Primena metoda veštačke inteligencije za rekonstrukciju geometrijskog modela tela donje vilice čoveka

Jelena Mitić^{1*}, Nikola Vitković¹, Miodrag Manić¹, Slađana Petrović², Mohammed Rashid³, Miroslav Trajanović¹

¹Mašinski fakultet, Univerzitet u Nišu, Srbija

²Medicinski fakultet, Univerzitet u Nišu, Srbija

³University of Al Muthana, Iraq

Personalizovana medicina teži da se medicinski tretman prilagodi svakom pacijentu. Tretman fraktura kostiju je najbolji ukoliko se koriste personalizovani implantati. Za njihovo projektovanje neophodno je postojanje parametarskih 3D modela kostiju koje su prilagođene konkretnom pacijentu. U radu je najpre metodom anatomskih entiteta, uz primenu višestruke regresije, kreiran 3D parametarski model tela donje vilice čoveka, definisan kao model tačaka. Uspostavljene su matematičke relacije između specifičnih parametara, očitanih sa medicinskih slika i anatomskih orijentira (koordinata tačaka). Radi dobijanja veće tačnosti u predikcij parametara u ovom radu se prikazuje primena metode veštačke inteligencije - neuronskih mreža za kreiranje parametarskog 3D modela donje vilice čoveka. Geometrijska tačnost kreiranih parametarskih modela testirana je primenom analize devijacije u CAD softveru CATIA. Analiza devijacije izvršena je između inicijalnog i rezultujućeg modela. Rezultati analize su i više nego zadovoljavajući.

Ključne reči: Donja vilica, Parametarski model, Veštačke neuronske mreže

1. UVOD

U okviru projekta VIHOS (Virtuelni koštano zglobovi čoveka i njegova primena u prekliničkoj i kliničkoj praksi) na Mašinskom i Medicinskom fakultetu Univerziteta u Nišu se radi na razvoju 3D parametrizovanih geometrijskih i simulacionih modela kostiju, kao i unutrašnjih i spoljašnjih fiksatora i skafolda. Modeli su izrađeni analizom snimaka određenih kostiju i uspostavljene su korelacije za geometrijsko definisanje 3D modela kostiju i u slučajevima kada nema dovoljno podataka sa snimaka, ili njih uopšte nema. Za akviziciju podataka o anatomskim strukturama (u ovom slučaju kosti čoveka), u većini slučajeva se koriste kompjuterska tomografija i magnetna rezonanca, jer omogućavaju različite vrste obrade podataka i precizne prostorne informacije [1]. Rezultat obrade medicinskih slika je trodimenzionalni (3D) geometrijski model anatomskih struktura, sa mogućnošću primene u računarskim aplikacijama u biomedicinskim studijama: preoperativnoj pripremi, simulaciji hirurških intervencija, planiranju i praćenju oporavka pacijenta, obuci medicinskog osoblja, proizvodnji osteofiksacionog materijala, itd [2, 3].

Sa tehničkog aspekta, geometrijsko modelovanje donje vilice čoveka (lat. *Mandible*) predstavlja veoma složen proces zbog složenih formi koje definišu njen oblik. Direktni postupak (tradicionalan pristup) kreiranja 3D geometrijskog modela donje vilice je nemoguće primeniti zbog nepoznavanja oblika površine i složene geometrije. Sa druge strane, indirektni postupak (reverzno modeliranje) zasniva se na upotrebi volumetrijskih medicinskih snimka, čiji kvalitet znatno utiče na rezultujući geometrijski model [4].

Donja vilica zbog svoje lokalizacije u skeletnom sistemu čoveka je mesto čestih fraktura različite etiologije. Pored preloma, deformacije i oboljenja mogu biti prisutna na donjoj vilici onemogućavajući kreiranje snimka

kompletne kosti. Neprecizne i nepotpune informacije o morfologiji i geometriji kosti, dovode do dodatnih problema koji mogu uticati na kvalitet rezultujućeg geometrijskog modela.

Rekonstrukcija oštećene ili nedostajuće anatomske strukture zahteva proučavanje geometrije, morfologije i morfoloških varijacija. Tehnika ogledala [5] je jedna od mogućih rešenja za rekonstrukciju manjih i geometrijski jednostavnijih anatomskih struktura. Potencijalno rešenje u rekonstrukciji kompletnog 3D geometrijskog modela donje vilice je i primena statističkih modela. Statistički modeli zasnivaju se na predikciji oblika modela, međutim varijacije oblika i geometrije izvan ulaznih podataka se ne mogu precizno predvideti [6].

