BIOMEHANIČKA ANALIZA POKRETA ČUČNJA U *ANYBODY MODELING* SISTEMU

BIOMECHANICAL ANALYSIS OF THE SQUAT MOTION IN *THE ANYBODY MODELING SYSTEM*

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REZIME
U radu je dat pregled softvera Anybody Modeling System, dizajniranog za virtualno modeliranje i biomehaničke analize različitih muskuloskeletnih sistema. Na primjeru muskuloskeletnog modela ljudskog tijela, demonstrirane su mogućnosti i neke od značajki sistema .
Analiziran je slučaj pri kojem model ljudskog tijela, sa i bez dodatnog opterećenja, izvodi pokret čučnja, pri čemu su dobijene individualne sile kvadriceps mišića, aktivnost mišića gornjeg dijela tijela, kao i reakcije u zglobu kuka.

Conference paper

SUMMARY
This paper reviews The AnyBody Modeling System, designed for virtual modelling and biomechanical analysis of different musculoskeletal systems. On the example of human body musculoskeletal model, capabilities and several features of the AnyBody System are presented.
An example of a full-body model doing a squat motion, with and without additional weight, is analysed, where individual forces in the quadriceps muscles, muscle activity of the upper body, as well as the reaction forces in the hip joint are obtained.

1. UVOD

AnyBody Modeling System (AMS) predstavlja softversko rješenje dizajnirano za simulaciju mehanike višesegmentnih sistema krutih tijela, sa posebnim naglaskom na modeliranje muskuloskeletnih sistema. Softver je razvila grupa istraživača sa Aalborg univerziteta [1], što je kasnije rezultiralo formiranju spin-off kompanije – AnyBody Technology [2]. AMS je baziran na primjeni generalnog formalizma višesegmentne dinamike [3], principima inverzne dinamike [4] te optimizacijskom algoritmu aktivacije mišića [5].

Za izradu višesegmentnih dinamičkih modela AMS koristi AnyScript – deklarativni, objektno orijentisani programski jezik koji posjeduje određeni broj predefinisanih klasa na osnovu kojih korisnici kreiraju objekte. Predefinisane klase sadrže osnovne tipove podataka, numeričke i *string* vrijednosti, mehaničke objekte – kao što su kosti (segmenti), različite spojeve-zglobove, sile, mišiće, i drajvere-pokretače (vremenske funkcije koje određuju vrijednost različitih kinematskih mjera, a također se mogu koristiti i kao virtualni pokretači u odsustvu mišića).

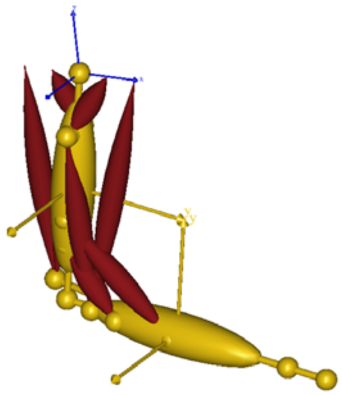
1. INTRODUCTION

The AnyBody Modeling System (AMS) is a software solution designed for simulating the mechanics of rigid multi-body systems – especially musculoskeletal ones. It was originally developed by a group of researchers from the Aalborg University [1], that has grown up in a spin-off company - AnyBody Technology [2]. The AMS is based on the application of general multi-body dynamics formalism [3], principles of the inverse dynamics [4] and the muscle recruitment optimization [5].

To develop multi-body dynamics models, the AMS provides a declarative, object-oriented programing language - the AnyScript [6], which has a number of predefined classes that the user can create objects from. The predefined classes comprise basic data types, such as numbers and strings, mechanical object types, such as bones (called segments), joints of various types, forces, muscles, and drivers (functions of time determining values of different kinematics measures, which can also be used as the virtual motors when there are not defined muscles).

Jedna od ideja iza AnyScripta je da njegov tekstualno bazirani format i objektno orijentisana struktura čini jednostavnim transfer elemenata između različitih modela. To znači da se može kreirati jedna biblioteka segmenata tijela za korištenje u različitim analizama, te da se modeli mogu jednostavno razmjenjivati među korisnicima AMS-a tokom saradnje na složenim projektima. Koristeći AnyScript jezik za modeliranje, korisnik također kontroliše grafički prikaz modela koristeći posebne objekte sa mogućnostima vizualizacije (slika 1).

