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An approach to the development of a low-cost anthropomorphic robotic hand

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***Abstract*— This paper provides an overview of the world's most famous and successful robotic hands design. Constructive solution was suggested based on analysis and critical reviews of existing robotic hands. In the world, from the technical point of view, there is a large number of solutions based on different types of actuation. The most common are tendons, embedded motors, pneumatic, hydraulic and other ways of actuation. Several tendon based finger prototypes were made in order to comprehend the design problems and make improvements for further work. Considering the high prices of available robotic hands, the emphasis is placed on the constructive solutions and selection of low-cost components. We also analyzed the possibility of using robotic hands as prosthetic devices. Proposed solution is a compromise between functionality and anthropomorphic characteristics.**

Keywords-component; antropomorphic robotic hand, tendon drive, multifinger

I. INTRODUCTION

The hand is a very complex part of human body. It has a wide capability in object manipulation. Man uses his hands in different tasks like holding, shaking, grasping, touching etc. Because of it, it is very hard to design a robotic hand that is able to perform all of these tasks in human manner. One robotic hand could be part of an industrial or humanoid robot. However, also can be a part of human body as prosthetic device. This means that design of the hand depends on its application.

Bio-inspired artificial hand is actually universal gripper capable to optimally manipulate with objects different sizes and shapes. Back in 1919. Schlesinger [1] has defined six basic ways of grasping Fig. 1.

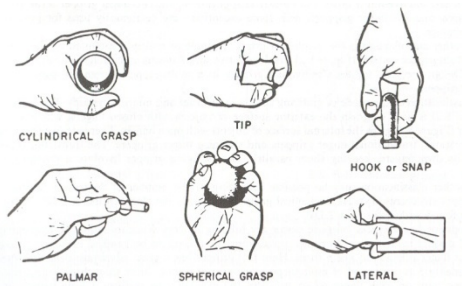

Figure 1. The various types of hand prehension

In order to achieve these movements it is necessary for finger parts to have some kind of actuation. For that matter, several types of actuators can be used, servomotors, pneumatic or hydraulic cylinders (artificial muscles) as well as some more modern "motors" such as piezoelectric, memory alloy etc. In this paper mechanical design was considered, while control will be reviewed in other one. [7]

II. OVERVIEW

More than 30 years a development of artificial hand has been the subject of interest in many research centers and institutes. Many studies have been made and large number of papers has been published in which researchers give advantage to different types of designs.

Reference [2] shows that serious approach to this subject began in early eighties at Stanford (JPL) and Massachusetts (MIT) Universities. Hands made at MIT and JPL represent milestone in robot hand design.

However, we cannot forget the fact that, in mid sixties, in Belgrade at Mihailo Pupin Institute was made "The Belgrade hand". Even then, this remarkable design was sold in Huston, USA and now it can be found in robotics museum in Boston. Even though it was actuated with only one geared motor, complex lever mechanism had enabled contraction and protrusion of fingers. Force sensors, situated in finger tips, controlled power supply during the contact with environment Fig. 3

Figure 2. The Belgrade hand

Figure 3. Lever mechanism in Belgrade hand

Although one of the conclusions in [2] was that compliance cannot be achieved with simple design, the elegant solution with elastic connections gave system a limited compliance.

If we want to copy human anatomy, we need the actuation for every joint in robotic hand. Since every finger has 3 joints of which metacarpal (MCP) has 2 degrees of freedom (DOF), it means that whole had has at least 20 DOFs. Thumb is problem for itself. This large number of joints would imply the use of large number of actuators. In order to solve this problem many analysis where conducted. From mechanical point of view, actuators could be placed in joints, near joints or far away from joints Fig. 4-5. All of these approaches have its pros and cons.[3], [10]

For example, in design where motors are not inserted near joints, a driving force is transferred via system of levers or using cables - tendons. This setup is also known in industrial robot design for the purpose of better mass distribution, but it also has lots of disadvantages i.e. additional elasticity, friction, nonlinearity etc. On the other hand motors integrated in joints or close to them have as result significant increasing costs due to producing new types of smaller mechanical components like gearboxes, servomotors, encoders, force sensors etc. In [4] motors built in DLR/HIT Hand I have diameter of 20 mm and height of 10 mm and have weight of only 15 grams and are paired with similarly sized gearbox. Transmission of torque to the joint is accomplished with miniature toothed belts.

