Design of a robotic finger combining a linkage-based design and the push-pull cable technology*

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Abstract— **This paper will study the architecture of two robotic fingers. Both of these architectures consist of a linkage-based approach. The first architecture inspired by the work of the University of Laval consists of a three phalanges finger with 3 Degrees of Freedom (DoF) actuated by one motor. The second one is inspired by the results of DeTop, a research project funded by H2020, consists of two phalanges and two DoF, the last two phalanges, Intermediate and Distal are fused in one unique phalanx.**

I. INTRODUCTION

The development of Human-Robotic Interaction (HRI) shall pass by the development of robots that guarantee the safe behavior in physical interaction with humans and the external environment. These robots need to adapt to an open dynamic environment, to help and interact with humans workers, and to manipulate human designed tools. To achieve these objectives, the hands play an important role. They are the frontier between the robot and the external environment. As humans adapted the tools, the daily objects, to their hands, the easiest solution for using these objects is to mimic the human hand. Moreover, for a robot in direct contact with humans, the human-like aspect and behavior are required, to gain the trust and the approval of the humans as Siciliano explained[1].

A human finger is articulated by different tendons and muscles, as described by Schwarz[2], the tendons, usually, one for extension and one for the flexion, are connected to muscles to actuate the finger. In humanoids hand, this architecture is often an inspiration, especially in the cable-driven approach, for example, the hand of ICub[3]. The cables are replacing the tendons and the motors are replacing the muscles. The main problems are the space required and the number of actuators used to move the fingers. Another architecture mainly utilized is the link bar approach such as the DLR/HIT Hand II[4]. This architecture has the advantage to be more robust than the tendon driven architecture.

This paper proposes to combine both of these architectures. The finger consists in a bar linkage, but it is actuated by a cable. Another particularity is that a push/pull cable drives the finger.

To achieve these objectives two architectures will be studied, the first one inspired by the work of Laval [5] consists in a 3 DoF finger, the second one inspired by the work of DeTop, the SSSA-MyHand [6], consists of a 2 DoF cross-bar mechanism.

II. APPROACH

This section details the main objectives that should be fulfilled by the finger. The main one is to mimic the aspect of a human hand; the second is to be robust and safe for the HRI.

A. Hand anatomy

To achieve the first objective, it is important to study the anatomy of a human finger. It is composed of four bones:

- The distal phalanx
- The medial phalanx
- The proximal phalanx
- One additional bone is located in the palm: The metacarpal bone

The muscles that action the fingers are located in the forearm, and they can move the fingers thank the tendons. There are three tendons that move the fingers:

- Deep and superficial flexor tendons
- Extensor tendon

Figure 1 shows the anatomy of a human finger. The architecture is inspired by it. Both architectures mimic this schema. However, in the second architecture, the two last bones of the finger, the medial and the distal phalanx, are fused in one.

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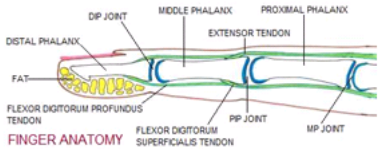

Fig. 1. Anatomy of the human finger

B. bar mechanism

For the finger architecture, the approach is to use a bar mechanism architecture. The main advantage of this method is the stiff transmission, thus the control of the finger is more precise. Usually, the motor that drives the finger is located in the palm of the hand, such as the DLR/HIT Hand II[4]. This configuration increases the weight of the hand, and, A.De Santis and al.[7] advises to limit the weight in moving member to increase the safety.

One solution is to keep this bar mechanism, but move the motor outside the palm, in the forearm; the advantage of the bar mechanism is conserved and the weight of the motor will be displaced in the forearm, increasing the safety.

C. push/pull cable

As the motors are located in the forearm, the movement must be transferred to the fingers. The chosen solution is to use a push/pull cable. In this way, only one motor and only one cable are used for both the extension and the flexion of one finger. The problem is the flexibility of the cable during the push phase. To limit it, the cable shall pass through a sheath.

The full design of the hand and palm, including the connection between the forearm and the finger, is under progress. The final design has not yet be chosen. However, a study was conducted about the configuration of two type of mechanisms bar for the finger: The Laval architecture and the Detop architecture.

III. Laval Architecture

A. Concept

The Laval hand [8] consists in a 4-phalanges finger, and three DoF. Figure 2 shows this architecture.

As explained by T.Laliberté and C.M. Gosselin in [9] the first parameters to choose are the lengths of the different phalanges, these lengths are chosen according to the existent lengths of the ICub conception, i.e. $l = 25.9mm; k = 22mm; j = 19mm$. Then the lengths of c_i are selected as the minimum possible, in our case $c_i = 5mm$. Then a ratio is selected: $R_i = a_i/c_i = 1.5$.

