Movement Control of a Prosthesis Forefinger

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Abstract—**The present paper approaches the problem of hand prostheses. Designing of hand prostheses implies the use of many types of mechanisms. One of them is the anti-quadrilateral mechanism. The control method chosen and presented in this paper is fuzzy method, applied to a dc motor that actuates each finger of the prosthesis.**

Index Terms— **computer programs, control systems, design, simulation.**

I. INTRODUCTION

The design of hand prosthesis should be done by considering the needs of each patient and so, there can be obtained very complex or less complex prostheses or simply activity oriented prosthesis [2, 5].

There are some factors that influence the performances of prosthesis. Among the mechanical ones (manufacturing accuracy, materials used, assembly precision, etc.), the control system has a very important influence.

From mechanical point of view there are many mechanisms that are used to design prostheses: link-rod mechanisms, wire mechanisms, pneumatic muscles. One of the most used mechanisms is the anti-quadrilateral one that is used to model a phalange of a finger. In the case of the prosthesis presented in the present paper are used one of this mechanisms for each phalange thus, each finger has two of them except the thumb that has only one mechanism of this type.

The control of prosthesis has two major aspects: one, regarding the driving system, and the other, regarding the feedback control. Modern technical literature says that the first aspect of the control is dominated by the myoelectric approach and the second one by the fuzzy or neural-fuzzy controllers.

The control of the prosthesis presented in the following is done by using a fuzzy controller for each dc motor that actuates one finger.

The goal of the design and control process was to compare results of both the simulation of the movement of forefinger of the prosthesis, based on mathematical equations, and real movement of the forefinger as output of the motor-controller-finger system.

To achieve this goal were followed some steps: the finger design from mechanical point of view; simulation of the finger movement; design of the controller; design a program that includes the mechanical part, the actuating part and the control one; simulation of movement.

II. MECHANICAL DESIGN

A. Mathematical laws of movement

The forefinger was modeled by using two anti-quadrilateral mechanisms. The figure 1 presents the two mechanisms, being set off (by heavy strike) the second one.
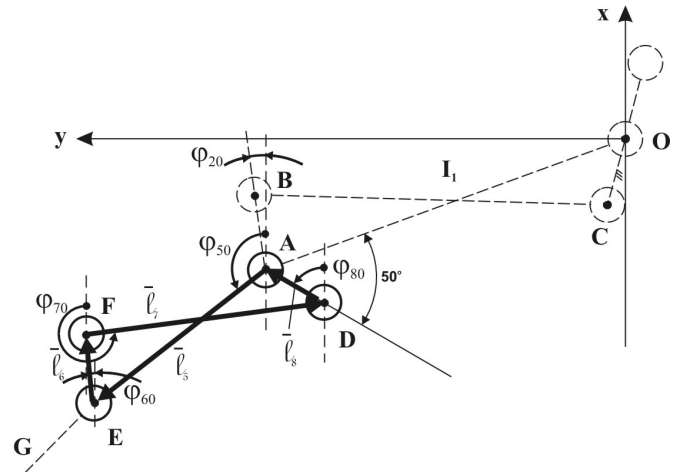
Figure 1. The diagram of the forefinger

To be able to determine the movement of the tip of the finger there were adopted some input values for the geometrical part of the finger. Thus,

$$
\begin{aligned}
OA &= \ell_1 = 55{,}2 \ mm; \\
AB &= \ell_2 = 10{,}8 \ mm; \\
BC &= \ell_3 = 50{,}9 \ mm; \\
CO &= \ell_4 = 9{,}9 \ mm; \\
AE &= \ell_5 = 31{,}3 \ mm; \\
EF &= \ell_6 = 10 \ mm; \\
FD &= \ell_7 = 34{,}8 \ mm; \\
DA &= \ell_8 = 9{,}8 \ mm; \\
EG &= \ell_9 = 22{,}5 \ mm; \\
\angle IOA &= 125°; \\
\angle COx &= \beta = 15°; \\
\angle OAD &= \gamma = 50°; \\
\angle BAE &= \delta = 120°; \\
\angle FEG &= \theta = 130^o.
\end{aligned} \tag{1}
$$