One of the ideas behind the AnyScript is that its text-based format and object-oriented structure makes it easy to transfer elements between different models. That means that a library of body segments could be built for the use in different analysis projects, and the models could be easily exchanged between users in collaboration on complex modelling tasks. Using the AnyScript modelling language, the user also controls the graphical appearance of the model by means of special objects with vizualization capabilities (Fig. 1).



Slika 1. *Pojednostavljeni muskuloskeletni model ruke*
Figure 1. Simplified musculoskeletal model of an arm

Za ulazne podatke model zahtijeva podatke o kretanju segmenata, te opciono vrijednost vanjskih sila (dobijene odgovarajućim mjerenjem ili definisane u vidu objekata unutar AnyScripta), preko kojih se onda računaju unutrašnje mehaničke karakteristike modela (npr. individualne sile u mišićima, aktivnost mišića, vrijednost ukupnih sila i momenata koje djeluju u zglobovima, itd). Kretanje modela može biti definisano na različite načine: a) koristeći podatake (u formi C3D ili BVH dokumenata) iz sistema za snimanje pokreta (npr. Vicon, Xsens, Kinetic, Animazoo, itd), b) preko interfejsa između modela i okoline – gdje se modelom upravlja iz okoline (npr. veza između stopala ili ruku sa nekim pokretnim dijelovima mašine), c) manuelni unos u formi parametara koji uključuju unos anatomskih uglova zglobova, ili definisanje vremenski zavisnih pokretača koji kontrolišu neku kinematsku mjeru (npr. poziciju ili kretanje ruke, položaj centara mase, itd).
Koristeći AMS moguće je modeliranje različitih muskuloskeletnih sistema, bilo da se radi o ljudskom, ili muskuloskeletnom sistemu drugih bića.

As the input data the system requires motion and optionally external forces (measured or defined as objects in the AnyScript), from which the internal mechanical properties of a multi-body system are calculated (individual muscle forces, muscle activity, net joint forces and moments, and much more). The motion could be applied in a different ways: (a) measured motion using a motion capture system (e.g. Vicon, Xsens, Kinetic, Animazoo, etc.) in a form of C3D or BVH data, (b) through the interface between a model and environment – where the model is driven by the motion from its environment (e.g. connection of the feet and hands with some parts of a machine), (c) manual input in the form of parameters which involve anatomical joint angles, or defining time-dependent drivers which control a kinematic measure (e.g. position and movements of hand, or centre of mass).
The AMS allows users to model just about any musculoskeletal system, be it a human or other creatures.

Također je moguće analizirati reakcije sistema sa objektima iz okruženja, koji mogu biti unutar modela (implanti, npr. koljena ili kuka), povezani sa modelom (egzoskelet, npr. potpora za koljeno), ili objekti sa kojima model vrši interakciju (npr. invalidska kolica, automobilsko sjedalo, pomoćni uređaji, dio opreme).
S obzirom da su muskuloskeletni modeli ljudi i životinja vrlo kompleksni, njihova detaljna izrada „od nule“ predstavljala bi ogroman zadatak za većinu korisnika. Iz tog razloga AMS dolazi sa detaljnim muskoskeletnim modelom ljudskog tijela (slika 2), koji je detaljno validiran [7]. Ovaj model sadrži većinu kostiju, zglobove i mišiće ljudske fizionomije (približno 1200 mišićnih snopova). Model je dimenzionisan tako da odgovara prosječnom Europljaninu (visina 1,76m, težina 75kg), ali je također moguće izvršiti i njegovo skaliranje prema nekoliko dostupnih zakonitosti.

