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Driving Software for an Artificial Human Hand Hydraulically Actuated

Loredana Ungureanu*, Nicolae Robu* and Viktor Manoilă**

* Department of Automation and Applied Informatics, "Politehnica" University of Timişoara, Faculty of Automation and Computer Science, 2 V. Pârvan blvd. 300223 Timişoara, Romania
Phone: +40256-403249, Fax: +40256-403223, E-Mail: loredana.ungureanu@aut.upt.ro, nicolae.robu@aut.upt.ro

***Abstract* – The human hand is a very complex system, composed from bodies connected through joints. Also, includes an important sensorial system and it is an essential tool in daily activities. When loosing it, the only solution for a patient is an artificial hand, but to create a prosthesis to comply with patient's needs and expectations is a challenge for the scientific community. This paper focuses on the implementation aspect of the human hand model the authors have created. We present here the hydraulic system used for actuation and the governing program made in LabView.**

***Keywords:* data acquisition, human hand prosthesis, artificial hand, hydraulic actuation.**

I. INTRODUCTION

The process to obtain an artificial model of the human hand, able to behave as much as possible as the natural model, is very difficult due to the fact that the human hand is a complex mechanism. The vast majority of the existing models are too complex and difficult to control and, also, the price is prohibitive for many patients who would need such help.

As a first step to efficient human hand prosthesis one has to study the natural model to determine the kinematical and dynamical models. The human hand consists of connected parts composing kinematical chains so that hand motion is highly articulated and constrained [1, 11]. The kinematical study of the human fingers is very useful to conceive a basic prosthetic device because the mass of phalanges is very small. An important problem is to choose the appropriate actuators able to assure the laws of motion described by the kinematical equations and to manufacture the phalanges and the joints, as anatomical as possible, in a light material like Aluminum, Titanium, rigid plastic material, etc.

Using Denavit-Hartenberg convention, we determined a 22 degrees of freedom (DoFs) kinematical model for the human hand, very similar with the natural model [2, 3, 8]. Still, some approximations have been considered to make easier the prosthesis design process: the thumb has only two phalanges and its position in the model has been established in such a way that it could move in opposition with the rest of the fingers to assure a certain object prehension.

The dynamic modeling of the human hand is necessary because its normal physiological motions require dynamics. The human hand having a significant number of degrees of freedom (DoFs), the system of differential equations obtained modeling the hand it is very complex and imposes a numerical solution. Most of the time, the resulting model is a simplified one, especially when modeling the human body where the phenomenons are of such a complexity that an exact mathematical reproduction is, practically, impossible. In order to obtain correct results when solving the differential equations, a study of the biological properties of the materials, which compose the system, and a determination of all the necessary dimensions are required.

Based of the Lagrange equations, we determined a dynamical model for the human hand [5] and studied the system in some particular cases: when only the gravity forces act over the system [4] and when the hand grabs an objects weighting 1 g [9].

Based on these studies we created a model of prosthesis capable to perform various tasks in a 3D environment. The model takes into consideration the constraints imposed by the joints' specific geometry, expressed by the minimum and the maximum angle values [6].

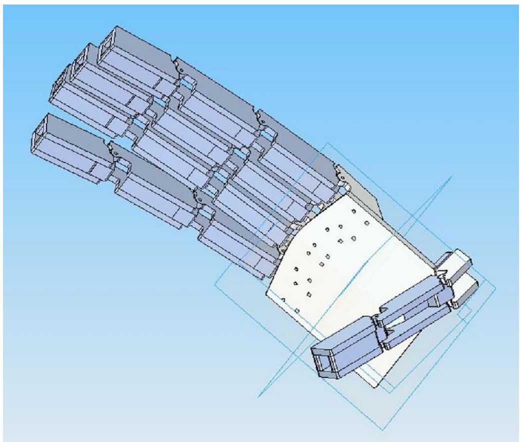

Fig. 1 The model of the artificial hand

One can observe than when grabbing an object the human brain is not focusing on the fingertips position, but on the data received during this process from the hand's sensorial system. This way, dangerous objects are not grabbed and no object is squeezed beyond breaking point. Following this approach, our artificial human hand (Fig.1) is capable to grab various objects in dimension and size.