U okviru ove studije biće prezentovan postupak kreiranja 3D parametarskog modela tela donje vilice čoveka reverznim inženjeringom. 3D parametarski model zasnovan je na primeni metode anatomskih entiteta (eng. Method of Anatomical Features - MAF), koja se do sada uspešno primenjivala u kreiranju ostalih kosti u skeletnom sistemu čoveka [7]. Cilj ovih istraživanja je unapređenje MAF metode, tačnije u primeni tehnika veštačke inteligencije u cilju dobijanja veće tačnosti u predikciji modela u odnosu na ostale statističke metode.

2. MATERIJAL I METODA

Proces kreiranja 3D parametarskog modela donje vilice čoveka zasnovan je na MAF metodi koja se sprovodi u nekoliko koraka prikazanih na slici 1 [7].

Ulazni podaci za geometrijsku analizu donje vilice su prikupljeni sa osamnaest CT snimaka zdravih muških mandibula dobijenih na Toshiba MSCT skenerom Aquillion u skladu sa standardnim protokolom. Nakon segmentacije, CT podaci se konvertuju u odgovarajući format (STL) i uvoze u softverski paket CATIA. U CAD aplikaciji CATIA vrši se čišćenje i ozdravljenje uvezenog

Slika 1. Proces kreiranja parametarskog modela kosti čoveka

modela u cilju kreiranja poligonalnog modela podesnog za dalju upotrebu.

2.1. Definisanje referentnih geometrijskih entiteta

U cilju definisanja anatomskih orijentira i referentnih geometrijskih entiteta sprovodi se postupak morfometrijske analize. Postupak morfometrijske analize izvršen je na svim poligonalnim modelima u skladu sa topologijom i geometrijom modela. Referentni geometrijski orijentiri (tačke, ose, linije, ravni) predstavljaju bazu za kreiranje konstitutivnih geometrijskih entiteta koji na najbolji mogući način aproksimiraju geometriju modela. Na slici 2 predstavljene su ravni koordinatnog sistema i karakteristične anatomske tačke definisane na poligonalnom modelu. Položaj anatomskih orijentira je predhodno definisan [8].

Slika 2. Anatomske orijentire na donjoj vilici

2.2. Definisanje anatomskih tačaka i morfometrijskih parametara

Položaj karakterističnih anatomskih tačaka na donjoj vilici poslužio je za definisanje 10 centralnih i bilateralnih morfometrijskih parametara, koji u potpunosti mogu da opišu konfiguraciju donje vilice [8]. Morfometrijski parametri prikazani su na slici 3, njihova definicija detaljno je predstavljena [8].

3D parametarski model donje vilice predstavlja geometrijski model definisan kao oblak tačaka. Za svaku tačku u oblaku tačaka postoji parametarska funkcija koja je opisuje.

Slika 3. Morfometrijski parametri

Na poligonalnom modelu donje vilice izdvojeno je 56 anatomskih tačaka (na telu donje vilice) kreiranih na spline krivama u skladu sa geometrijom i morfologijom kosti (slika 4). Izmerene vrednosti koordinata anatomskih tačaka u odnosu na usvojeni koordinatni sistem predstavljaju ulazne podatke za statističku analizu.

Slika 4. Definicija anatomskih tačaka na poligonalnom modelu donje vilice

2.3. Statistička analiza

Koristeći skup ulaznih podataka (izmerenih vrednosti morfometrijskih parametara) i izlaznih (izmerenih vrednosti koordinata anatomskih tačaka) razvija se matematički model, sa ciljem uspostavljanja veze (matematičke jednačine) između ulaznih i izlaznih promenljivih.

Kod MAF metode uspostavljanje relacije između ulaznih i izlaznih promenljivih izvršeno je primenom višestruke regresione analize. Opšti oblik regresione jednačine je:

$$C = \beta_0 + \beta_1 C_1 + \beta_2 C_2 + \beta_3 C_3 + \dots + \beta_p C_p + \varepsilon \quad (1)$$

gde: C – zavisna promenljiva, C_{1-p} – vrednosti morfometrijskih parametara izmerenih na svakom uzorku donje vilice, β – izračunati parametar i ε – greška merenja.