It is also possible and analyse reactions with them and an environment - which can be something within the model (implant, e.g. knee or hip device), attached to it (exoskeleton, e.g. knee brace) or something interacting with the model (e.g. wheelchair, automotive seat, assistive device, piece of equipment).
Since musculoskeletal models of humans and animals are very complex and their accurate modelling from scratch would be an enormous task for most of users, the AMS comes with a full body model (Fig. 2), which is broadly and deeply validated [7], containing most bones, joints and muscles in the human physiognomy (roughly 1200 individual muscle fascicles). By default the body model represents the size and weight of an average European male (1.76m, 75kg), but the model can easily be scaled according to several scaling laws.

Slika 2. *Detaljan model ljudskog tijela*
Figure 2. *The full human body model*

Korisnici AMS-a na raspolaganju također imaju repozitorij muskuloskeletnih modela (AMMR) implementiranih za AMS [8]. Obično se radi o modelima koji su rezultat istraživačkih projekata akademskih institucija ili su nastali u kolaboraciji akademskih institucija i kompanije Anybody Technology. Repozitorij sadrži bazne modele tijela i aplikacijske modele. Bazni modeli su generički modeli koji mogu biti upotrijebljeni u odgovarajućem kontekstu, odnosno situaciji koja se želi analizirati. Aplikacijski modeli koriste bazni model tijela, specifikuju određene parametre, te ga postavljaju u odgovarajuće okruženje/aktivnost koje se želi analizirati.

In addition, users of the AMS are also provided with the AnyBody Managed Model Repository (AMMR) [8], which is the repository of musculoskeletal models that has been implemented for the AMS. Typically the models are originally developed by research projects at academic institutions or by AnyBody Technology in collaboration with academic institutions. The repository contains body and application models. The body models are generic models which can be applied in investigation/analysis and placed in the right context-application. The application models typically include a body model, specify optional parameters for it, and insert it into the environment/activity that is wished to be analysed.

U zavisnosti od nivoa znanja korisnika, AMS se može koristiti na nekoliko načina. Standarda procedura uključuje analizu svakodnevnih aktivnosti (npr. hodanje, trčanje, guranje/ povlačenje) u cilju dobijanja informacija o aktivnostima i silama u mišićima, reakcijama u zglobovima, kinematike segmenata modela, itd. Za napredni nivo korištenja AMS-a, korisnicima je omogućen unos specifičnih informacija vezanih za subjekt koji se želi analizirati (modeli kostiju dobiveni CT/MRI dijagnostikom, antropometrijski podaci, jačina mišića, broj mišića ili pozicija njihovih hvatišta, kinematski podaci), kao i izmjena mehaničkih i fizičkih karakteristika modela.

Pored toga što nudi različite tipove izlaznih podataka, AMS omogućava i njihovo eksportovanje u druge softvere u cilju vršenja naknadnih analiza ili obrade podataka (Python, Matlab, Office aplikacije). Dostupni su interfejsi za eksport podataka prema softverima baziranim na primjeni metoda konačnih elemanata (Abaqus i Ansys). Na ovaj način mogu se aplicirati i analizirati vrlo detaljni i složeni scenariji opterećenja kostiju. Također je moguće u AMS učitati različite CAD modele izrađene u softveru SolidWorks (npr. različiti komadi namještaja, sportska oprema ili mašine) [9], povezati ih sa muskuloskeletnim modelom , te izvršiti brojne analize.

Pored generalnog uvoda u AMS, cilj ovog rada je provesti nekoliko biomehaničkih analiza u svrhu procjene opterećenja u pojedinim zglobovima i mišićima muskuloskeletnog modela ljudskog tijela prilikom simulacije pokreta čučnja u varijantama sa i bez dodatnog opterećenja.

2. MODELIRANJE POKRETA ČUČNJA

U svrhu izrade simulacije čučnja, korišten je muskuloskeletni model ljudskog tijela postavljen u stojeći položaj. Ovaj model dostupan je iz baze predefinisanih AMS predložaka, a karakteriše ga sljedeće:

- Oba stopala modela povezana su sa podlogom. Stopala je moguće pomjerati sa izmjenom držanja tijela, ali je njihova veza sa podlogom stalna.
- Držanje tijela kontroliše se promjenom anatomskim uglova zglobova (svih osim skočnih).
- Model automatski balansira držanje tijela podešavajući uglove skočnih zglobova, tako da težište tijela uvijek bude vertikalno iznad skočnih zglobova.

