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A 3D Vizualization and Simulation of the Individual Human Jaw

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ABSTRACT

A new biomechanical three-dimensional (3D) model for the human mandible based on computer-generated virtual model is proposed. Using maps obtained from the special kinds of photos of the face of the real subject, it is possible to attribute personality to the virtual character, while computer animation offers movements and characteristics within the confines of space and time of the virtual world. A simple twodimensional model of the jaw cannot explain the biomechanics, where the muscular forces through occlusion and condylar surfaces are in the state of 3D equilibrium. In the model all forces are resolved into components according to a selected coordinate system. The muscular forces act on the jaw, along with the necessary force level for chewing as some kind of mandible balance, preventing dislocation and loading of nonarticular tissues. In the work is used new approach to computer-generated animation of virtual 3D characters (called »Body SABA«), using in one object package of minimal costs and easy for operation.

Key words: *human jaw, 3D vizualization, 3D simulation*

Introduction

In the relevant literature several biomechanical models have been proposed[1–4] in the form of planary stationary beams that should satisfy mandibular equilibrium conditions. These models were assumed to be constrained by means of a fixed joint, with the two exeptions in their reports. In reports were temporomandibular joints presented as a movable joints, present the preliminary charater of biomechanical analysis only at finding out just the possibilities of such an analysis.

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In solving a mechanical problem concerning the equlibrium of a free body, it is essential to consider all the forces acting on the body; it is equally important to exclude any force which is not directly applied on the body. Omitting a force or adding an extraneous one would destroy the conditions of equlibrium. Therefore, the fisrt step in the solution of the problem consist in drawing a free-body diagram of the body under consideration.

The necessary and sufficient conditions for the equlibrium (at this moment supposed as a rigid body) may be obtained setting

$$\boldsymbol{F_R = 0} \text{ and } \boldsymbol{M_O^R = 0}.$$

Resolving each force and each moment into rectangular components, we may express the necessary and sufficient conditions for the equlibriom od a body by following six scalar equations:

$$F_{1x} + \ldots + F_{nx} = \sum_{i=1}^{n} F_i \cos\alpha_i = F_{Rx} = 0$$

$$F_{1y} + \ldots + F_{ny} = \sum_{1}^{n} F_i \cos\beta_i = F_{Ry} = 0$$

$$F_{1z} + \ldots + F_{nz} = \sum_{1}^{n} F_i \cos\gamma_i = F_{Rz} = 0$$

$$M_{1x} + \ldots + M_{nx} = \sum_{1}^{n} M_{ix} = M_x = 0$$

$$\mathrm{M}_{1y} + \ldots + M_{ny} = \sum_{1}^{n} M_{iy} = M_y = 0$$

$$\mathrm{M}_{1z} + \ldots + M_{nz} = \sum M_{iz} = M_z = 0$$

Material and Methods

Model

In our case the bone of mandibula is the body under consideration. To make a free-body diagram, we should to isolate a jaw on the only possible manner as it is shown in the figure. A spatial three-dimensional model of mandibla was developed on the basis of macerated human jaw of the person of 30 years. What is nec-

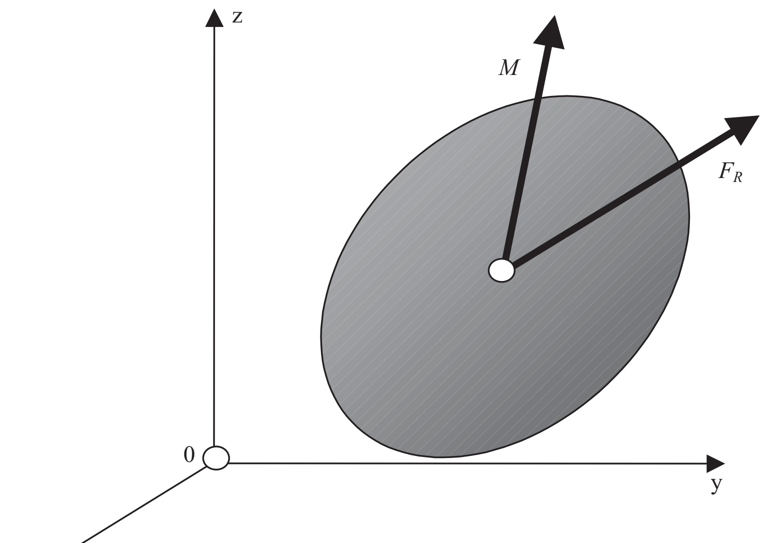

Fig. 1 A general case of the loaded body in the 3D.

essary to extract from a such body? As first a proper dimensions of characteristic points of the model, and then values and angles of the forces as well as moments. After, we are intersting in the possible way of the body movement.

