P.B. Enberg, J.-G. Postaire, "Surface Modeling by using Self Organizing Maps of Kohonen", *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, vol. 3, pp. 2418-2423, Washington DC (USA), 2003.
- [4] E. Ferley, M. C. Gascuel, D. Attali, "Skeletal Reconstruction of Branching Shapes", *Proceedings of Implicit Surfaces*, pp. 127-142, 1996.
- [5] T. Kohonen, "Self-organized Formation of Topologically Correct Feature Maps", *Biological Cybernetics*, Springer-Verlag, 1982.
- [6] S. Lanquetin, "Etude des Surfaces de Subdivision : Intersection, Précision et Profondeur de Subdivision", PhD Thesis, Université de Bourgogne, October 2004.
- [7] W. E. Lorensen, H. E. Cline, "Marching Cubes: A High Resolution 3D Construction Algorithm", *Proceedings of SIGGRAPH*, 21(4), p. 163-169, 1987.
- [8] S. Muraki, "Volumetric Shape Description of Range Data using Blobby Model", *Proceedings of SIGGRAPH*, pp. 227-235, 1991.
- [9] S. Pontier, "Reconstruction d'Objets Déformables à l'aide de Fonctions Implicites", PhD Thesis, Université de Lyon I, April 2000.
- [10] R. A. Tafilery, "3D Object Modeling using Radial Basis Function", Research Report, EPFL, Lausanne, Switzerland, 2003.
- [11] B. Couteau, P. Mansat, R. Darmana, M. Mansat, J. Egan, "Morphological and Mechanical Analysis of the Glenoid by 3D Geometric Reconstruction using Computer Tomography", *Clinical Biomechanics*, 15(1), Elsevier, 2000.
- [12] E. Bittar, N. Tsingos, M. Gascuel, "Automatic Reconstruction of Unstructured 3D Data: Combining a Medical Axis and Implicit Surfaces", *Proceedings of EUROGRAPHICS*, pp. 457-468, 1995.
- [13] P.Boileau, G.Walch, "The three-dimensional geometry of the proximal humerus", *Journal of bones and joint surgery* 79-B, 857-865, 1997.
- [14] P. Trouilloud, N. Cheynel, M. Benkhadra, O. Trost, H. Atmani, D. Fofi, F. Merienne, E. Baulot, « Modélisation de l'articulation de l'épaule et navigation », 87e Congrès de l'Association des Morphologistes, Constanta, Roumanie, Mai 2005.