U cilju minimalizacije broja morfometrijskih parametara, ali ne i kvaliteta podataka, izvršena je analiza uticaja parametara na tačnost modela. Visoke vrednosti prostih koeficijenta korelacije između dve nezavisne promenljive ($C1$ i $C4$), uslovile su isključenje promenljive $C4$ iz matematičkog modela [9].

Parametarsko modelovanje donje vilice čoveka zasniiva se na razvoju matematičkog modela, odnosno matematičke jednačine. Kvalitet i tačnost matematičkog modela zavisi od složenosti izabrane funkcije i od vrste matematičkog modela [10]. Višestrukom regresionom analizom izvršeno je statističko ocenjivanje matematičkog modela. Koristeći izabranu funkciju (polinom nultog stepena), matematički model je ocenjen kao adekvatan i rešenja dobijena ovim matematičkim modelom se u opsegu vrednosti adekvatnih promenljivih. Međutim, sam postupak kreiranja parametarskog modela sastoji se od velikog broja ulaznih podata, tako da su nam u tu svrhu neophodni složeniji matematički modeli. Složeniji matematički model omogućava veću tačnost u predikciji.

2.4. Razvoj nove metode za predikciju

Jedna od alternativa za kreiranje matematičkih modela je i primena sve popularnije tehnike veštačke inteligencije.

Najčešće korišćena tehnika veštačke inteligencije je tehnika veštačkih neuronskih mreža (eng. Artificial Neural Networks - ANN). Veze, kojim su povezani neuroni, predstavljaju snagu neuronske mreže, čijim se podešavanjem vrši obučavanje sistema do dostizanja željenih rezultata.

Uspostavljanje preciznih veza između ulaznih i izlaznih promenljivih je izvršeno primenom veštačkih neuronskih mreža. Na slici 5. predstavljena je šema modela ANN sa ulaznim podacima (izmerene vrednosti morfometrijskih parametara) i izlaznim (vrednosti X, Y i Z koordinate).

U prvoj fazi analize definisan je skup pravila po kome se sprovodi učenje mreže i skup ulazno – izlaznih parova. Ulazno - izlazni parovi predstavljaju primere koji se predstavljaju mreži kako bi stekla određeno znanje. Ulazni (nezavisni) parametri u ovom slučaju predstavljaju vrednosti morfometrijskih parametara, dok su izlazni (zavisni) izmerene vrednosti koordinata anatomskih tačaka. Za kreiranje matematičkog modela korišćeno je 75% slučajno izabranih podataka, dok je preostalih 25% iskorišćeno za validaciju. Kako bi se izbegla nestabilnost neuronske mreže, pre faze učenja izvršeno je preprocesiranje (skaliranje) ulazno-izlaznih podataka u cilju smanjenja raspona vrednosti. Bezdimenzioni oblik sa rasponom vrednosti od 0 do 1 ili -1 do 1 se koristi u zavisnosti od izbora prenosive funkcije. U ovom slučaju, kreiran je model ANN sa normalizacijom vrednosti u rasponu od 0 do 1 kojem odgovara sigmoidna prenosna funkcija. Sigmoidna aktivaciona funkcija izabrana je u sakrivenom i izlaznom sloju. Kako bi se osiguralo dobre karakteristike modela ANN u smislu tačnosti predikcije, metodom “probe i greške” izvršen je izbor parametara arhitekture (broj sakrivenih slojeva i broj sakrivenih neurona). ANN model je razvijen i treniran primenom

algoritma propagacije greške unazad (eng. Backpropagation – BP). Treniranje mreže je prekinuto kada nije bilo daljeg smanjenja greške između očekivanih i dobijenih izlaznih vrednosti. Srednja kvadratna greška (eng. Mean Squared Error - MSE) korišćena je u cilju određivanja predikcione tačnosti modela i praćena je tokom procesa treniranja.

Slika 5. Šema modela ANN

3. REZULTAT I DISKUSIJA

Obuka ANN modela za predikciju koordinata anatomskih tačaka izvršena je pomoću procedure *trainlm* u softveru MATLAB. U tabeli 1 predstavljeni su parametri treniranja i parametri arhitekture koji su se koristili za razvoj modela.