The problems of mechanics of jaw movement is highly complex, especially in the case of spatial movement. Here we simplified movement of the jaw just to the opening of the mouth, what means rotation of mandibla about its »fixed« axsis that passing through temporomandibular joints, as it is shown in the Figure 2.

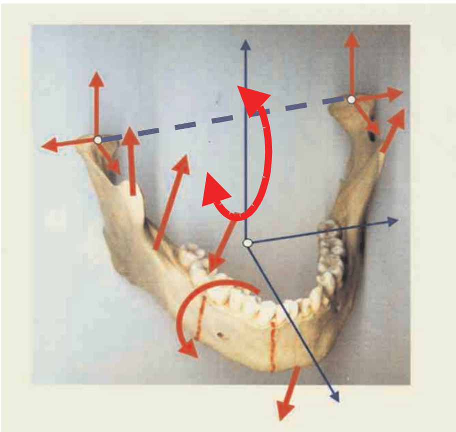

Fig. 2. The general case of simplified loading of human jaw, with choosen coordinate system, and denoted axis of possible rotation of the jaw.

Virtual 3D model in a computer environments

Computer 3D animations of a virtual model and computer-generated environment is defined by the sequences of surfaces, bordered with 3D cloud coordinate points, obtained by means of 3D scanners. This results in a characteristically equal model of the subject, corresponding to a particular dotted cloud, and describing the segmental measures of the real model in question.

The whole of the virtual model of the human segment, in our case the human head, is made on the basis of the knowledge of body volume and cross section, as well as approximate mechanical behavior of the body in movement.

To animate virtual 3D characters it is necessary to:

– design and develop animated skeleton model of the head, with adequate data basis for movements;

– design and model 3D head of character model, to be animated by skelatal movements;

– perform computer animation of the interaction between the virtual model and its near and far environment.

Conventional approach to the animation of 3D segment body models includes the animation of key frames. In this work is used S. Baksa new approach to computer-generated body segment model of virtual 3D characters called »*BodySABA*« using in one object package[7]. This approach offers, relatively modest costs and not much more time spent, for a quite good scanning results.

A virtual model of a real body segment (in our case the bone of mandibla) can be developed employing hand modeling methods, using conventional anthropometric measuring procedures, or by import of contemporary 3D digitally scanned real models[7].

To design and model a virtual character using hand techniques and at adequately high level of quality, it is necessary to be familiar with anthropometric characteristics of the human body used as a starting point. Software package *ERSABA 4.2.*, developed by I. Baksa, was used to determine anthropometric values of the model. The software calculates, using some measured values, twenty-two characteristic anthropometric values, ne-

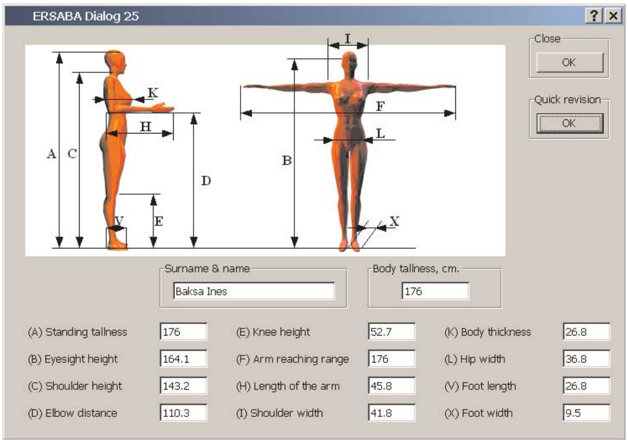

Fig. 3. On-screen presentation of characteristic antropometric values of a real model, 176 cm tall, in standing posture.

cessary for conventional CG modeling of digital virtual characters, Figure 3[7].

Based on photographs of a real SFG model (P. Antičević), and using conventional CG techniques, digital virtual character model is designed and constructed. Figure 4 shows the phases of constructing the segment of the head of the virtual model.