To determine the mathematical equations for the movement of the forefinger it has to be determined the outputs of each anti-quadrilateral mechanisms. These outputs are obtained by writing the contour equations for each mechanism. The equations (2) ÷ (5) describe the output of the first and, respectively, the second mechanism.

$$\overline{OA} + \overline{AB} + \overline{BC} + \overline{CO} = 0 \tag{2}$$

$$(2) \Rightarrow \begin{cases} l_1 \cos\varphi_{10} + l_2 \cos\varphi_{20} + l_3 \cos\varphi_{30} + l_4 \cos\varphi_{40} = 0 \\ l_1 \sin\varphi_{10} + l_2 \sin\varphi_{20} + l_3 \sin\varphi_{30} + l_4 \sin\varphi_{40} = 0 \end{cases} \tag{3}$$

$$\overline{AE} + \overline{EF} + \overline{FD} + \overline{DA} = 0 \tag{4}$$

$$(4) \Rightarrow \begin{cases} l_5 \cos\varphi_{50} + l_6 \cos\varphi_{60} + l_7 \cos\varphi_{70} + l_8 \cos\varphi_{80} = 0 \\ l_5 \sin\varphi_{50} + l_6 \sin\varphi_{60} + l_7 \sin\varphi_{70} + l_8 \sin\varphi_{80} = 0 \end{cases} \tag{5}$$

The movement of each joint of the forefinger mechanisms is described by the equations (6) and (7):

$$\begin{cases} x_A = l_1 \cos(180 - \varphi_{10}) \\ y_A = l_1 \sin(180 - \varphi_{10}) \end{cases} \tag{6}$$

$$\begin{cases} x_E = l_5 \cos(180 - (\varphi_{20} + \delta)) \\ y_E = l_5 \sin(180 - (\varphi_{20} + \delta)) \end{cases} \tag{7}$$

The coordinates of the forefinger tip are given by the vector $\bar{r}_G$ (figure 2). The equations are:

$$\bar{r}_G = \overline{OA} + \overline{AD} + \overline{DF} + \overline{FE} + \overline{EG} \tag{8}$$

$$\begin{cases} \overline{OA}\,[l_1 \cos\varphi_{10},\ l_1 \sin\varphi_{10}] \\ \overline{AD}\,[l_8 \cos(\varphi_{10} - \gamma + 180),\ l_8 \sin(\varphi_{10} - \gamma + 180)] \\ \overline{DF}\,[l_7 \cos(\varphi_{70} - 180),\ l_7 \sin(\varphi_{70} - 180)] \\ \overline{FE}\,[l_6 \cos(\varphi_{60} + 180),\ l_6 \sin(\varphi_{60} + 180)] \\ \overline{EG}\,[l_9 \cos\varphi_{90},\ l_9 \sin\varphi_{90}] \end{cases} \tag{9}$$
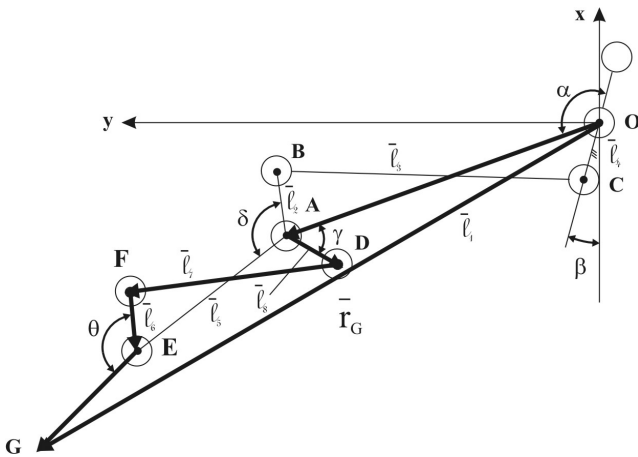

Figure 2. The diagram of $\bar{r}_G$ vector

B. Simulation of the movement of each joint of forefinger

Simulation was done by considering as input the geometrical values, given at the beginning of the previous subchapter, and the mathematical relations given by equations (6), (7) and (8). The figure 3 presents the three movement of the forefinger: the two joints and the tip of the finger.