Tabela 1. Parametri treniranja i arhitekture

Broj ulaznih neurona	9
Broj sakrivenih neurona	50
Broj izlaznih neurona	3
Algoritam	BP
Momentum	0.625
MSE	0.001
Broj epoha	1464
Trans. fun. u sakr. sloju	logsig
Trans. fun. u izlaz. sloju	logsig

Bitno je napomenuti da je za određivanje predikcione tačnosti modela pored srednje kvadratne greške, korišćen još jedan kriterijum – razlika između dobijenih vrednosti predikcije i izmerenih vrednosti. U tabeli 2. predstavljene su statističke greške ANN modela.

Tabela 2. Performanse modela ANN

ANN	MSE		Odstupanje (mm)		
	Skup za treniranje	Skup za testiranje	X	Y	Z
1	0.001	0.024	0.296	0.257	0.388

Geometrijska tačnost kreiranih modela testirana je analizom devijacije između ulaznih i rezultujućih modela u CAD softveru CATIA. Analiza je izvršena na rezultujućim modelima kreiranih primenom višestruke regresije (red 1 u tabeli 3) i primenom veštačke neuronske mreže (red 2 u tabeli 3).

Tabela 3. Analiza devijacije

Analiza devijacije (mm)		
Uzorak	1	2
1	1.53	0.30
2	1.03	0.38
3	2.38	0.33
4	2.06	0.35
5	1.97	0.38

6	1.74	0.37
7	2.05	0.32
8	1.64	0.36
9	1.82	0.33
10	1.62	0.38
11	1.97	0.35
12	1.74	0.36
13	1.06	0.34
14	2.11	0.35
15	1.67	0.33
16	2.57	0.24
17	1.45	0.13
18	1.56	0.26

Rezultati iz analize devijacije ukazuju da maksimalna vrednost odstupanja kod modela kreiranih primenom višestruke regresije je 2.38 mm, dok kod modela kreiranih primenom veštačke neuronske mreže iznosi 0.38 mm. Na osnovu rezultata komparativne analize prikazanih u tabeli 3. može se zaključiti da nova metoda za predikciju položaja anatomskih tačaka u potpunosti opravdala očekivanja. Maksimalna devijacija površinskog modela tela (jednog dela) donje vilice kreiranog primenom veštačke neuronske mreže prikazana je na slici 6.

Slika 6. Maksimalna devijacija površinskog modela tela donje vilice i ulaznog modela

4. ZAKLJUČAK

Preliminarna studija ukazuje da nov pristup u razvoju metode geometrijskog modeliranja tela donje vilice čoveka predstavlja znatan doprinos u poboljšanju geometrijske i anatomske tačnosti rezultujućih modela.

Rezultujući modeli zasnovani na tehnici veštačke neuronske mreže imaju nivo preciznosti koji je klinički prihvatljiv i kao takvi imaju mogućnost široke primene: u obuci medicinskog osoblja, preoperativnom planiranju, kreiranju implantata, itd.

Razvojem i primenom novog pristupa otvoreni su predlozi za dalja istraživanja usmerena u nekoliko pravaca: u kreiranju geometrijskog modela kompletne donje vilice, preciznijoj analizi morfoloških karakteristika i primeni drugih matematičkih modela u cilju postizanja veće geometrijske tačnosti modela.

ACKNOWLEDGEMENTS

The paper presents results of the project III 41017 Virtual Human Osteoarticular System and its Application in Preclinical and Clinical Practice sponsored by the Ministry of Education, Science and Technological Development of the Republic of Serbia for the period of 2011- 2018.