A contactless coordinate-measuring device, so called digital 3D scanner, can be used instead of conventional tape measure and the equipment for defining human body dimensions and volumes. The result of stereoscopic measurements of the body is a 3D cloud of coordinate points, which represent the body measured. These measurements enable easy construction of a digital virtual model. The measuring system employed enhances accuracy and efficiency, compared to conventional methods. The results obtained are not just the object measurements, but also its forms and volumes.

Digital 3D scanners consist of one or more (most modern up to four) digital high-resolution measuring modules, translator units for moving the device, and quite often software solutions for determining 3D characteristics of the objects to be measured. As far as construction and size are concerned, there are small desktop models, ideal for digitizing smaller objects for CAD/CAM industries, de-

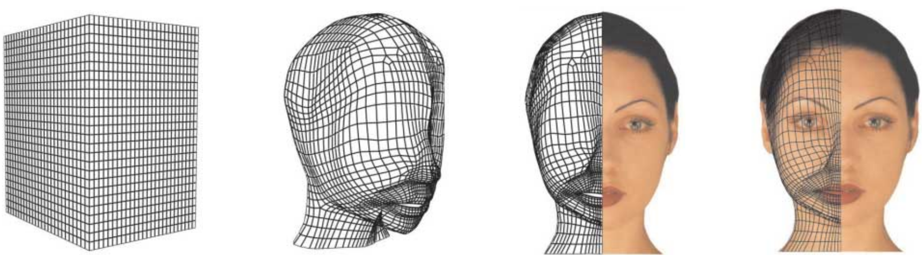

Fig. 4. Phases in hand modeling of a virtual 3D character's head[7].

velopment of prototypes, research, animations, special effects, medicine and reverse engineering[5]. Mini models are used to digitize medium size objects, where measuring accuracy and preciseness are important factors. This type of scanners offers best results in medical research, anthropometry, esthetic surgery and artistic manufacturing of portrait sculptures. This type of a 3D scanner is used to digitize the face of the fashion model I. Gomerčić[7]. The result is shown in Figure 5.

Body models obtained using a 3D scanner are ideal for 3D computer animators, ergonomists, anthropologists, physicians, designers, and other professionals who require a precise and reliable 3D model of the body in question. The equipment described can, in some 15 seconds, scan an average adult human body in three dimensions, and record more than 200,000 measuring points defined by coordinates, as seen in Figure 6. As real actors are an agglomeration of highly diverse variants of shapes and body sizes, the above density of measuring points is adequate to calculate and present on-screen a reliable virtual model. The set of points scanned corresponds with the 3D model body and ideally presents the subject in unit time[7].

Attributing parameters to unorganized individual coordinate points of a 3D measuring cloud. The results obtained through computerized investigations make possible to construct a surface model out

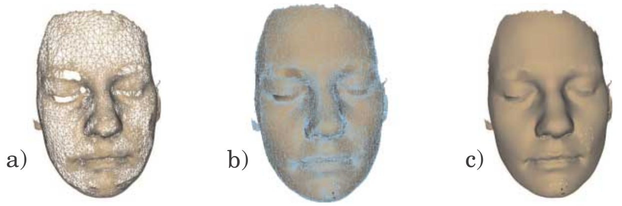

Fig. 5. Perspective of 3D scanned and triangulated model of a face a) in Wireframe, b) Smooth and Highlights presentation with Edged Face option included and c) Smooth and Highlights presentation.

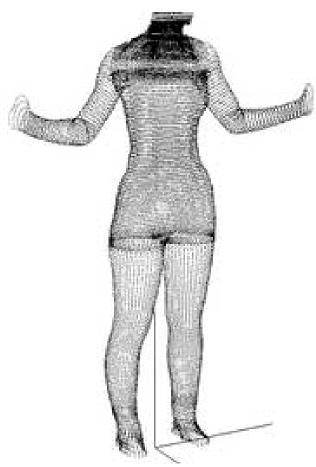

Fig. 6. 3D cloud of coordinate points of a virtual model of the subject scanned.

