ACTIVE CONTROLLED MUSCLES IN NUMERICAL MODEL OF HUMAN ARM FOR MOVEMENT IN TWO DEGREES OF FREEDOM

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ABSTRACT

This paper describes the development of numerical model of human upper extremity able to perform movements and stabilization tasks in two degrees of freedom as a result of muscle activation controlled by a PID-based controller. These tasks are defined by functions of specified angle for every degree of freedom. Comparisons between model behaviour and experimental results show, that under certain conditions the model is able to perform reliable movements. But at the current stage of work, the level of muscle activation in fast movements can not be compared directly with the experimental values.

Keywords: ANATOMY, ARMS, BONES, MODELS, MULTI BODY

Currently used safety-related computer models of human used in automotive industry are predominantly developed and validated for crash conditions, in which the active muscle actions have small influence. This is caused by a long muscles reaction time. However, in the phase prior to crash, majority of car occupants typically attempt to react, trying to respond to the emergency situation. In the last second before the inevitable crash, modern vehicle restraint systems can start actuation. In this pre-crash phase, human activity is of significant influence as it determines the location of the occupant relative to the vehicle interior, the kinematics during the event and the internal forces acting on the human body.

While passive stiffness of muscles can be implemented relatively easy in multi body or finite element models, the active muscles response requires more advanced methodology, especially when considering controlled movements. The research was aimed at the development of a numerical arm model that can perform movements in two degrees of freedom as a result of muscle activation controlled by a PID-based controller. This is the first step towards creating a computer human model capable of reproducing vehicle occupant pre-crash reactions.

This paper presents work performed within a European Commission 6th framework project (APROSYS).

MODEL DEVELOPMENT

In the first part of the research a computer model of upper extremity was developed to be used in the MADYMO software package. It consists of a multi body structure with a FE mesh as a geometrical representation and muscles described by a Hill-type model. Considered movements are: flexion/extension and pronation/supination of forearm. Most of the parameters were taken from the literature.

MULTI BODY STRUCTURE AND FE MESH

The mesh of human arm and shoulder was taken from the mesh developed in the HUMOS2 project. Only the shell elements describing the cortical bones of hand, ulna, radius, femur, clavicle and scapula are represented in the current mesh. The FE mesh is rigidly supported to a multi-body framework consisting of bodies with mass moments of inertia, kinematical joints with limited degrees of freedom. These kinematical joints allow for a specified number of degrees of freedom and reveals stiffness in those directions, both translational and rotational.

The voluntary ranges of motion stem from the anthropometric database RAMSIS and the friction parameters are based on the literature data on passive friction torques of the human joint with relaxed muscles.

IMPLEMENTATION OF MUSCLES

In the MADYMO software package, Hill-type muscle model represents the behavior of contractile element and the parallel elastic element. Total force in each muscle is calculated as a sum of forces generated by these two elements. This force depends on various parameters, some of which can be assumed as common for all muscles, other are muscle-specific and have to be obtained for each muscle. These are: maximum isometric muscle force, optimal muscle length and maximum contraction velocity. In the research parameters were obtained from the literature.

The muscle force also depends on variable active state, representing the level of muscle activation. This parameter enables controlling of muscle activity.

For the task of forearm two degrees of freedom rotation (flexion/extension and pronation/supination), the following muscles have been selected and implemented in the model: 2 heads of *biceps brachii* (BIC), 3 heads of *triceps brachii* (TRI), *brachialis* (BRA), *brachioradialis* (BRD), *pronator teres* (PT) and *supinator* (SUP).

PID-BASED CONTROLLER

The main parameter responsible for controlling every muscle is its active state. It can assume values between 0 (no activation) and 1 (full activation). With no activation, there is no active force generated by the muscle, with full activation this force is maximal possible under current conditions (muscle length and speed). By appropriate setting the values of active state at every moment of time for each muscle in the system of muscles, various movements can be arranged. But the question is: how to determine these values to force the model to move to the specified angle, or – in general – to follow specified trajectory?