REFERENCES

- [1] H. Lamecker, S.Zachow, A. Wittmers, B. Weber, H. Hege, B. Elsholtz and M. Stiller, "Automatic Segmentation of Mandibles in Low-Dose CT-Data", Int. J. Comput. Assist. Radiol. Surg, Vol. 1(1), pp. 393–395, (2006)
- [2] M. Manić, Z. Stamenković, M. Mitković, M. Stojković and D. Shepherd, "Design of 3D model of customized anatomically adjusted implants", F. U. Mech. Eng., Vol.13(3), pp. 269-282, (2015)
- [3] J. Watson, M. Hatamleh, A. Alwahadni and D. Srinivasan, "Correction of Facial and Mandibular Asymmetry Using a computer aided design/computer aided manufacturing Prefabricated Titanium Implant", J. Craniofac. Surg., Vol.25 (3), pp. 1563, (2014)
- [4] J. Mitić, N. Vitković, M. Manić, M. Trajanović, S. Petrović and S. Arsić, "Reverse modelling of the human mandible 3D geometric model", Vojnosanit. Pregl., Online-First, pp.63-63, (2018)
- [5] S. Benazzi, E. Stansfield, O. Kullmer, L. Fiorenza and G. Gruppioni, "Geometric morphometric methods for bone reconstruction: the mandibular condylar process of Pico della Mirandola", Anat. Rec., Vol. 292(8), pp. 1088–1097, (2009)
- [6] S.G. Kim, W.J. Yi, S.J. Hwang, S.C. Chio, S.S Lee and M. S. Heo, "Development of 3D statistical mandible models for cephalometric measurements", Imaging Sci. Dent., Vol. 42 (3), pp. 175-182 (2012)
- [7] M. Majstorović, M. Trajanović, N. Vitković and M. Stojković, "Reverse engineering of human bones by using method of anatomical features", CIRP Ann. - Manuf. Techn., Vol. 62(1), pp. 167-170 (2013)
- [8] S. Arsić, P. Perić, M. Stojković, D. Ilić, M. Stojanović, Z. Ajduković and S. Vučić, "Komparativna analiza linearnih morfometrijskih parametara humane mandibule dobijenih direktnim i indirektnim merenjem", Vojnosanit. Pregl., Vol.65(7), pp. 839-846, (2010)
- [9] J. Mitić, N. Vitković, M. Manić and M. Trajanović, "Improvement of the geometrical accuracy of the human mandible body parametric model", ICIST 2018 Proceedings, 8th International Conference on Information Society and Technology, Kopaonik (Serbia), 11-14 Mart 2018, pp. (2018)
- [10] M. Madić and M. Radovanović, "Methodology of developing optimal BP-ANN model for the prediction of cutting force in turning using early stopping method", F. U. Mech. Eng., Vol. 9(1), pp. 21-32, (2011)

Application of Artificial Intelligence Methods for the Reconstruction of the Geometric Model of the Body of the Human Mandible

Jelena Mitić^{1*}, Nikola Vitković¹, Miodrag Manić¹, Slađana Petrović², Mohammed Rashid³, Miroslav Trajanović¹

¹Faculty of Mechanical Engineering, University of Niš, Serbia

²Medicinski fakultet, Univerzitet u Nišu, Srbija

³University of Al Muthana, Iraq

The tendency of personalized medicine is to adapt the medical treatment to each patient. Bone fracture treatment is best if personalized implants are used. For their design, there is a need for parametric 3D bone models that are adapted to a specific patient. In this the paper, the 3D parametric model of the body of the human mandible, defined as a model of points was created using the method of the anatomical entities, with the application of multiple regression. Mathematical relations between specific parameters (dimensions which are read on medical imaging) and anatomical orientations (measured values of coordinates of points) were established. In order to obtain greater accuracy in parameter prediction, this paper presents the application of the artificial intelligence method - neural networks for creating the 3D parametric model of the human mandible. The geometric accuracy of the created parametric models was tested using the deviation analysis in CAD software CATIA. The deviation analysis was performed between the initial and the resulting model. The results of the analysis are more than satisfactory.

Keywords: Human mandible, 3D parametric model, Artificial neural networks

1. INTRODUCTION

Within the framework of the VIHOS project (Virtual Human Osteoarticular System and its Application in Preclinical and Clinical Practice), two faculties, the Faculty of Mechanical Engineering and The Faculty of Medicine, the University of Niš are working on the development of 3D parametrized geometric and simulation models of the human bones, as well as on internal and external fixation and scaffolds. The geometrical models were created by analyzing the medical images of specific bones and correlations were established for the geometric definition of the 3D model of bones even in cases where there is not enough information from the medical images, or they are not present at all. In most cases, computer tomography and magnetic resonance were used for the acquisition of information on the anatomical structures (in this case human bones) because they allow different types of data processing and precise information [1]. The result of the processing of medical images is the three-dimensional (3D) geometric model of anatomical structures, with the possibility of utilizing them in computer applications in biomedical studies: preoperative planning, surgical simulation, post-operative recovery of the patient, design of osteofixation material, etc. [2, 3].