III. SIMULATION PROGRAM

A. Structural diagram of the program

The idea of the program is to offer the opportunity to simulate prosthesis, modeled by anti-quadrilateral mechanisms, of any dimension (different length of the fingers or different distance between the fingers). It is also useful in designing of anthropomorphic robotic hands, the program offering the possibility to choose the number of the fingers and which of them.

The program was written in Delphi program, the animation being created in GLScene [4] toolbox of Delphi program [3].

The structural diagram of the program is given in figure 4. The diagram could be divided in three main modules: input data module; functional module and output data module.
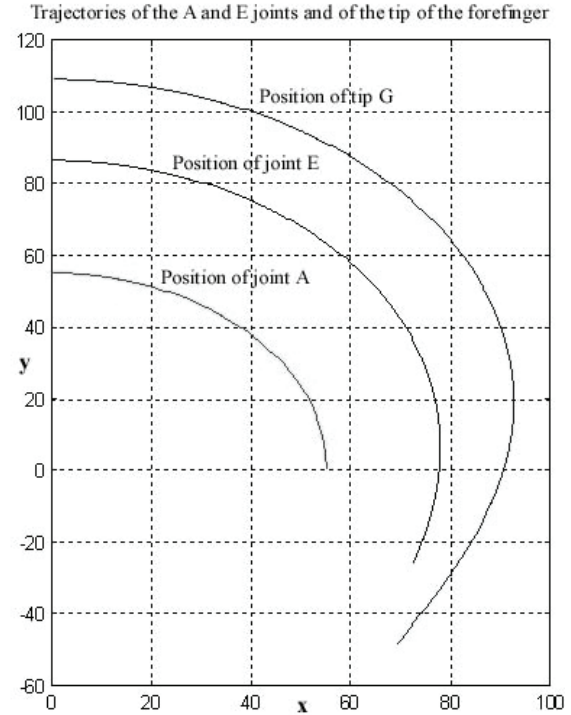

Figure 3. Diagram of movement of: tip of the finger and the joints A and E

The *input data module* contains: *timer* that allows to choose the simulation time; *test stimuli*, which are characteristics of the desired position for the time simulation period (the stimuli are predefined and the starting time is zero); *mechanical and electrical parameters* - some parameters of the incremental transducer, power circuit and motor; *initial conditions* that describe: initial position, speed and acceleration; initial condition of the stimuli and of the load; *load*, which is time variable load torque at motor axle.

The *functional module* contains: *microcontroller* that includes *SAISD (Sequential Automat for Incremental Sensor Decoding), speed determination, acceleration determination, fuzzy, limit* [1]. This module closely describes the functionality of the controller that is applied on the electronic circuit.

Another submodule is the *motor* that contains *real position determination, real speed determination and real acceleration determination* (there were called *real* because they act according to a movement laws of a body that has an external force applied). This module implements the mathematical equations that define the DC motor. On the motor act the load torque, supplying voltage, controlled by the microcontroller, and has the commanded initial conditions.

The last submodule includes the *incremental transducer* that samples the instantaneous position relative to its own step that is commanded by the mechanical and electrical parameters.

The *output data module*: generate diagrams that could be

optional visualized on window of the program. These modules are: *desired position; instantaneous position; position error; determined speed; real speed; instantaneous PWM value.*

B. Interface of the program

The program interface contains a main window (figure 5), which allows the visualization of the fingers, dynamic movement (animation based on mathematical equations described above) and access to controller window [1] and graphical visualization of the movement of the forefinger

tip.