The paper focuses on the implementation aspect of the human hand model we have created. We present here the hydraulic system used for actuation and the governing program made in LabView.

II. METHODS

Due to current technologies, the designer of a human hand prosthesis has to make some compromises to obtain a functional model. In our case, the model assures the main function of the hand, prehension. In order to move the hand we use a hydraulic actuation with stepper motors. The model has five fingers, four of them with three phalanges each, and the fifth, the thumb, with only two phalanges (Fig. 1). To grab an object the adduction/abduction motion of metacarpophalangeal articulation's degree of freedom (DoF) is not needed, so the model has only 14 DoFs. To attenuate this loss, we placed the fingers in such way that they can grab an object, no matter its shape. The hydraulic actuation allows us to place the motors and the drivers on the forearm to obtain a lighter prosthesis. We decided to use stepper motors because it provides high torque even at very low rotational speed, which can allow precision movements of the phalanges, without loosing grasp of the prehended object [10]. When not moving, the stepper motor provides an even higher braking torque, which allows to keeping firmly the grabbed object. That way, there is no danger of dropping the object when the motion of the phalanges stops.

The motors are used to move the hand, meaning flexion and extension, and to support the grabbed objects. When the motor pushes the hydraulic liquid into the actuator through the nozzle, the increasing pressure will try to push outwards the piston (Fig. 2). Because the piston is attached to the hinge between phalanges through a sleeve bearing, only the outer cylinder of the actuator can move, in the opposite direction, in the channel inside the phalange. To maintain a linear proportionality between pressure in the hydraulic circuit and the force applied to the phalange, we created a mechanism, by using a cylindrical sector concentric with the articulation of the phalanges and attached to it and a hinge linked to this sector [7]. Because the hinge is not capable to push, only the motors are not enough to open the hand, repellent springs being necessary.

When the prosthesis will have to grab an object, the control circuitry will issue to the pumps the command for increasing pressure. A pressure limit has to be set for every phalange, according to the nature of the object to be grabbed.

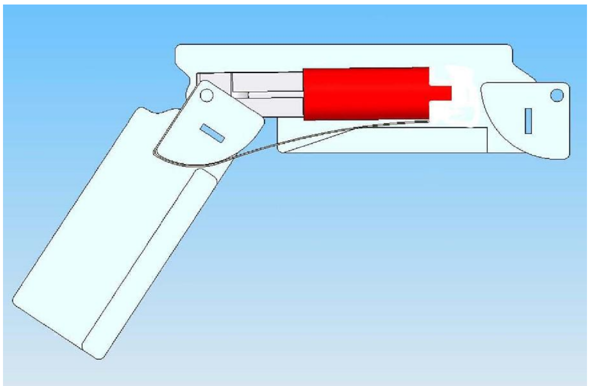

Fig. 2 Articulation between two phalanges

Every phalange will start closing in around the object and the movement will stop automatically the moment all the pressure limits were reached. This means that pressure sensors are necessary for a correct and a precise motion.

The stepper motor chosen to move the phalanges is UBL23 of RS Component. This is a unipolar stepper motor which, despite its size a little higher than necessary, has the huge advantage of linear motion for the shaft. In this way we solved the delicate problem of transforming the rotational motion of the motor's shaft into a translational motion. The motor receives the necessary driving signals from SAMOTRONIC101 driver (specially designed for that), meaning the step and the motion's direction. Each motor's shaft is connected to a hydraulic pump (Fig. 4), which through a hydraulic tube is linked to a hydraulic actuator placed in a phalange (Fig. 3).