From a technical point of view, the geometric modeling of the human mandible (lat. *Mandible*) is a very complex process due to the complex form that defines its shape. The direct procedure (traditional approach) of creating the 3D geometric model of the human mandible is impossible to apply due to the lack of knowledge of the shape of the surface and the complex geometry. On the other hand, the indirect procedure (reverse modelling) is based on the use of volumetric medical images, whose quality significantly influences the resulting geometric model [4].

Due to its localization in the skeletal system of a man, the human mandible is the site of frequent fractures of

different etiology. In addition to fractures, deformations and diseases may be present on the mandible/thus hampering the creation of an image of a complete bone. Incorrect and incomplete information about morphology and geometry of human bones leads to additional problems that can affect the quality of the resulting geometric model.

The reconstruction of the damaged or missing part of the bone requires the study based on geometry, morphology and morphological variations. The method of mirror imaging [5] is one of the possible solutions for the reconstruction of smaller and geometrically simpler anatomical structures. The potential solution in the reconstruction of the complete 3D geometric model of the patient's bone is the application of statistical models. Statistical models are based on a prediction form of a model; however, shape variations and geometry outside the input data cannot be accurately predicted [6].

This paper will explain the procedure of creating the parametric model of the body of human mandible with reverse engineering. The 3D parameter model is based on the Method of Anatomical Features (MAF), which has so far been successfully applied in the creation of the geometrical models of various bones in the human skeletal system [7]. The goal of this research is to perfect the MAF method in comparison to other statistical methods, especially in applying the MAF method in artificial intelligence techniques in order to achieve higher accuracy in predicting the model.

2. MATERIAL AND METHOD

The process of creating the 3D parametric model of human mandible is based on the MAF method. The steps to creating a parametric model are shown in Figure 1 [7].

The input data for the geometric analysis of the human mandible were collected from eighteen CT images of healthy male mandibles obtained on the Toshiba MSCT

*Corresponding author: Aleksandra Medvedeva 14, Niš, jelena.mitic153@gmail.com

Figure1: Steps of creation 3D parametric model

Aquillion Scanner according to the standard flow. After the segmentation, CT data was converted to the appropriate format (STL) and imported into the CATIA software package. In order to create the most precise polygonal model cleaning and healing of acquired point cloud were performed.

2.1. Definition of the referential geometrical entities

In order to define anatomical orientations and referential geometric entities, the morphometric analysis was performed on all polygonal models. Referential geometric entities (points, axes, lines, planes) represent a base for creating constituent geometric entities which in the best possible way approximate the topology and geometry of the model of human bone. Planes of the coordinate system and the characteristic anatomic points defined on the polygonal model are represented in Figure 2. The position of anatomical orientations has been previously defined [8].

Figure 2: Referential geometrical entities on human mandible

2.2. Definition of the anatomical points and morphometric parameters

In accordance with the anatomical and morphological characteristics of the bone, the anatomical characteristic points were used to define 10 central and bilateral morphometric parameters, which can fully describe the configuration of the human mandible [8]. The morphometric parameters are shown in Figure 3, and their definition is presented in detail [8].

The parametric model of the human mandible is a geometric model defined as a point cloud. Each point in point cloud is defined by a parameter function.

Figure 3: Morphometric parameters

On the polygonal model of the mandible body, 56 anatomical points were created on the spline curves in accordance with the geometry and morphology of the bone (Figure 4). The measured values of the coordinates of the anatomical points in relation to the predefined coordinate system represent the input data for the statistical analysis.

Figure 4: Definition of the anatomical points on polygonal model of the body of the human mandible

2.3. Statistical analysis

Using a set of input data (measured values of morphometric parameters) and output (measured values of coordinates of anatomic points), a mathematical model is developed, with the aim of establishing a connection (mathematical equation) between input and output variables.

With the MAF method, the establishment of the relationship between input and output variables was performed using a multiple regression analysis. The general form of the regression equation is:

$$C = \beta_0 + \beta_1 C_1 + \beta_2 C_2 + \beta_3 C_3 + \dots + \beta_p C_p + \varepsilon \quad (1)$$

where: C - dependent variable, C_{1-p} - values of morphometric parameters measured on each sample, β - parameters to be assessed and ε - error measurement.

