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A Hydraulic Solution for Implementing Human's Hand Prehension Function

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Abstract

It is possible that a good part of humans becoming the dominant species on the planet resides in the natural design on the hand. That is why researchers give a lot of attention to modeling it, in order to obtain a good hand prosthesis. Despite many attempts, very few solutions are implemented, and even those are far to expensive to reach the general public. Our solution restricts the purpose of a human hand prosthesis only to its prehension function, considering 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.

1. INTRODUCTION

There are quite a few solutions for human hand prosthesis, based on mechanical [3], [10], electrical [1], [9], electromechanical [7], pneumatic [4], [8] or hydraulic [5] implementations, some of them reaching already to the market. The main setback is that each of them is to complex to be afforded by the majority of patients in need. Our solution simplifies the requirements by observing that the main function of human hand prosthesis is prehension [2], [6]. Bearing that in mind, we simplified the model to such an extent that we do not anymore need sensors for position and temperature. Even more, the sensor for measuring the mechanical tension in the phalanges was replaced by a simple pressure sensor of the hydraulic fluid. Since the pressure in the hydraulic circuit is basically the same in any given point, this observation allowed us to move the sensor from the hand itself near to the command module, making possible a smaller implementation, closer to the real anatomy of the human hand. Another original observation is that position sensors are needless for grabbing things. What are to be known are the nature and the approximate weight of the object to be grabbed. The grabbing motion will end for every phalange the moment the maximum supported force by the specific object to be grabbed is reached. Of course, a comprehensive set of parameters should be measured and stored for the most common objects susceptible to be grasped. Our model, despite its limitation only to prehension function, creates the premises for obtaining good and reliable hand prosthesis at an affordable price.

2. INITIAL CONSIDERATIONS

Technologically speaking, it is not feasible yet to design a human hand prosthesis which can mimic all the natural functions. Bearing that in mind, we considered that we should exclude from the initial design specifications the implementation of some marginal functions like: using sign languages, puppetry, needle point, hand writing, Braille reading, painting, and other similar activities. With all these excluded and focusing only on the prehension function, we observed that knowing the position of the phalanges at any given time is no longer necessary. Studying the way human hand grabs various objects, we observed that the phalanges are closing in, trying to follow the object's contour (Fig. 1, [5]).

Studying further the natural model, we observed that, when grabbing, the human perception does not focuses on acknowledging every phalange's position, but paying attention to tactile sensations instead. That allows not grabbing dangerous objects (too hot or too cold, harsh, cutting, puncturing, etc.) or to squeeze them beyond the breaking point. In our model, we considered that by using strong materials like titanium, the use of thermal sensors is no longer necessary. However, due to the various natures of the objects to be manipulated, pressure sensors are mandatory.

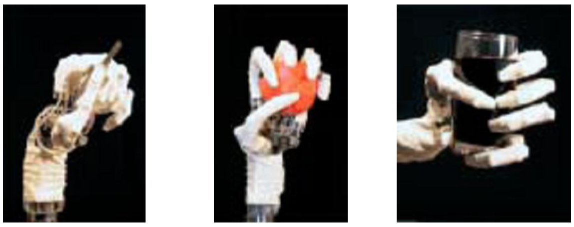

Fig. 1 Examples of grabbing various objects

Unfortunately, good pressure sensors with a shape to comply with the phalanges are hard to find, expensive, and influencing the grabbing characteristics (Fig. 2 [5]). The reason resides in the fact that those sensors are usually build by using a compressible silicone compound, which can not stand the same temperatures and rugosities like a titanium phalange.

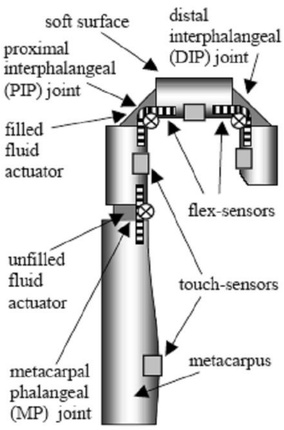

Fig. 2 Schematic construction of a finger [5]

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. This idea led us to the hydraulic powering of our hand prosthesis. 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. 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 (Fig. 3).