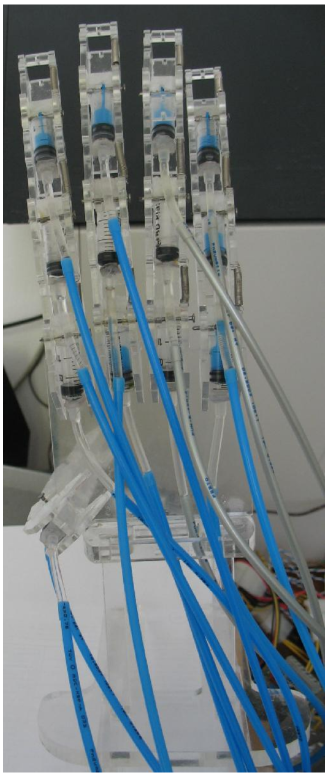

Fig. 3 The artificial hand

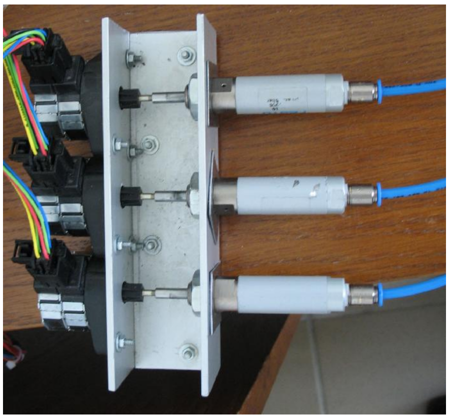

Fig. 4 Articulation between two phalanges

After establishing the driving logical sequence one has to send this sequence to the motor to be executed. We used for that NI-PCI-6509 data acquisition board from National Instruments which is an industrial interface having 96 digital channels for PCI systems. They are compatible with TTL, CMOS, and 5 V digital logic levels and can input and output at 5 VDC digital levels and directly drive external digital devices with current up to 24 mA per channel. Each port can be individually configured for input or output, and no external power supply is required for outputs.

Each motor has to receive its driving signals from a SAMOTRONIC101 control board. In order for this board to work, one has to correctly connect its terminats: ground at terminal 1, an external clock for stepping the motor at terminal 5, the direction for motor's motion at terminal 4. The clock and the direction signals comes from a computer through the NI PCI-6509 data acquisition board, connected to a block CB 100 I/O with a cable R1005050. The connecting bloc has 50 terminals groupped in 6 I/O ports and can be used to connect external ecquipments to the data acquisition board. As an example, for the pinky finger of the artificial hand, we connected the driving signals as in Table 1.

Table 1. The terminals used for driving the pinky finger

Terminal	Function
39	External clock for the motor driving the proximal phalange
37	External clock for the motor driving the medial phalange
35	External clock for the motor driving the distal phalange
33	The signal to specify the motion's direction

The actions of the artificial hand are governed by software running on a computer. This software should send the driving signals to the motors and should receive signals from the sensors through the data acquisition board. The technological limitations encountered when implementing the artificial hand's structure and the driving part led to a simplified version of the program. The resulting structure does not use sensors (the pressure in the system has pretty low values and the resulted force will not be able to break an object).

III. THE DRIVING SOFTWARE

The application uses the LabView platform of National Instruments, which is specially designed for implementing data acquisition applications. The application offers a very friendly and easy to use interface (Fig. 5) which contains a command block for every finger of the hand. Due to the fact that, when closing the hand, the phalanges of a finger move approximately with the same speed, the application allows the user to specify that speed at finger level. Actually, the user can set the frequency of steps sent to the motors of a finger (using a knob from the application's interface) which is directly proportional with the speed of phalange's motion.