According to the users' level, the AMS could be used in a several work flows. Standard work flow involves analyses of daily living activities (e.g. walking, lifting, pushing/pulling, etc.) in order to provide information about muscle activities and forces, joint reactions, kinematics of segments, etc. In advance work flow users may use subject specific information (models of bones from CT or MRI scans, anthropometry data, strength of muscles, numbers of muscles or the position of their attachments, motion and external force data) and modify the mechanical and physical characteristics of the body model.

In addition to obtaining different sorts of output data, the AMS is also capable to export them to other software solutions for the subsequent analysis or post processing (Python, Matlab, Office applications). There are interfaces for exporting data to finite element modelling software (Abaqus and Ansys). In this way a very detailed and complex load scenarios on the bones could be applied and analysed. It is also possible to import various CAD models designed in 3D CAD design software SolidWorks (for example different pieces of furniture, sports equipment or machines) [9], put them in connection with the body model and make numerous analyses.

The main objective of this paper, besides the general introduction of the AMS, is to make several biomechanical analyses in order to estimate loads in the selected human body joints as well as muscles activities and forces, which are developed during the squat of the body with/without dumbbells.

2. MODELING THE SQUAT MOTION

For the purpose of the squat simulation of the body model, the standing model from the template library was used. This model has a few predefined features and some that can be modified:

- The model is supported by having both feet connected to the ground. The feet can move with the posture, but they are always supported by the connection with the floor.
- The posture of the model is controlled via anatomical angles for all major joints except the ankles.
- The model automatically balances its posture by means of the ankle angles such that its collective centre of mass remains vertically above the ankle joints.

Modificirajući anatomske uglove glenohumeralnog zgloba (fleksija = 100 stepeni, abdukcija = 90 stepeni, vanjska rotacija = -20 stepeni), model je postavljen u početni položaj.
Za trajanje simulacije izabran je interval od 2 sekunde sa rezolucijom od 30 koraka u sekundi. Tokom ovog perioda model je mijenjao svoju poziciju vršeći fleksiju u zglobovima koljena i kuka obje noge (fleksija koljena od 0 do 90 stepeni, fleksija kuka od 0 do 45 stepeni). Ove promjene uglova definisani su odgorarajućim drajverima koji prate sinusne funkcije. Dvije pozicije modela, za vremenske korake od 0 i 1 sekunde, prikazane su na slici 3.

By modifying the anatomical angles of the glenohumeral joint (flexion = 100 degrees, abduction = 90 degrees, external rotation = -20 degrees), the body model was set in the starting position.
The simulation time was chosen to be 2 sec with the resolution of 30 steps per second. During this time, the model changed its position by simultaneously varying the values of the knee flexion (from 0 to 90 degrees) and the hip flexion (from 0 to 45 degrees) of the both legs. It was done by following the sine functions defined by the drivers. Two positions of the model, for the time step 0 and 1sec, are presented in Figure 3.

Slika 3. *Dvije pozicije modela tokom izvođenja čučnja*
Figure 3. *Two positions of the model during the squat motion*

Pored navedenog scenarija, analiziran je još jedan slučaj sa određenom promjenom u postavkama modela. Ovoga puta model je bio opterećen vanjskim silama (F=25 N) koje su djelovale na poziciji dlanova u smjeru naniže. Ovaj scenario opisuje čučanj tijela u kombinaciji sa dodatnim utezima u rukama. U posljednjem koraku izvršena je analiza kinematike i inverzne dinamike modela.

An additional case was also investigated, with one change in the set-up. This time the model had two external forces (F=25N) acting on the position of the palms in the downwards direction. The scenario described the squat with the additional dumbbells. As the last step, kinematics and inverse dynamics analyses were conducted.