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 will 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.

3. Implementation

Our solution is based on hydraulic transportation of the force needed to move the phalanges from a pump to a hydraulic actuator. By using the same diameter on both of them, the force and the motion of the pump will be replicated by the actuator, while the pressure will be the same throughout the circuit, for a given load (Fig. 3). A hydraulic pressure sensor can be attached anywhere on the hydraulic circuit (but, preferably, closer to the pump), using a normal T-shape derivation.

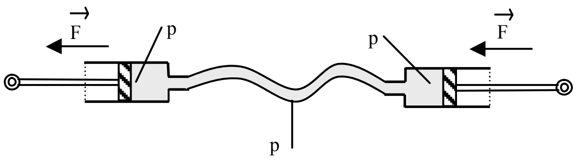

Fig. 3 The hydraulic circuit

The main idea in mimicking the tactile function in our model is to measure the pressure of the hydraulic liquid. The problem is that if we use a simple crankshaft mechanism to connect the actuator to the phalange, then the variation of the pressure will not be linearly proportional to the variation of force applied to the phalange (but being weighted with the sinus function of the angle between crank and the connecting rod from the actuator.) In order to keep this variation linear and independent from the relative position of one phalange to the other, we need to keep the above mentioned angle always at 90°.

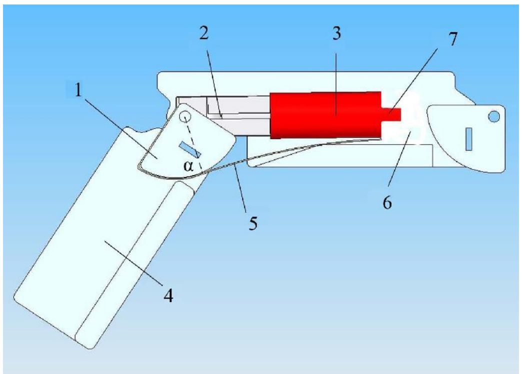

Fig. 4 Working principle

To achieve this goal, we devise a simple yet effective mechanism, by using a cylindrical sector (item 1, Fig. 4) concentric with the articulation of the phalanges and solidified to it. When the hydraulic liquid is pushed into the actuator (item 3, Fig. 4) through the nozzle (item 7, Fig. 4), the increasing pressure will try to push outwards the connecting rod (item 2, Fig. 4). Because the connecting rod 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 (Fig. 5).

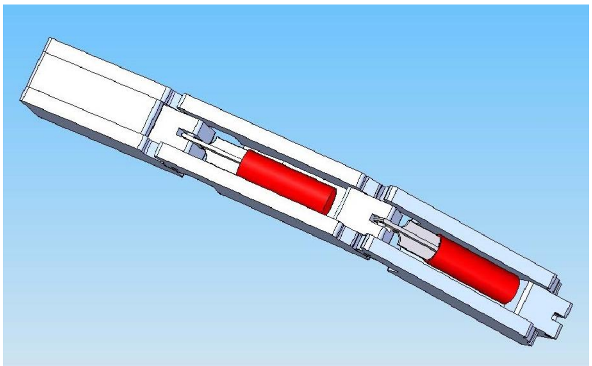

Fig. 5 One finger without top cover

There is a steel belt (item 5, Fig. 4) attached to the actuator and wrapped around the 100° cylindrical sector. When the actuator pulls the steel belt, the next phalange will be flexed. The steel belt is tangent all the time to the cylindrical sector (the α point, Fig. 4). 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. It is easy to see that α 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. An assembly view of the proposed prosthesis can be viewed in Fig. 6 and Fig. 7.