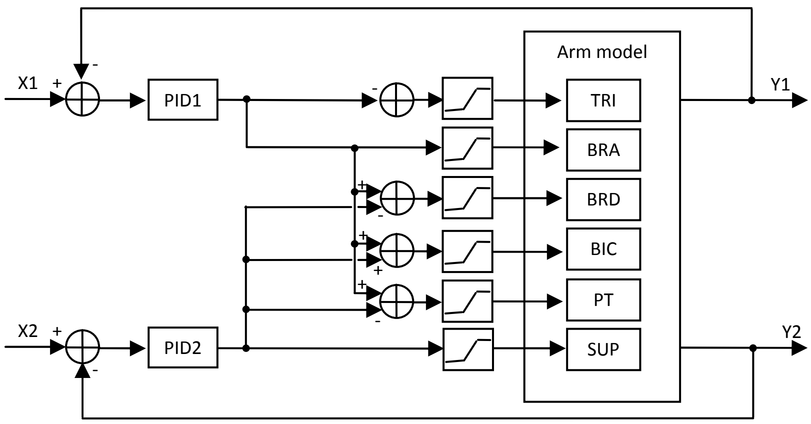

Fig. 1 – Scheme of PID-based controller

The proposed solution causes in using a PID-based controller. The main operating parameters are angles in joints – the controller is trying to modify activation of muscles to achieve the specified values of these angles. In case of one degree of freedom (flexion/extension of forearm) this looks as follows:

All involved muscles are divided into two groups, performing antagonistic movements – flexion and extension. Current value of specified angle (X1) in this joint (which can represent a wished end-position, but in general is represented as a function of time) is taken as an input to the controller. At the first step, deviation is calculated in terms of difference between values of specified angle and actual angle in the joint (Y1). Value of this deviation becomes an input for a PID element (PID1). PID output is maintained at the level between +1 and -1. At the next step, this signal is divided into two groups and one of them is multiplied by -1. Both signals are maintained at the level of muscle activation (between 0 and 1) and set as the activation parameter of two antagonistic groups of muscles. At the current stage of work, while acting in one degree of freedom, all muscles from one group are subjected to the same activation level. However, some more complex muscle cooperation model should be considered in the future. Activation of muscles affects forces exerted by them, what causes changes of angle in the joint (Y1), which is provided as an input for the controller.

Increasing the capabilities of the controller to cover the second degree of freedom (pronation/supination) was more complex, because most of the muscles involved in these movements, while activated, perform rotation in more than one direction. Second PID element was added (PID2), working similarly as PID1, but operating in different degree of freedom (pronation/supination – Y2), with different function of specified angle (X2). Signals from these two PIDs are combined for every muscle by addition or subtraction – depending on muscle role.

Parameters for both PIDs were set experimentally basing on fast movements performed by the model (when specified angle changes between two values in a very short time). There were two criteria: 1) movement should be performed as fast as possible, 2) oscillations should be minimal.

ASSESSMENT OF MODEL BEHAVIOUR

First simulations show, that the controller is able to perform stabilization tasks, as well as follow time trajectories in two degrees of freedom. It can perform stabilization under variable external conditions (for example when dropping small weight on the hand), but also during movements in other degrees of freedom.

To evaluate behaviour of the model some experiments with registration of the EMG signals were done. Due to technical reasons, measurement of angle in the second degree of freedom (pronation/supination of forearm) was not possible during performed tests – these movements were considered only in terms of stabilization. During tests only fast movements were performed ("as fast as possible"). It was done because slow motion do not allow for verification of model limits and in the same time the model is considered to be used in the pre-crash simulations, where actions are taken in a very short time.

During tests, the EMG signal from the following muscles was registered: *biceps, triceps, brachioradialis* and *pronator teres* (selected because of easy access). Signals were measured using surface electrodes, data were rectified, filtered and normalized. The angle in elbow joint was measured through goniometer in the first series of tests and by tracing markers on the film recorded during the second series. All tests were made in a sitting position and consisted of flexion and extension of forearm in various configurations.

