

Hydraulically Actuated Artificial Hand Model

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Abstract. To replace the lost hand of a patient with a prosthesis able to provide the same capabilities is one of the most challenging problem of rehabilitation and medical engineering. There are many solutions, but none of them close enough to the natural hand. The present paper offers a model of the human hand, actuated hydraulically. The model is capable to insure the prehension function, while being a low cost solution for the Romanian market.

Keywords: data acquisition, human hand prosthesis, hydraulic actuation

I. INTRODUCTION

For each human person, the lost of the upper limb will induce a dramatic decrease of its performances and an obvious cosmetic disadvantage. To replace the lost hand with prosthesis able to provide the same capabilities is one of the most challenging problems of rehabilitation and medical engineering. Comparing the capabilities of the human hand versus the existing prostheses, the results are very discouraging for the one working in this field. Despite this, the human hand complexity determined the researches over time to create functional models to replace it when necessary. The fact that the problem is still open even nowadays is determined by its complexity and not by the lack of talent or effort. The last years' progress proves it.

The human hand consists of connected parts into kinematical chains, resulting in a highly articulated natural mechanism. At the same time, the many constraints among the fingers and the joints make the hand motion modeling even harder. There are various solutions for a human hand model ([1], [3], [7], [12], [13]) and most of them are created having in mind a certain task like computer animation, designing of human hand prostheses, medical studies, etc.

There are quite a few solutions for human hand prostheses, based on mechanical [4], [15], electrical [2], [16], electromechanical [14], pneumatic [5], [17] or hydraulic [6], [8] implementations, some of them reaching already to the market. Studying what happened in this field during last few years, it is easy to observe that there is a trend to increase dexterity of the prosthesis for the human hand. On the other hand,

it is desirable to create simpler and more practical and applicable devices. The models proposed so far (LMS Mechanical Hand [4], Robonaut Hand [15], DLR Hand [2], Barret Hand [16], Shadows Dexterous Hand [17], etc.) represent acceptable solutions, but most of them are too complex to be afforded by the majority of patients (and difficult to control, as well).

This paper presents a model for a human hand prosthesis simple enough not to induce high production costs, but able to assure the prehension function, the most important capability of the natural model. To create a lighter prosthesis we decided to place the driving system on the forearm, so the hydraulic actuation was the solution able to fulfill this demand. An innovative mechanism placed in each articulation insures the proportionality between the force applied by the motor and the force applied by the phalanges.

II. DESIGN OF THE MODEL

Studying the existing models we could draw an important conclusion: all of them follow the trend of growing complexity, not only constructive, but also functionally. Confronting this with the needs of potential patients and the therapeutic possibilities of our country, we evaluate that the current designing trend will not generate usable results in a predictable future. So, our design paradigm limits the functional “abilities” of the prosthesis to the prehension function only. The reasoning behind this design decision is to considerably simplify the model in such a way to offer an acceptable economical efficiency, based on the observation that the majority of the patients have one functional natural hand, to be used for high precision tasks.

The second notion to fulfill through our design paradigm refers to the mechanical linearization of the ratio between the generated force and the grabbing force. We created a simple and original system, very efficient, which saves a lot from the computing power necessary to generate and apply the driving impulses.

The third and last notion of our design paradigm tries to solve the difficult problem of the constrictive actuator (the so called artificial “muscle”), needed to

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move the artificial hand's phalanges. It is obvious that the force necessary to close the hand is much higher than the one to relax it. From this reason, using a direct driving system with pushing elements will generate results opposed to the natural model (high force to open, reduced force to close). So, we used the "reversed" force of the actuator to mimic the natural model.

As it can be seen from Fig. 1, our prosthesis model has a very similar structure with the natural model. There are five fingers: four of them have three phalanges each and the fifth, the thumb, has only two phalanges. According to the first notion of our design paradigm, we eliminated a degree of freedom (DoF) from the metacarpophalangeal joint, the one due to adduction/abduction motion. To ameliorate this loss, we linked the four central fingers in such way to the palm to assure the grabbing of objects having various shapes. With this constrain, our model has 14 DoFs, plus the 3 DoFs of the wrist.