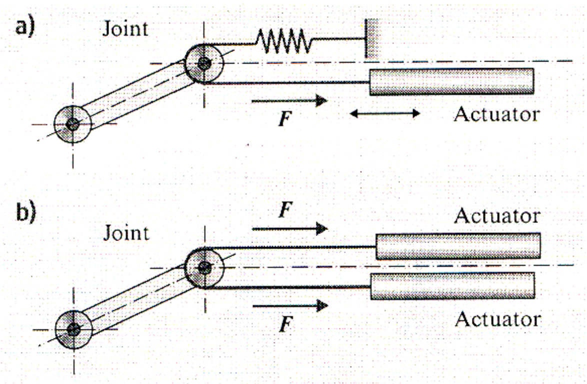

Figure 4. a) single acting actuator with an antagonist passive element (spring) b) an agonist – antagonist configuration

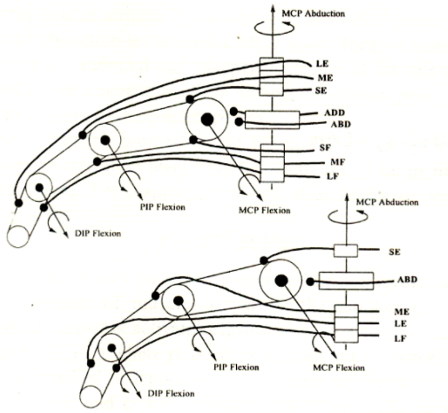

Figure 5. 2N and N+1 tendon robot fingers, where N is the number of DoFs (in this example DoF=4)

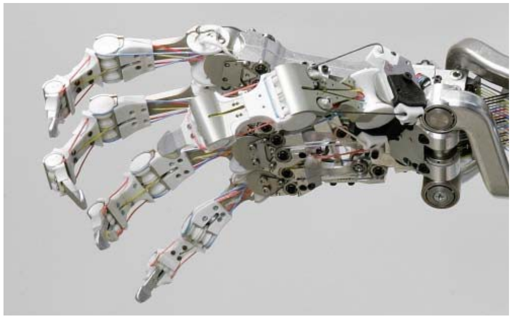

Figure 6. DLR hand with tendons

Example of joint actuation with 2N and N+ 1 tendon can be seen on Fig. 5. German Institute for mechatronics and robotics (DLR) in the past 10 years has significant results in this area. Substantial funds have been invested and large number of scientists has been involved in this project. As a result few different types of the robotic hands where designed Fig. 6-7. In [9] are also analyzed some of designs mentioned above with similar conclusions. Either price is too high or performances are not at satisfactory level or simply they are not commercialized yet. Therefore KITECH hand was suggested, where actuation system consists of RC servo modules, because of their cheap price and their accessibility on the market. As in some other solutions pinkie finger was removed, since it participate in load

Figure 7. DLR/HIT hands

capacity from about 5% while we save up to 20% (mass, actuators, sensors,...) by removing it. This hand is considered for low-cost hands on the market and its price is around 10 000 dollars.

III. MECHANICAL DESIGN

Based on this assumptions and analyzed papers, in accordance with available resources, we decided to try and design low-cost tendon-based robotic hand. RC motors will be integrated in forearm together with power and control electronics as well as power source - batteries. In the beginning, solutions based on pneumatic or hydraulic actuation (artificial muscles) were discarded, because they need external power supplies. This is important because we have intentions to use this robotic hand as a prosthetic device with a certain type of amputations.

In order to reduce the cost of production first finger prototypes shown in Fig. 8 are built using 3D printer. This way of production is commonly used in rapid prototyping processes. Many researches use this method to build artificial fingers and robotic hands. Two models were made, first one designed only for 3D printing while the other one could easily be remodeled for production purposes and be built from standard aluminum profiles (tubes, U profiles, etc). Contact surfaces would be covered with soft artificial materials (like synthetic rubber or polyurethane) with the aim of creating the human qualities. This rapid method provided us in a short time with useful information relating primarily on the method, how a tendon can be attached to finger parts and how to conduct it along the finger to the motor. Tests were made by using ordinary fishing nylon. However, our intention was to acquire and use more reliable material. In many papers so called DYNEEMA material was analyzed and used.