3. REZULTATI

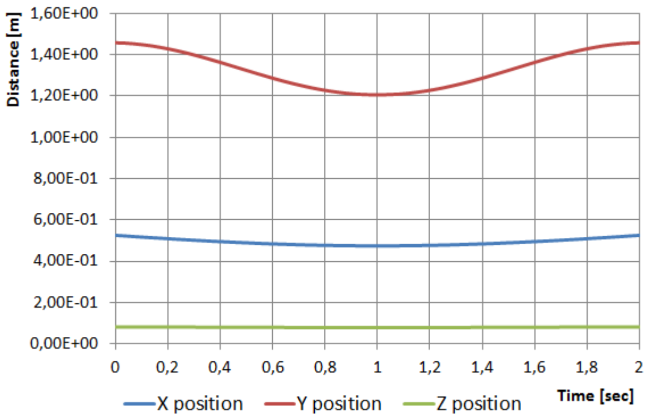
Svaki pojedinačni objekat definisan u AMS-u generiše određene izlazne podatke (rezultati analiza kinematike i inverzne dinamike), koji se koristeći dostupne alate mogu grafički predstaviti u vidu 2D/3D grafikona.
Kao neophodan preduslov za obavljanje analize inverzne dinamike, prvo se mora izvršiti kinematska analiza, čiji se podaci često koriste prilikom različitih ergonomskih studija.

1. RESULTS

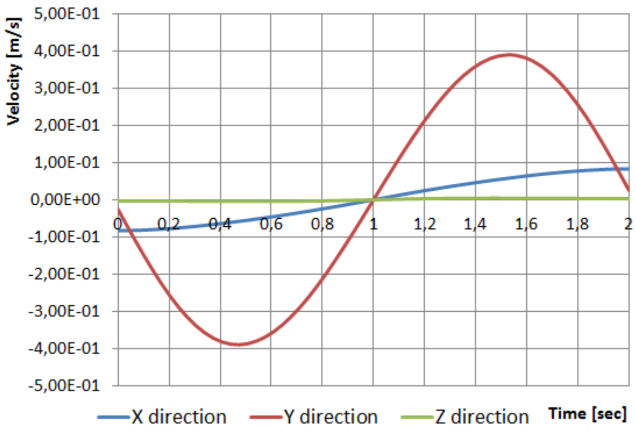
Every object defined in the AMS model generates some form of the output data, either kinematic or dynamic. After having done the inverse dynamics analysis, using a standard graphing tool, the user can investigate huge amount of data presenting them in the form of 2D/3D charts.
As the prerequisite for the operation of the inverse dynamics, the kinematics analysis of the model is done first.

Uzevši u obzir analiziranu aktivnost, na grafikonima 4 i 5 prikazani su položaj i brzina desne ruke modela.

The data obtained from this type of analysis could be used for various ergonomic studies. Taking into account the observed activity, the position, measured from the ground level, and velocity of the right hand are shown in Figures 4 and 5.



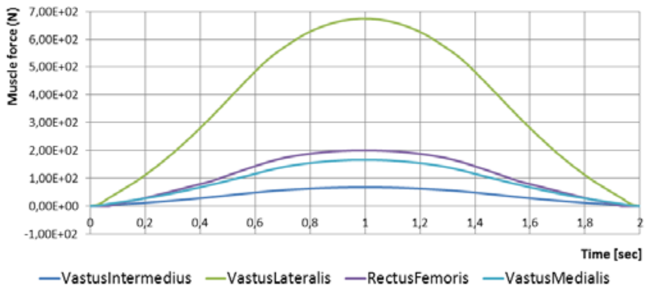
Slika 4. *X,Y,Z koordinate desne ruke*
Figure 4. *X,Y,Z coordinates of the right hand*



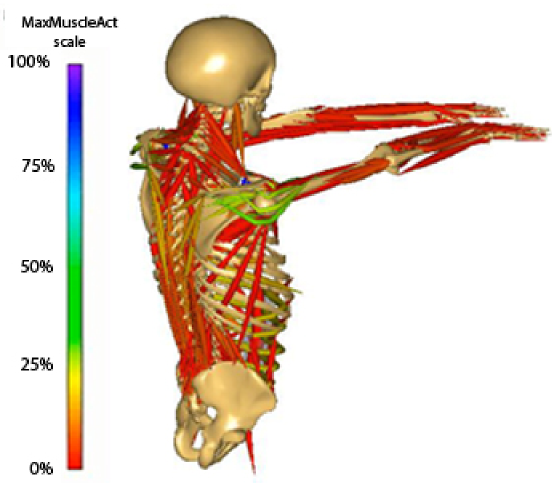
Slika 5. *Brzina desne ruke*
Figure 5. *Velocity of the right hand*