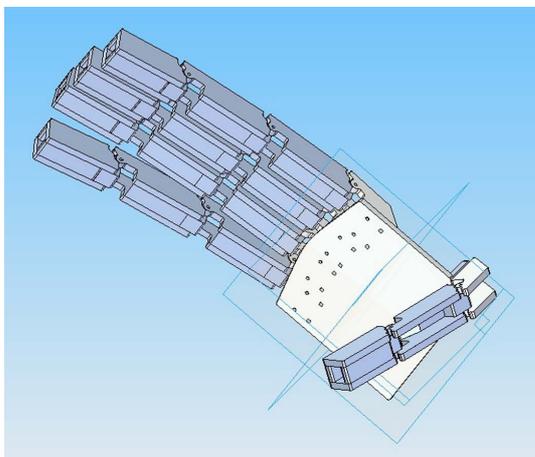


Fig 1. The model

Studying the way the natural hand grabs the objects, we noticed that the phalanges wraps around the objects trying to follow their shape. Also, when grabbing, the human perception do not pays attention to the exact position of each phalanges, but focuses on the tactile sensation instead. In this way dangerous objects are not grabbed and no object is squeezed beyond it breaking point. Based on these observations, we designed the driving system of the prosthesis, which impose pressure sensors due to the large variety in shapes and sizes of the grabbed objects.

Obviously, there is no way to get rid of the pressure sensors without seriously limiting the range of the objects to be handled, but it would be extremely helpful if they will not be located near the contacts with the objects under prehension. Based on this idea we have chosen a hydraulic powering for our prosthesis. On the other hand, this powering system will allow us to place the motors and the driving units on the forearm, obtaining a reduced weight of the prosthesis. In this way, the forces and torques exerted by the phalanges will be proportional to the pressure of the hydraulic fluid, which will be practically

constant (due to negligible quantities and movements of it) in any point of the hydraulic circuit (Fig. 2, [9]). This allows the replacing of tactile pressure sensors (located at the contact point) with fluid pressure sensors (located remotely, i.e. near to the hydraulic pump), very important because will eliminate two possible problems: the high difficulty of integrated tactile sensors on the phalanges, and the probability that tactile sensors will not be able to cover the whole surface of the phalanges, so some objects having irregular shapes can have a contact point outside the sensors' area.

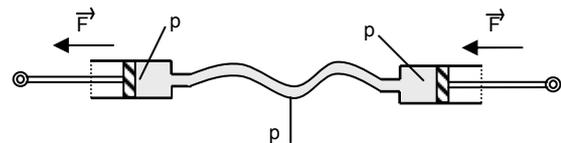


Fig. 2 The hydraulic circuit

The pressure into the hydraulic circuit being constant, results that the proportionality between the force applied by the motor and the force applied by the phalanges is directly influenced by the surfaces of the two pistons, according to relation (1). In this way, if the travel of motor's shaft is long enough to close the phalange, the two cylinders can be identical, so the forces will be equal.

$$F_f = \frac{S_f}{S_m} \cdot F_m \quad (1)$$

- where F_f — the force applied by the phalange
 F_m — the force applied by the motor
 S_f — the surface of the hydraulic pump's piston from the phalange
 S_m — the surface of the hydraulic pump's piston from the motor

When there is a need to grab an object, the control circuitry will issue to the pumps the command for increasing pressure. A pressure limit should be set for every phalange, according to the nature of the object to be grabbed. Every phalange will begin closing in around the object, without the necessity of knowing its instantaneous position. The movement will stop automatically the moment all the pressure limits were reached. The object is considered grasped and can be moved. [10]

Studying the natural model, we observed that the motion of the human hand is constrained and the hand couldn't perform arbitrary gestures. So, we designed the phalanges in such way to limit the range of motion for each possible joint to 90° (although proximal interphalangeal joint of the natural model allows a larger range of 110°).

Each joint is moved by a stepper motor which pushes the piston of a hydraulic pump. Through the hydraulic system the motion will be transmitted to a piston

linked to the joint, which will induce the phalange's motion. This motion will surely stop when the angle from two adjacent phalanges is 90° . Also, constructively, the motion of the joints towards negative values is restricted.

To achieve this goal, we devised a simple yet effective mechanism, by using a cylindrical sector concentric with the articulation of the phalanges and solidified to it [9]. A steel belt is attached to the actuator and wrapped around this cylindrical sector which will transform the motion of the piston (attached to the hinge between phalanges) in the motion of the outer phalange (Fig. 3). The steel belt is tangent all the time to the cylindrical sector. Basically, using this simple mechanism, the pressure in the actuator will be linearly proportional to the force normal on a given point on the distal phalange, regardless its position to the proximal phalange. The angle equals 90° all the time, which corresponds to the particular case of having maximum transfer of a force into a torque, in a crankshaft mechanism.

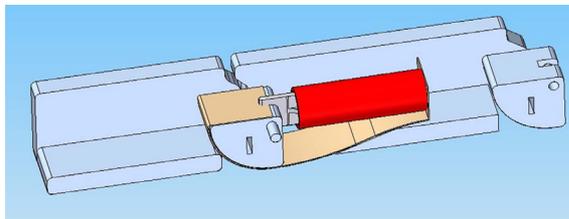


Fig. 3 The joint between two phalanges

The extension of the phalanges can not be completed on this model only by using negative pressures in the hydraulic circuit, because the steel belt is not capable

of pushing. That it is why a repellent spring must be used.