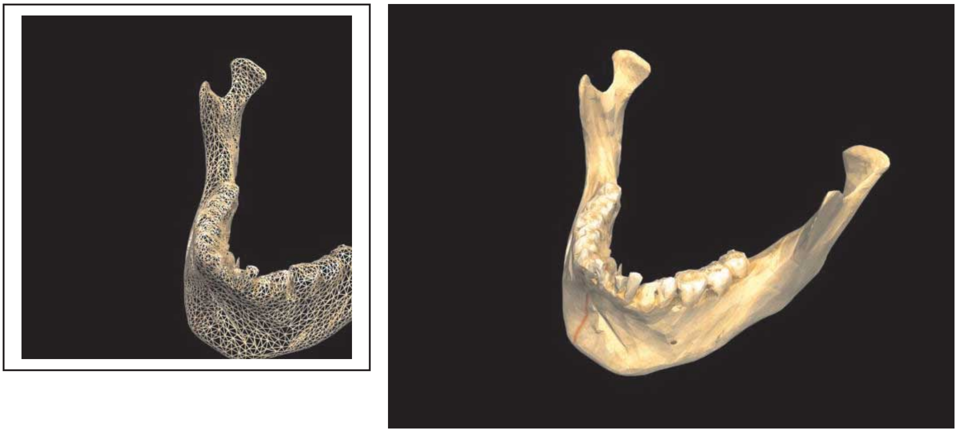

Fig. 7. Presentation of the analysed mandibla with mesh configuration and later as smooth and highlights presented 3D model.

of a dotted 3D cloud, or constructing a characteristic arc, based on spatially coordinate defined points[6]. To construct a digital model based on 3D coordinate measuring cloud, it is necessary to define the characteristics used in a mathematical triangular interpolation[7]. Either surface definition or volume definition can be used as methods in defining these characteristics.

Most researchers, in designing a geometrical model employing reverse engineering, focus upon the procedure of taking a series of surfaces defined by coordinate points of a 3D measuring cloud. This results in a characteristically equal model of the actor, corresponding to a particular dotted cloud, and describing the bodily measures of the character in question. The whole of the virtual model of human body is made on the basis of the knowledge of body volume and cross section, as well as mechanical behavior of the body in dynamic movements.

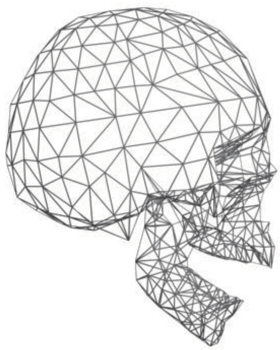

Fig. 8. Adapted mandibla to the head skelton showing a possibility of jaw rotation.

Results

Because of the preliminary character of the present biomechanical analysis aimed only at finding out just a possibilities of such an analysis, we analysed only one macerated mandibla. The adequte presentation is given in Figure 7.

Later we adopted such a mandibla to the head skeltom, to show a possible movement of the jaw, as it is presented in Figure 8.

The last set of Figure 9, show us a composition of 3D mandibla involved in the cloud of selected face.

Conclusions

Using conventional, hand, or more modern (but more expensive), digitally scanned 3D anthropometric human body characteristics, it is possible to construct a digital 3D biomechanical model, with adequate kinematic-dynamic rules of internal skeleton construction movement.

Computer animations of characters and virtual environments are broadly used in entertainment, for practical and educational purposes. Some of the most outstanding areas include advertising, archeology, fine arts, bioengineering, entertainment, movies, forensics, medicine, multimedia, simulation, scientific simu-