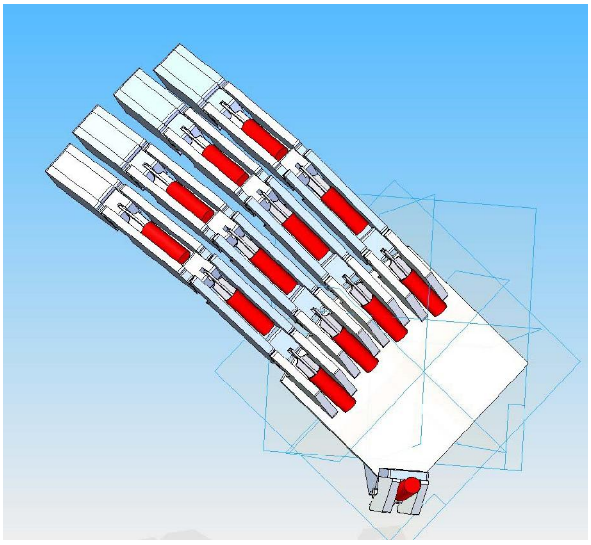

Fig. 6 Top view of extended prosthesis

Using the "reversed" force of the actuator was dictated by the observation that there is needed much higher forces for flexion than for extension. In our model it is mandatory to use positive pressures for flexion, because the negative ones are limited by the atmospheric pressure.

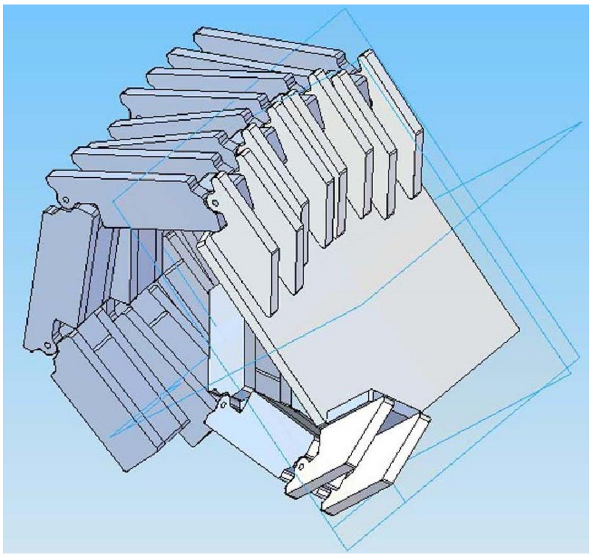

Fig. 7 3D view of the partially flexed model

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.

4. Conclusions

The proposed model is capable of insuring the prehension function for large diversity of objects of either regular or irregular shapes. The solid state design, using materials like titanium, stainless steel, and high boiling point hydraulic liquid, renders the usage of thermal sensors completely unnecessary. The pressure in each hydraulic circuit varies linearly proportional to the force exerted by its respective phalange on the grabbed object. By limiting the prosthesis' functionality only to prehension, the necessity of encoding the instant position of every phalange was also eliminated. Those characteristics make our model one of the simpler, yet reliable and non-expensive, among the specific research in the field.

5. Further Research

In order to be fully functional, our model must be supplied with further work. One short-time goal is to design the model's powering up. To have this done we choose miniature stepper motors with 1:16 gearbox, connected to the pump's rod through a leading screw. The stepper motor seems to be, at this point, the best solution for our model, because of many reasons. 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. 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. One foreseen disadvantage is the electrical energy consumption, which is highest when there is no movement at all. There is a workaround by lowering stepper motor's voltage when still. It is true that DC motors are much more energy efficient (since there is no voltage applied to them when not moving) and came in even smaller sizes, but they show an usable torque only at high revolution speed and have no braking torque at all when still. There is a workaround too by using Archimede's infinite screw, or a fine leading screw, or both. In the stepper motor's case the complexity of driving electronics is lower, while in the DC motor's case is higher. The tradeoff between the two solutions should be carefully evaluated.

One long-term study will start with the experimental work. Objects of different shapes, weights, and textures should be prehended from a table, using our model. A database should be build, containing the pressure limits in every phalange, for every given object. This study should be carried out both statically (meaning to find out which are the necessary forces to grab firmly every given object against its on weight, without destroying it), as well as dynamically (meaning that the object should be kept without dropping it and without crushing it while moving the artificial hand.)

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