Čučanj predstavlja pokret kojim se aktiviraju uglavnom mišići nadkoljenice (vastuslateralis, vastusmedialis, vastusintermedius i rectus femoris), kuka i glutealne regije. Vrijednost sila generisanih od strane kvadriceps grupe mišića prikazane su na grafikonu 6.
Uzimajući u obzir pozicuju ruku tokom izvođenja čučnja, aktivnost mišića gornjeg dijela tijela također su istražene. Analizirana su dva različita slučaja, sa i bez dodatnog opterećenja ruku prilikom izvođenja vježbe. Da bi držali ruke u zadatoj poziciji, mišići gornjeg dijela tijela, posebno deltoidni, aktivirani su na način kako je prikazano na slikama 7 i 8.

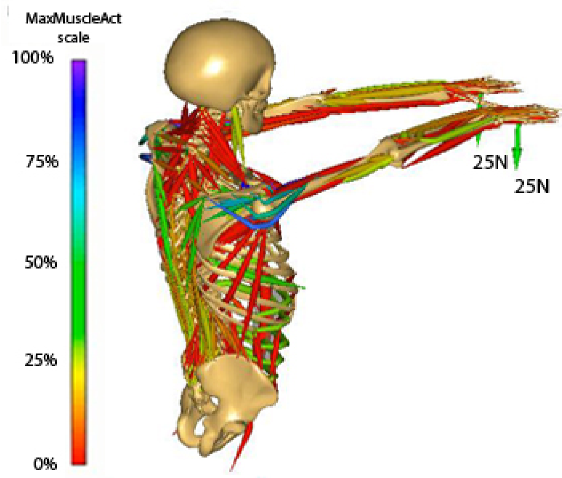
The squat is compound, full body exercise that trains primarily the muscles of the tights, hips and buttocks, quadriceps (vastuslateralis, vastusmedialis, vastusintermedius and rectus femoris). The forces generated by this muscle group are shown in Figure 6.
Taking into account the position of the arms, the muscle activity of the upper body were also investigated. Two different cases were analysed, with and without the additional dumbbells in the hands. In order to keep arms in the chosen position, the upper body muscles, especially the deltoid muscle, were activated as shown in Figures 7 and 8.



Slika 6. *Vrijednost sila generisanih u kvadriceps mišiću*
Figure 6. *Forces produced by the quadriceps muscle*



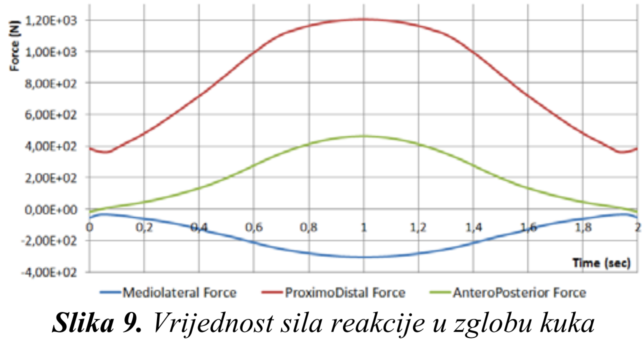
Slika 7. *Aktivnost mišića u gornjem dijelu tijela*
Figure 7. The upper body muscle activity



Slika 8. *Aktivnost mišića u gornjem dijelu tijela – slučaj sa dodatnim opterećenjem*
Figure 8. *The upper body muscle activity – the case with additional loads*

Pored informacija o aktivnostima i silama mišića, za istraživače koji se bave biomehanikom od posebnog značaja su i informacije o reakcijama koje se javljaju u zglobovima modela. Vrijednosti ovih sila za zglob kuka prikazane su na grafikonu 9.

Besides the muscle activity and forces, many biomechanical researchers are also interested in joint reaction forces. Their values for the hip joint, generated during the observed activity, are presented in Figure 9.