In order to minimize the number of morphometric parameters, but not the quality of the data, an analysis of the influence of parameters on the accuracy of the model was performed. The high values of the correlation coefficients between the two independent variables ($C1$ and $C4$) caused the elimination of an independent variable $C4$ from the mathematical model [9].

Parametric modeling of the human mandible is based on the development of a mathematical model, or a mathematical equation. The quality and accuracy of the mathematical model depends on the complexity of the chosen function and on the type of a mathematical model [10]. A multiple regression analysis provided a statistical evaluation of the mathematical model. Using the chosen function, the mathematical model was estimated to be adequate, and the solutions obtained by this mathematical model were in the range of the values of the corresponding variables. However, the process of creation a parametric model consists of a large number of the input data, so for this purpose we need more complex mathematical models. A more complex mathematical model allows for greater accuracy in the prediction.

2.4. Development of a new prediction method

One of the alternatives for creation mathematical models is the application of popular techniques of artificial intelligence.

The most commonly used artificial intelligence technique is the Artificial Neural Networks (ANN). The neurons are linked by weighted connections where the knowledge possessed by the networks is held.

Establishing precise connections between input and output variables was performed using artificial neural networks. The ANN model with input data (measured values of morphometric parameters) and output data (values of X, Y and Z coordinates) is shown in Figure 5.

The first phase of the analysis defines: the set of rules used in the training of the ANN and the set of input - output data. Input - output data represent examples that were presented to the network in order to acquire knowledge. The input (independent) parameters in this case represent the values of the morphometric parameters, while the output (dependent) values of the coordinates of the anatomical points were measured. To create a mathematical model, 75% of randomly selected data was used, while the remaining 25% was used for a validation. To avoid the instability of the neural network, the pre-processing (scaling) of input-output data was performed before the training process in order to reduce the range of values. Usually, the data preparation was done in the form of data normalization (scaling) to some standard ranges such as 0 to 1 or -1 to 1. In this case, all the inputs and the desired outputs are normalized within the range from 0 to 1 corresponds to a sigmoid transfer functions. Sigmoid transfer functions were selected in a hidden and output layer. The most elementary method for selection of architectural parameter settings (the number of hidden layers and the number of hidden neurons) is the use of a trial/error method. ANN models were developed and trained using the backpropagation (BP) algorithm. The

training of the ANN was interrupted when there was no further reduction in the error between the expected and the resulting output values. Mean sum of Squared Error (MSE) was used to evaluate the predictive accuracy of the ANN model.

Figure5: The ANN model with input and output data

3. RESULTS AND DISCUSSION

The training of the ANN models for the predicate of coordinates of anatomic points was carried out using the procedure *trainlm* in MATLAB. Table 1 summarizes the ANN training parameters and architectural parameters used for developing the ANN models.

Tabela 1: ANN training parameters

Number of input neurons	9
Number of hidden neurons	50
Number of output neurons	3
Algorithm	BP
Momentum	0.625
MSE	0.001
Number of training epochs	1464
Trans. fun. in hidden layer	logsig
Trans. fun. in output layer	logsig

It is important to note that in order to estimate the prediction capability of the developed ANN models, another statistical criterion was used - the difference between the predicted values and the measured values. In Table 2, statistical errors of the ANN model are presented.

Tabela 2: Performanse modela ANN

ANN	MSE		Deviations (mm)		
	Training set	Test data set	X	Y	Z
1	0.001	0.024	0.296	0.257	0.388

The geometric accuracy of the obtained models was tested by application of the deviation analysis between the input and the resulting models in the CAD software CATIA. The analysis was performed on the resulting surface model created using multiple regression (row 1 in Table 3) and the resulting surface model created by using an artificial neural network (row 2 in Table 3).