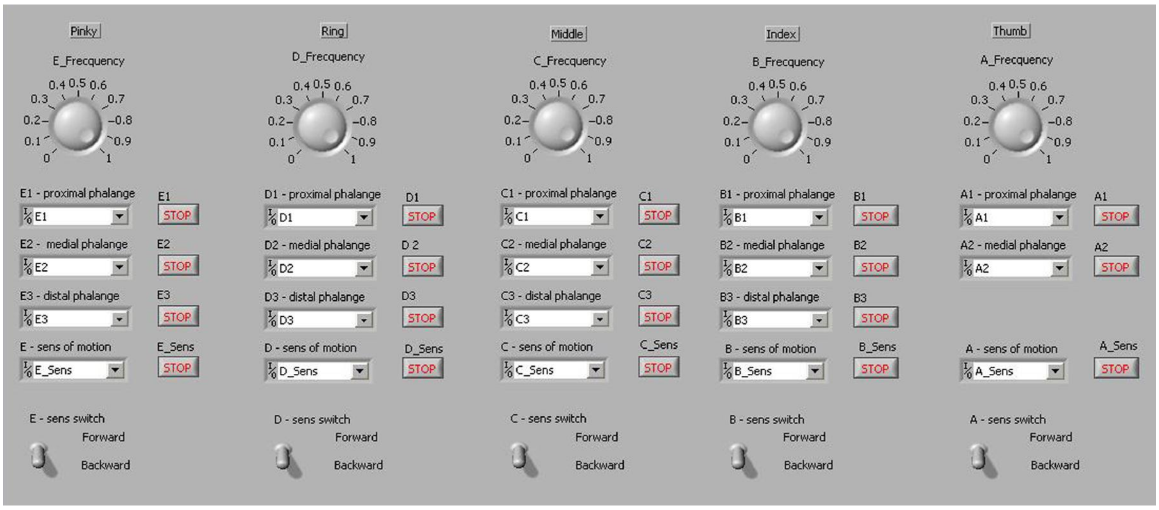

Fig. 5 The application

Table 2. The virtual channels for pinky finger

Motor	Task	Port/line
Proximal	E1	0/4
Medial	E2	0/5
Distal	E2	0/6

When starting the application, one has to make the necessary connections to link the virtual instruments used to generate the driving signals with a certain motor. In this purpose, on the application interface there are selection lists for all the motors in the system and the user has to choose from those lists the needed virtual channels. Table 2 presents the necessary virtual channels, the port and the port's lines for the pinky finger.

The user can change the motors' rotational direction, which will determine the fingers to close (when the motors are going forward) or to open (when the motors are going backwards). For that he has to click a switch (one for each finger) placed on the application interface.

The actions of the application's elements are controlled by the application's block diagram. For each finger, excepting the thumb (only three algorithms), the block diagram contains four algorithms. Three of them are identical (Fig. 6) and controls the stepping clock for each motors, and the forth controls the direction signal for the finger.

When starting, the application allocates memory for the task *E1- proximal phalange* which steps the proximal phalange's motor, creates a measuring task (the *DAQmx Create Channel* block) and allocates memory for it (the *DAQmx Start Task* block). Because the step is periodically and repetitively generated, a while loop is needed. In this loop, the *DAQmx Write* block writes data samples from the *Simulate Signal* block in the logical channel. The *Simulate Signal* block generates data samples with the frequency from *E_Frequency* knob. The algorithm will run until the *Stop* button is pushed (by the user from the control panel of the application) or an error occurs when reading or writing data. When stopped a task is removed from the memory by the *DAQmx Clear Task* and cannot be reused until the restart of the program.

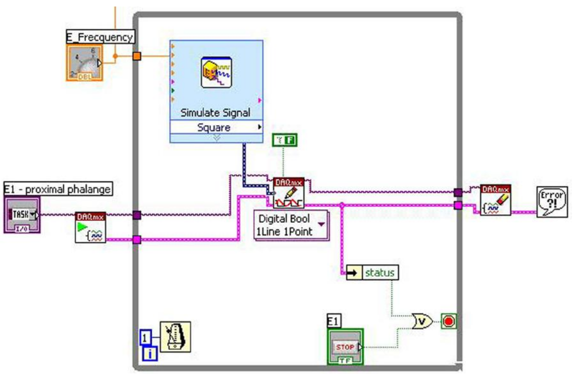

Fig. 6 The algorithm for stepping signal generation

The fourth algorithm is very similar. In this case the *DAQmx Write* block writes in the channel the current state of the swich with a periodicity of 100 ms set by the *wait until miliseconds* block.

III. CONCLUSIONS

The paper presents an artificial hand model and the application in charge with its actuation. This application is able to drive 14 stepper motors to induce motion in the artificial hand having 14 DoFs and a hydraulic actuation. Each motor needs to receive from the application through a data acquisition board a step signal and a directional signal. All the fingers can move with the speed and in the direction decided by the user from the application.

At this stage, the application drives the system without having any feedback from it, due to the fact that the pressure in the hydraulic system cannot have high values to break the grabbed object. A future goal will be to improve the hand's structure so the application can consider the system's feedback.

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