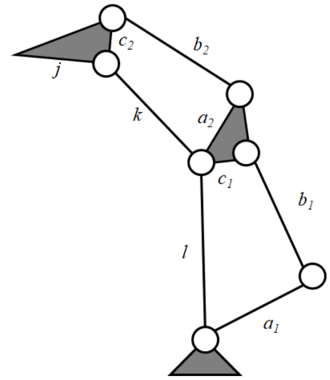

Fig. 2. The architecture of the laval design.

So $a_i = 7.5mm$. Another computation gives the lengths b_i: $b_1 = 25.78mm; b_2 = 21mm.$.

The finger is actuated thanks to a crank system. The final architecture can be seen in figure 3.

The part number one is the metacarpal phalanx, the number two is the proximal, the number three is the medial, the number four is the distal, and the number five is the crank system.

B. Component

The main actuation components of the finger are made of bronze. This material allows a frictionless joint without using bearings. It gives the advantage of using smaller pins, thus allowing more space for the sensor. These metallic parts are covered by a 3D printed cover to give the shape of the finger. In the future, a tactile skin will cover the whole finger.

For the experiment, the actual prototype is actuated manually. The finger is attached to the palm and the cable will go through a sheath to be moved at the end. The cable is 1.5 mm diameter and the sheath is 1.8 mm diameter, this allows the movement of the cable through the sheath, and in the same time, it also limits the fold of the cable.

C. Experiment

As the prototype is not yet built, there is no physical experimentation. However, some digital simulations showed that the displacement of the cable between a full closure and a full opening is 26.8 mm. One of the main problems is the independence of the link in

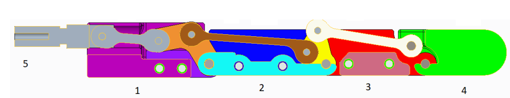

Fig. 3. The simulation of the finger, with a section in the middle.

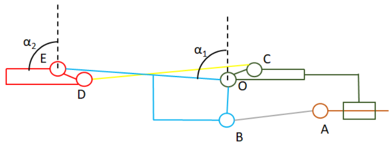

Fig. 4. The architecture of the DeTop design.

the finger. The only way to know the exact position of each link is to implement sensors in the finger. A type of sensors that can be used is magnetic sensors.

IV. DeTop Architecture

A. Concept

This finger consists of three phalanges and two DoF finger. Contrary to the previous architecture, the last two phalanges, middle and distal, are fused in one. Figure 4 shows this architecture.

The lengths of the phalanges are the same. One of the objectives of this finger was to make the pivot axis as close as possible to the internal surface of the finger. In this way, the contact surface varies less during closure and opening and thus permits the pose of a tactile skin.

For actuation, a crank system is also used. The final architecture can be seen in figure 5. The part number one is the metacarpal phalanx, the number two is proximal, the number three is the medial and distal, and the number four is the crank system.

B. Component

The main components are 3D printed for fast prototyping. Except the yellow part is in bronze. There is no need of sensor as the movements of the phalanges are linked. There is a relationship between the two joints, and the knowledge of the position of the crank gives the exact position of the finger.

As previously the actuation is done manually and uses the same system of cable and sheath.

C. Experiment

As the prototype is not ready yet, there is an only digital simulation of the finger. Yet it showed some relationship between the two main angles α_1 and α_2.

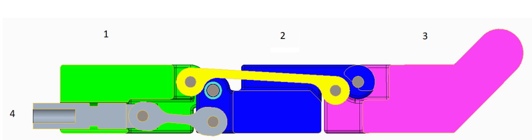

Fig. 5. The simulation of the finger, with a section in the middle.

The displacement of the cable between closure and opening is only 6mm.

V. Future Work

In the future, some investigation will be done with both prototypes. One experimentation will be the force and the friction to move the finger. Another works need to be done is all the actuation and implantation of the hand. As the motor gives more power during the pull phase than the push phase and now the pull phase serves to open, the movement should be inverted as more force is required during the closure.

VI. CONCLUSIONS

This paper was an introduction to two different design of a linkage-based finger. The combination of the push/pull cable and the linkage-based mechanism is newly utilized. Future investigations are needed to develop it.

The Laval architecture has the advantage to be more realistic with 3 DoF. However, it needs sensors to know the exact position of the finger. The DeTop architecture is simpler and has the advantage to have a displacement of the cable four time smaller.

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