Tabela 3: Comparing the obtained value of deviation

Deviations analysis (mm)		
Samples	1	2
1	1.53	0.30
2	1.03	0.38
3	2.38	0.33
4	2.06	0.35

5	1.97	0.38
6	1.74	0.37
7	2.05	0.32
8	1.64	0.36
9	1.82	0.33
10	1.62	0.38
11	1.97	0.35
12	1.74	0.36
13	1.06	0.34
14	2.11	0.35
15	1.67	0.33
16	2.57	0.24
17	1.45	0.13
18	1.56	0.26

The results of the deviation analysis indicate that the maximum deviation value for the models created using multiple regression is 2.38 mm, while in the model created using an artificial neural network it is 0.38 mm. Based on the results of the comparative analysis (shown in Table 3), it can be concluded that the new method for prediction of the of anatomical points fully justified the expectations. The maximum deviations of a surface model of body of human mandible created by an artificial neural network is presented in Figure 6.

Figure 6: Maximum deviations of a surface model of the body of human mandible from the input model

4. CONCLUSION

A preliminary study suggests that the improved approach for the geometric modeling of the human mandible represents a significant contribution towards improving the geometric and anatomical accuracy of the resulting models.

The resulting models based on the artificial neural network technique have a precision level that is clinically acceptable and can be applied in: preoperative planning, surgical simulation, post-operative recovery of the patient, design of osteofixation material, etc.

By developing and applying an improved approach, there have been proposals for further research in several directions: in creating a geometric model of the complete human mandible, a more precise analysis of morphological characteristics and the application of other mathematical models in order to achieve greater geometric accuracy of the model.

ACKNOWLEDGEMENTS

The paper presents results of the project III 41017 Virtual Human Osteoarticular System and its Application in Preclinical and Clinical Practice sponsored by the Ministry of Education, Science and Technological Development of the Republic of Serbia for the period of 2011- 2018.

REFERENCES

- [1] H. Lamecker, S.Zachow, A. Wittmers, B. Weber, H. Hege, B. Elsholtz and M. Stiller, "Automatic Segmentation of Mandibles in Low-Dose CT-Data", Int. J. Comput. Assist. Radiol. Surg, Vol. 1(1), pp. 393–395, (2006)
- [2] M. Manić, Z. Stamenković, M. Mitković, M. Stojković and D. Shepherd, "Design of 3D model of customized anatomically adjusted implants", F. U. Mech. Eng., Vol.13(3), pp. 269-282, (2015)
- [3] J. Watson, M. Hatamleh, A. Alwahadni and D. Srinivasan, "Correction of Facial and Mandibular Asymmetry Using a computer aided design/computer aided manufacturing Prefabricated Titanium Implant", J.Craniofac. Surg., Vol.25 (3), pp. 1563, (2014)
- [4] J. Mitić, N. Vitković, M. Manić, M. Trajanović, S. Petrović and S. Arsić, "Reverse modelling of the human mandible 3D geometric model", Vojnosanit. Pregl., Online-First, pp.63-63, (2018)
- [5] S. Benazzi, E. Stansfield, O. Kullmer, L. Fiorenza and G. Gruppioni, "Geometric morphometric methods for bone reconstruction: the mandibular condylar process of Pico della Mirandola", Anat. Rec., Vol. 292(8), pp. 1088–1097, (2009)
- [6] S.G. Kim, W.J. Yi, S.J. Hwang, S.C. Chio, S.S Lee and M. S. Heo, "Development of 3D statistical mandible models for cephalometric measurements", Imaging Sci. Dent., Vol. 42 (3), pp. 175-182 (2012)
- [7] M. Majstorović, M. Trajanović, N. Vitković and M. Stojković, "Reverse engineering of human bones by using method of anatomical features", CIRP Ann. - Manuf. Techn., Vol. 62(1), pp. 167-170 (2013)
- [8] S. Arsić, P. Perić, M. Stojković, D. Ilić, M. Stojanović, Z. Ajduković and S. Vučić, "Komparativna analiza linearnih morfometrijskih parametara humane mandibule dobijenih direktnim i indirektnim merenjem", Vojnosanit. Pregl., Vol.65(7), pp. 839-846, (2010)
- [9] J. Mitić, N. Vitković, M. Manić and M. Trajanović, "Improvement of the geometrical accuracy of the human mandible body parametric model", ICIST 2018 Proceedings, 8th International Conference on Information Society and Technology, Kopaonik (Serbia), 11-14 Mart 2018, pp. (2018)
- [10] M. Madić and M. Radovanović, "Methodology of developing optimal BP-ANN model for the prediction of cutting force in turning using early stopping method", F. U. Mech. Eng., Vol. 9(1), pp. 21-32, (2011)