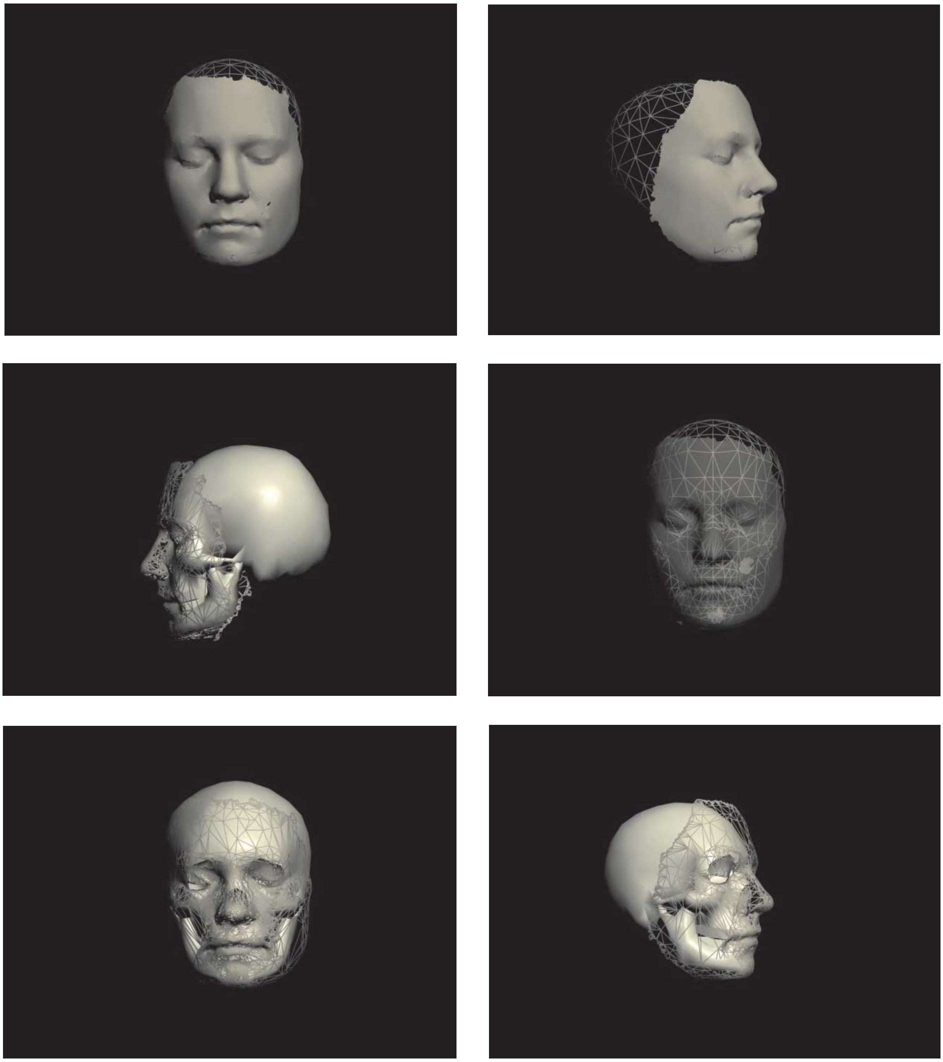

Fig. 9. Final results of the presentation of 3D mandibla that is Jointed with head skelton and soft tissue of the head.

lations and visualizations, space exploration, sports, TV, etc.

Computer animators should possess extensive knowledge of anthropological and biomechanical characteristics of human body, should be experts in design and construction of virtual 3D characters, but should also a feeling for time, mechanical behavior and movements of both living and non-living systems. They should be able to recognize, define and produce the feeling of liveliness and neutrality, so as to be able to give virtual life to their cyber subjects.

Future developments of the software application *BodySABA* will result in improved automatic defining of anthropometric and ergonomic characteristics of biomechanical models and digital subjects, as well as in better matching of anatomic and psycho-physiological investigations of human body, based on 3D virtual simulations and analysis of virtual characters. The purpose of future versions of software accessory *CLOSABA 0.4.* is to develop more advanced computer-based simulation for biomechanical use in a different bioengineering problems.

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3D VIZUALIZACIJA I SIMULACIJA MANDIBULE ČOVJEKA

SAŽETAK

Prikazan je novi biomehanički trodimenzionalni (3D) model mandibule čovjeka temeljen na računarski stvorenom virtualnom modelu. Upotrebom mapa dobivenih posebnim vrstama fotografija lica moguće je dodati osobnost virtualnoj osobi dok računarska animacija omogućuje pokrete i osobine unutar vremena i prostora virtualnog svijeta. Jednostavan dvodimenzionalni model čeljusti ne može objasniti biomehaniku pri čemu su mišićne sile kroz okluziju i površine kondila u stanju trodimenzionalne ravnoteže. U modelu sve sile su raščlanjene u dijelove ovisno o odabranom koordinatnom sustavu. Mišićne sile djeluju na čeljust kao i razina snage nužna za žvakanje kao vrsta ravnoteže mandibule, sprečavajući njezinu dislokaciju i opterećenje nezglobnih struktura. U radu je korišten novi pristup računarski stvorene animacije virtualnih 3D likova (zvan »BodySABA«) koji nije skup i jednostavan je za rukovanje.

Ključne riječi: mandibula, 3D vizualizacija, 3D simulacija