The first window that appears when the program is started allows the user to choose the number of the fingers that are needed and also the type of the finger (figure 6a). After that, is opened, for each chosen finger, a window that contains all the geometrical parameters that describe the finger (figure 6b) [1]. The main window of the program will not be active until all the geometrical elements and all the desired fingers are completely defined.
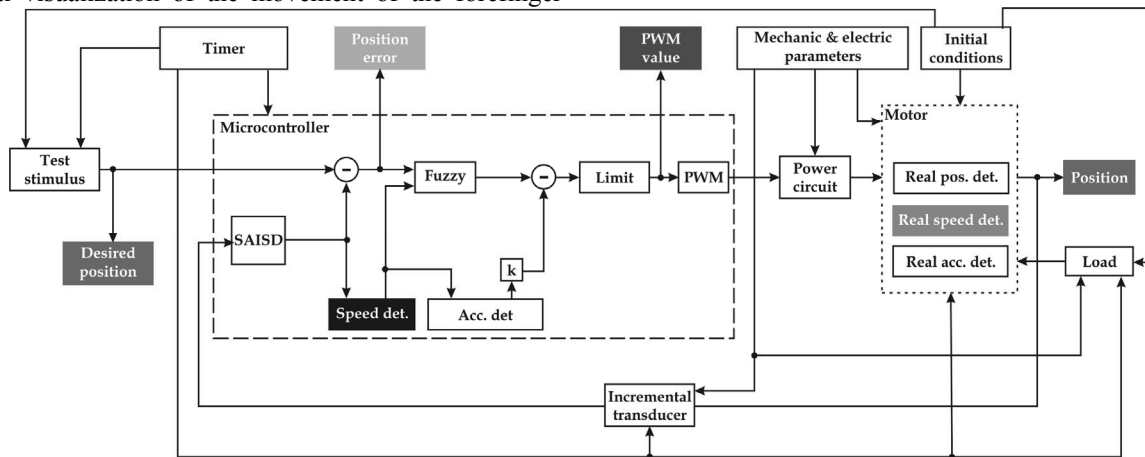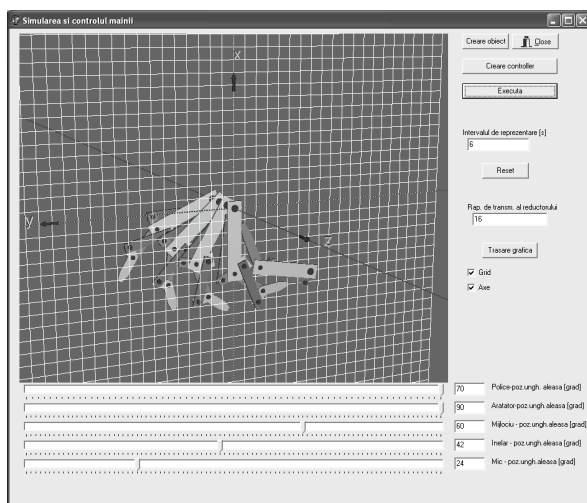

Figure 4. Structural diagram of the simulation program

Figure 5. The main window of the simulation program

C. Simulation of movement

The simulation of the movement of the forefinger can be obtained by given, in the main window, the desired position of the finger and by creating the fuzzy controllers for each finger.

The desired positions can be introduced by changing the track-bar position for each finger. In the right box will appear the value of the input angle in the first mechanism of the finger.