Slika 9. *Vrijednost sila reakcije u zglobu kuka*
Figure 9. *Reaction forces in the hip joint*

4. ZAKLJUČAK

Modeliranje muskuloskeletnih sistema ljudskog tijela, kao i drugih bića, predstavlja izuzetno zahtjevan zadatak. Gotovo je nemoguće simulirati realne muskuloskeletne sisteme ručno (analitički) ili ih razviti uz pomoć matematičkih softvera za generalne namjene. Jedino moguće rješenje jeste koristiti kompjuterski sistem dizajniran isključivo za tu svrhu.

U radu je dat opći pregled softvera AnyBody Modeling System, namijenjenog modeliranju i simulaciji mehanike muskuloskeltenih sistema. Koristeći muskuloskeletni model ljudskog tijela u stojećem položaju iz AMS repozitorija, uz odgovarajuće prilagodbe anatomskih uglova pojedinih zglobova, izvršena je simulacija pokreta čučnja sa i bez dodatnog opterećenja. Za definisanje potrebnog kretanja modela, određeni detalji programirani su koristeći AnyScript programski jezik.

Nakon provedenih analiza, kinematike i inverzne dinamike, prikazano je nekoliko izdvojenih rezultata (kinematski podaci segmenta ruke, sile koje generiše kvadriceps mišićna grupa, aktivnost mišića gornjeg dijela tijela, reakcije u zglobu kuka).

Na osnovu prikazanog može se zaključiti da AMS predstavlja savremeno softversko rješenje sa izuzetnim mogućnostima, namijenjeno istraživačima u polju biomehanike, inženjerima dizajnerima, kao i medicinskim radnicima, zainteresovanim za istraživanje muskuloskeletnog sistema ljudskog tijela, te izradu proizvoda optimiranih za ljudsku upotrebu.

4. SUMMARY AND CONCLUSIONS

Modelling humans and other creatures in the forms of musculoskeletal systems is a very demanding task. It is virtually impossible to simulate realistic musculoskeletal systems by hand or even develop them bottom-up by general mathematical software. The only viable solution is to use a computer system designed for this particular purpose.

This paper gives a general overview of the AMS, the state-of-the-art software solution for modelling and simulating mechanics of musculosceletal systems. Using the full body standing model of the human body from the AMMR, in combination with some adjustment of the joints anatomic angles, simulation of the squat motion with and without additional load was done. In order to define required motion of the model, certain details were programmed using AnyScript programming language.

Following the kinematics and inverse dynamics analyses, some of the results were presented (kinematic data of the hand, forces produced by the quadriceps muscle group, the upper body muscle activity, force reactions in the hip joint).

According to presented material, it could be concluded that the AMS seems to be a contemporary software solution with great capabilities, intended to the biomechanics researchers, designer engineers and physicians, interested in investigation of the musculoskeletal system of the human body and making optimised products to be in contact with humans.

5. LITERATURA - REFERENCES

[1] Aalborg University, http://www.enaau.dk (12.5.2015)

[2] AnyBody Technology, http://www.anybodytech.com (12.5.2015)

[3] P.E. Nikravesh, *Computer-Aided Analysis of Mechanical Systems*, Prantice Hall Inc.,Englewood Cliff,NJ,1988.

[4] Gordon Robertson, Graham Caldwell, Joseph Hamill, Gary Kamen, Saunders Whittlesey, *Research Methods in Biomechanics,* Human Kinetics; 2nd edition, 2014.

[5] Michael Damsgaard, John Rasmussen, SørenTørholm Christensen, EgidijusSurma, Mark dee Zee, Analysis of musculoskeletal systems in the AnyBody Modeling System, *Simulation Modelling Practice and Theory, Volume 14,* Issue 8, 2006, pp 1100 – 1111.

[6] AnyScript community, http://www.anyscript.org (12.5.2015)

[7] AnyBody Technology publication list, http://www.anybodytech.com/index.php?id=publications (12.5.2015)

[8] AnyBody Model Repository, http://forge.anyscript.org/gf/ (12.5.2015)

[9] SolidWorks, http://www.solidworks.com (12.5.2015)

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