III. IMPLEMENTATION

During a SOCRATES/ERASMUS scholarship at IUT Bethune, France, we executed the prosthesis by cutting the composing elements from PolyMethyl MethAcrylate (PMMA), known as *Plexiglas*. We used laser machining and Table 1 presents all the necessary cutting parameters. After cutting, all the needed elements were glued using trichloromethane. In the end, assembling all the elements we obtained the prosthesis as in Fig. 4.

Table 1. The cutting parameters

Process	Cutting
Protective medium	Nitrogen
Speed [mm/min]	3000
Distance from the piece [mm]	1
Power [W]	500

To drive the prosthesis we decided to use stepper motors, which seems to be the best solution. A stepper motor assures a high torque even at low rotational speeds, which allows precision motion of the phalange. When stopped, the motor has a higher breaking torque, necessary to sustain the grabbed object. One disadvantage is the electrical energy consumption, which is highest when there is no movement at all, but the complexity of driving electronics is lower than in the DC motor's case.

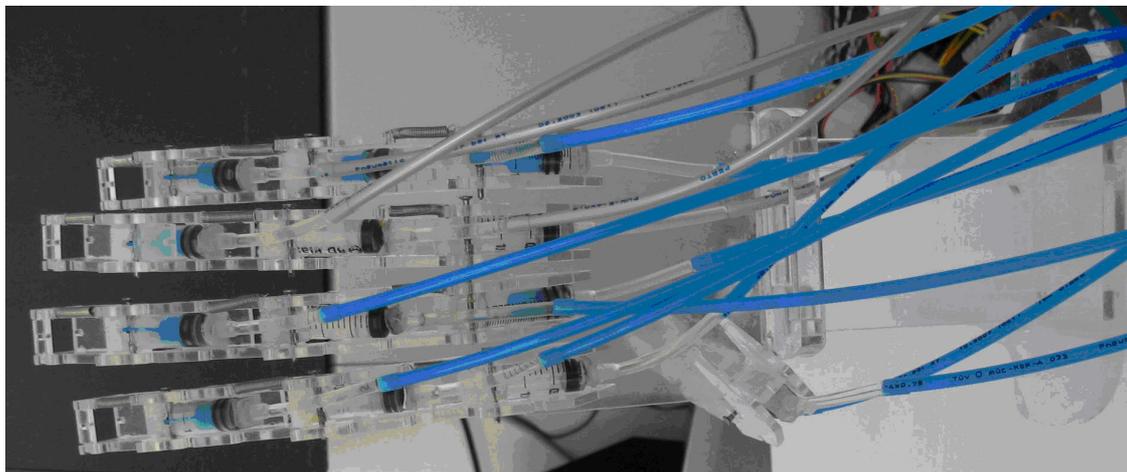


Fig. 4 The realized prosthesis

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 a specially designed driver, SAMOTRONIC101, meaning the

step and the motion's direction. Each motor's shaft is connected to a hydraulic pump (Fig. 5), which through a hydraulic tube is linked to a hydraulic actuator placed in a phalange.

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.

Each motor has to receive its driving signals from a SAMOTRONIC101 control board. The clock and the direction signals come from a usual computer, through the NI PCI-6509 data acquisition board, connected to a CB 100 I/O block with a R1005050 cable. The connecting block has 50 terminals, grouped in 6 I/O ports, and can be used to connect external equipments to the data acquisition board.

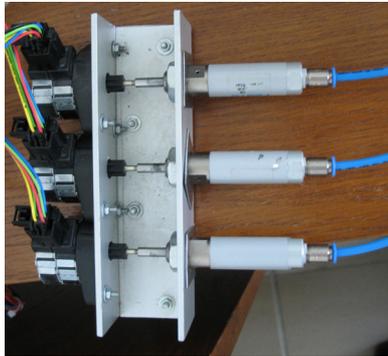


Fig. 5 The motors and the pumps

The actions of the artificial hand are governed by software running on the computer. This software sends 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 [11]. 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).

IV. CONCLUSIONS

We realized that the most important function of the hand for the patients who lost their upper limb is prehension, so our solution restricts, for the moment, the purpose of human hand prosthesis only to this function, intending as future work to implement a fully functional prosthesis. This idea originates from the fact that the vast majority of potential patients have one good hand for delicate actions and one affordable prosthesis with grabbing capabilities (to replace the missing one) will help them to manage through most of the daily activities.

Our proposed model is capable to perform the prehension function for large diversity of objects (of either regular or irregular shape). The pressure in each hydraulic circuit varies linearly proportional to the force exerted by its respective phalange on the grabbed object. Those characteristics make our model one of the simpler, yet reliable and non expensive, among the specific research in the field.

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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