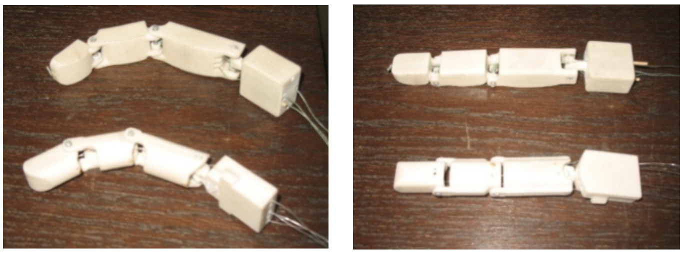

Figure 8. Prototypes of Pupin's fingers

Figure 9. CAD model of Pupin's Hand

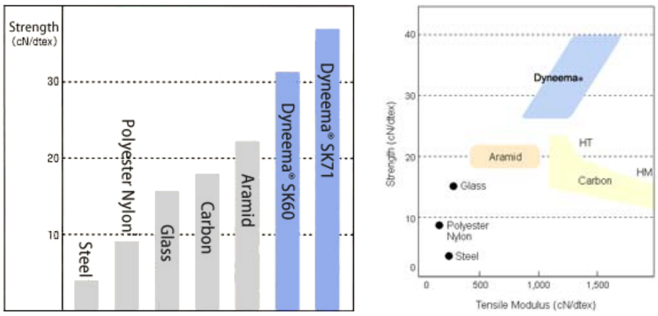

Figure 10. Dyneema properties

In [5] it can be seen that this material was chosen over steel cables, Kevlar or Aramid. Steel is too heavy and susceptible to constant and interchangeable bending loads, has more friction from the others and also has a destructive effect on the surface of softer materials in direct contact with them. On the other hand, Kevlar and Aramid have much better properties in relation to the friction and deformation. Their termination is complicated since knots weaken the tendon strength significantly. Compared to before mentioned materials, Dyneema has the best performances, the lower friction and termination can be done accurately by splicing. Tendons made from Dyneema have easy implementation and maintenance. Fig. 10 shows some mechanical properties. Also, Dyneema has a good vibration characteristics, excellent abrasion and fatigue resistance, and chemical and temperature persistency [12].

The equations of motions were formulated according to [11]. The following assumptions were made: No inertial coupling between the motors and the joints, since the motors are fixed in the forearm. The link side system equation is:

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + \tau_{q,fric} + g(q) = \tau_q + \tau_{ext} \quad (1)$$

Where $M(q)$ is the link inertia matrix, $C(q,\dot{q})\dot{q}$ are Coriolis and centrifugal terms, $\tau_{q,fric}$ are joint friction torques and $g(q)$ is a vector of gravity torques. On the right side the joint torques is τ_q and the external torques are τ_{ext}, which are exhibited by the environment. The (1) can be extended by inserting (2):

$$\tau_q = Pf_t \quad (2)$$

Where P (the coupling matrix) has full row rank and f_t is the pulling constraint for tendon forces.

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + \tau_{q,fric} + g(q) = Pf_t + \tau_{ext} \quad (3)$$

The motor side equations are:

$$B\ddot{\theta} + \tau_{\theta,fric} + Ef_t = \tau_m \quad (4)$$

- Speed (sec/60°): 0.20
- Torque (Kg-cm): 8.9
- Size (mm): 49.5x20x38
- Weight (g): 46.5
- Metal Gears

Figure 11. RC motor S3305

Where B is the motor inertia matrix, $\tau_{\theta, fric}$ are motor and tendon friction, Ef_t are torques produced by the tendon forces and τ_m are the motor torques.

For actuation we have selected RC motors S3305 shown on Fig. 11.

Assuming that drum for winding a tendon has a diameter of 10 mm, which gives radial force of about 45 N. As part of that force will be lost on friction, we still have desired 30 N force per finger. The Futaba S3305 High-Torque Servo Motor is a good choice when your project requires high torque from a standard size servo motor. Price of 30 $ per piece is acceptable for checking conceptual design.

Pupin's hand is designing to be modular and made of fabricated aluminum profiles that are available on the market, out of there it's sharp look. However, in the first phase functional check will be verified on 3D printer. All fingers have the same look and design, and the length will be adjusted by position of the finger. At the bottom of each finger, where finger connects to the palm, reinforcements will be done.

There is an interesting connection between the lower segments which can be realized with a strong composite glue, few millimeters thick. This will give the hand a certain elasticity related to the vertical axis, and it will be manifested during grasping the objects that lie in the palm. The phalanges are connected with tendons through the pulley and every finger has 4 DOFs. This means that all of 20 cables should be implemented and connected to RC motors that are packed in the forearm in two rows, each of them shifted for the thickness of the tendon so it wouldn't come to mutual friction between the tendons.

To ensure compliance, as well as shock prevention to the driving system, it is planned to integrate springs into tendons. For now, two possibilities are considered. Spiral spring is inserted in between the phalanges or spring can be inserted in the line with tendons. Regardless of the specific side effects, this will contribute to a better tendon behavior, primarily in terms of disturbances as well as while grasping the objects of variable shape. All tendons from fingers concentrate and go through the wrist, which also has two rotational degrees of freedom, like human hand. At fingertips contact sensors will be placed, while other system sensors will be considered later in accordance with available resources. [6], [8], [10]

IV. CONCLUSION

We will continue with further activities in the development of these inexpensive robotic hands. First of all we need to design a forearm to accommodate the engine, then design and make associated electronics and conduct necessary tests. Into account should be taken delays due to lack of financial resources.

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