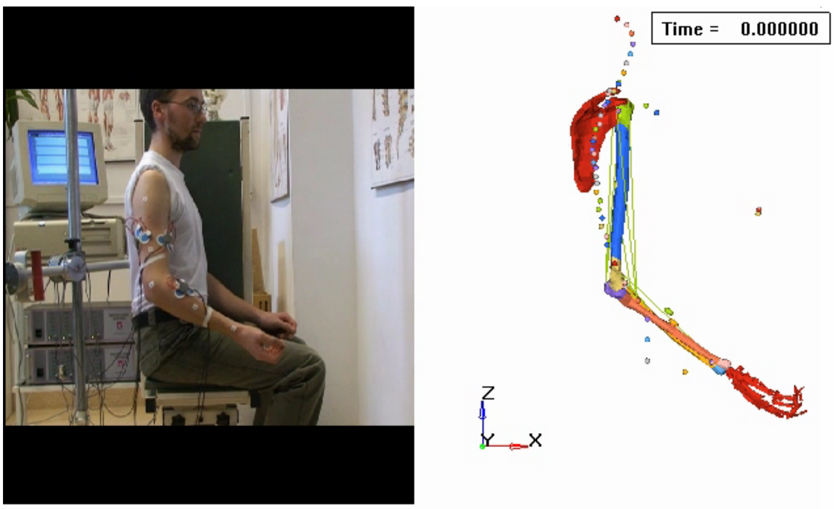

Fig. 2 – Experimental and simulation setups

Two kinds of tests were performed: 1) movement from the extended position to maximum flexion and back to the initial position, 2) movement between two selected positions with a brake (for stabilization) after every movement. Each movement was made on a researcher's sign, volunteers were asked to accomplish the task as fast as possible. Both experiments were reproduced in computer simulation.

RESULTS

The evaluation was made by comparing times of movement in the experiment and simulation. It shows that the model is capable of arranging movements with a similar speed as in the real experiment. For example, while performing movement from the extended position to the maximum flexion and back to initial position (angle changed in the range of 1.6 rad) it took between 0.5 and 0.7 s in the real experiments and around 0.6 s in simulation. Similar results were observed in second experiment.

Due to the nature of EMG signal (which is almost irrepeatable even in similar experiments) direct comparison of activation curve from EMG and set by the controller was not done. However, some information can be obtained comparing maximal values of these activations. In the same experiment as described above, the mean value (from 3 tests) of maximum activation of *biceps* muscle for one of the volunteers was 0.868 (values 0.810, 1.032 and 0.762) and for *triceps* it was 0.080 (0.036, 0.096 and 0.109). In the simulation activation of both these muscles reached value 1.0 (100%) and held it for 0.12s in case of *biceps* and 0.04s in case of *triceps* (in the experiment maximum were only a peak values).

DISCUSSION

When considering very fast movements ("as fast as possible") the model seems to be able to act with a similar speed as in the real experiments. When the specified angle suddenly changes from one value to another, the controller reacts by modifying activation of muscles causing a movement similar to the one obtained from experiments. However, these activations of muscles set by the controller reach higher level than those observed in the experiment (obtained from EMG). But – in the same time – in static experiments the model is able to generate a similar force with similar muscles activations as in the corresponding experiment. This can be caused by improperly selected muscle parameters (which in the reality differ for each human/volunteer) or/and by problems with the hill-type muscle model used in the research (implemented in MADYMO) and its behaviour during fast movements. There can also be some inaccuracies caused by the fact, that only the main muscles involved in these movements were taken into consideration.

CONCLUSIONS

The results show that controller parameters can be set in an appropriate way to perform stabilization tasks and to generate movements within two degrees of freedom. These actions correspond to the experimental results. However, at the current stage of research, activation of muscles during fast movements can not be compared directly with the experimental values.

Concluding, the model seems to be reliable under certain conditions. When adapting to other kind of movements in other configuration of a body the same methodology can be used, but parameters of controller should be changed before.

REFERENCES

De Luca, C. J., *The Use of Surface Electromyography in Biomechanics,* Journal of Applied Biomechanics, 1997, 13, 135-163

Lemay, M.A. and Crago, P.E. *A dynamic model for simulating movements of the elbow, forearm, and wrist*, Journal of Biomechanics, 29 (19), pp. 1319-1330, 1996

Seireg and Arvikar R., *Biomechanical Analysis of the Musculoskeletal Structure for Medicine and Sports*, Himisphere Publishing Corporation, 1989

TNO, *MADYMO Theory Manual - Version 6.3*, TNO, December 2005

Winters, J M. and Woo, S, L-Y., *Multiply Muscle Systems,* Springer-Verlag New York Inc. 1990