The controllers' parameters that can be changed are the domains of the membership functions. In the same window, activated by the button *Creare controllere* (*create controllers*), can be modified the value of the PWM input date, the value of the mass of the mobile system, etc. [1].
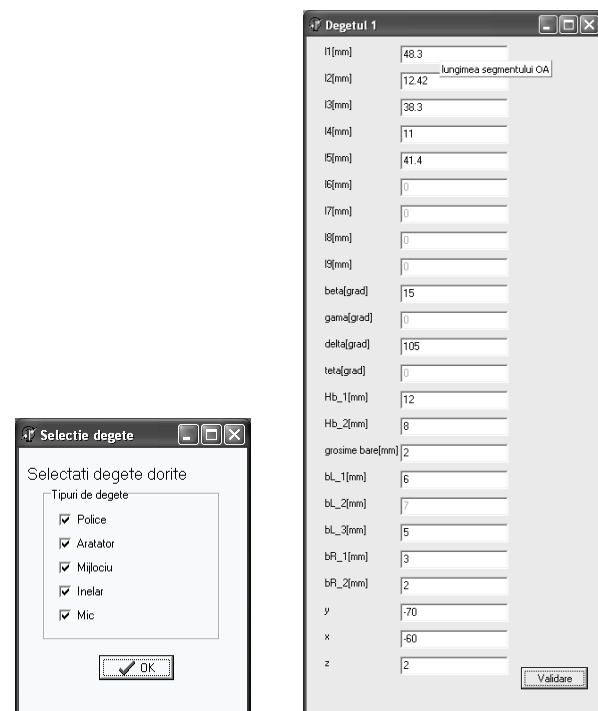

a) b)
Figure 6. The Input data windows of the simulation program

After the simulation is started, by the button *Executa* (*execute*) can be visualized, the movement of the forefinger. For the extreme position given in figure 5 (the input angle of the forefinger has maximum value of 70°) the movement is that drawn with black line in figure 7. There is also possible to be visualized the time variation of position along *x* and *y*, respectively (figure 8).
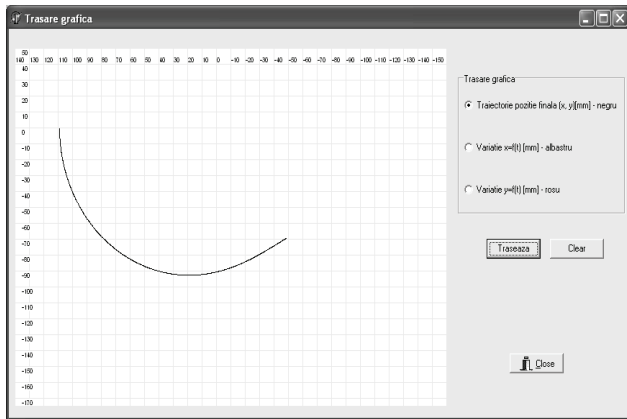
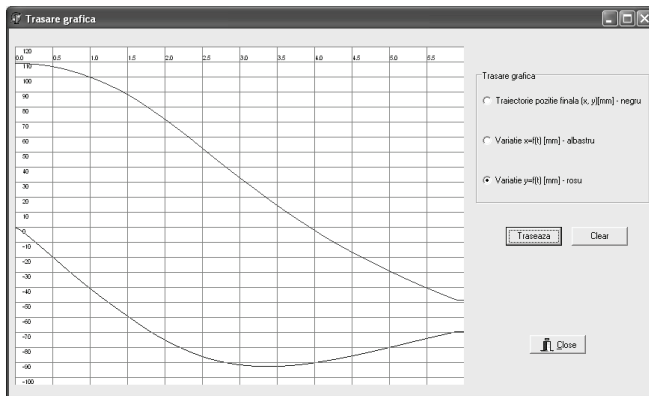Figure 7. The graphical window. The movement of the forefinger tip

Figure 8. The graphical window. Time variation of position along *x* and *y*

IV. CONCLUSION

If there are compared position of point G, which is the tip of the forefinger, presented in figure 3 with the diagram from figure 7, it can be remarked that the two diagrams are almost identical.

The first one is drawn starting from mathematical equations but it does not consider the friction or mass or any other parameter than the geometrical one.

The second one is obtained after the control. The desired position is introduced in the system and, using mathematical model of the forefinger, fuzzy controller, the motor-gear assembly, it is obtained the position of the tip of forefinger.

There is a difference between the two diagrams. The diagram of real movement (figure 7) oscillates around the final value, this oscillation appearing during the damping time of the system.

The disadvantage of this program is the fact that it does not include a structural analysis so, the values that are given in the second window (figure 6b) may not satisfy the stress conditions. This is the goal of the future work of the author.

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