Revisions Letter

Dear Reviewer,

We are writing to thank you for your response and your effort in reading and revising in detail our paper. We believe that all your suggestions have greatly improved the manuscript. You may find below your comments to the revision of the paper machines-1339980: “Development and implementation of an anthropomorphic underactuated”, and our answers.

We are also sending, separately, a new version of the paper with all changes highlighted in blue. If you have further questions, we will be glad to answer them.

Comments about Technical remarks

<u>Comment N°1</u>

1. Regarding the finger design, the author said that a finger can realize extension/flexion movements. In Figure 7, a single tendon for flexion movement is shown, and Figure 4 only describes the flexion movement. However, in this manuscript, the extension movement was realized using other tendon than the one used for the flexion movement, and it is explained that “the extension movement is controlled by a cable that passes through the channel located at the top.”. Here, it is difficult to understand because three motors were used in the system. I would like to add specific explanation in Figure 4.

- Describe Flexion/Extension movements, separately, and represent the movement of each tendon in detail.
- I could not find the explanation related to the top tendon anywhere in the manuscript.

Answer

The reviewer's suggestion is sincerely appreciated, there was no description for the extension movement. This was done intentionally because this part of the design has no additional complexity, same as in the flexion movement. Additionally, it is not used for any of the hand grips described in figure 3, where the emphasis is done on the closing motion. However, we agree with the reviewer’s comment and the text has been modified in section 4.3 to include a description of the extension movement. Additionally, as the reviewers stated the difficulty to understand how it is possible to use only three motors in the system, figure 4 was modified to include the motor drive pulley setup, along with a description of the extension and flexion movements.

<u>Comment N°2</u>

In the thumb design, both movements, Extension/Flexion and Opposition/Reposition, (shown in Figure 7), are implemented using a single tendon and the distance difference between the path of tendon and the rotation axes. I have questions here.

- Are Extension/Flexion and Opposition/Reposition movements decoupled? Or, do they happen simultaneously?
- If two movements are decoupled, is the order of movements flexion -> opposition -> reposition -> extension?

- It's difficult to understand, so I hope you add a video about the movement.

Answer

According to the reviewer suggestion, the movements are decoupled and performed in sequence to improve the gripping capabilities of the prosthetic hand. The order of movement is opposition → flexion for grasping, and extension → reposition for opening, this sequence is explained in the text as follows:

"The execution of these movements must be performed sequentially as shown in Figure 6. The movement starts with the opposition (Figure 6a), performing a 90°rotation relative to the red axis, followed by the flexion movement represented in Figure 6b, reaching the final position in Figure 6c. This sequence of movements is achieved in the same manner as in triphalangeal fingers, i.e. by adjusting the distance between the axis of rotation and the tendon."

The opening movement is not explained, mainly because it is not used for any of the hand grips described in figure 3, and thus it is not necessary to perform a specific sequence. However, due to the reviewer's comment, we modified the text in section 4.4 accordingly.

We share with the reviewer two short videos in which the prosthesis can be seen in action.

- https://youtu.be/F8F93_5Q_so This video shows a 3kg weight lifting capability.
- https://youtu.be/yb9zd77D-s8 This video shows a pincer grip, highlighting that the thumb executes the opposing movement first.

Comment N°3

To realize the opposition/reposition of the thumb, I think the tendon installed with an angle difference between the axis of rotation and the tendon path. However, the tendon path was located in parallel with the rotation axis, as shown in Figure 7. Is this a possible design to implement opposition/reposition movement?

Answer

We are sincerely grateful to the reviewer for pointing out this problem generated by switching from a two dimensional to a three dimensional image. We have added the figure 7 to describe in detail the path of the tendons. Additionally, an explanatory text is incorporated in section 4.4 to describe the figures and tendon paths.

Comment N°4

In Figure 7, the tendon for index finger movement is made to pass through the thumb frame. And, I think the movement of the thumb affected the index finger motion. Is there no effect when controlling the index finger?

Answer

As mentioned in comment N°3 we made a mistake in figure 7 and we thank the reviewer for detecting the problem. The tendon for the index finger passes through a hollow shaft located behind the thumb. We replaced figure 4 to show this detail and added figure 8

Comment N°5

In this manuscript, three motors were used. Although I could understand the process of flexion movements in all fingers, please explain in detail how to implement extension motion.

Answer

We acknowledge the reviewer's concern. As mentioned in a previous answer (comment N°1), the flexion/extension movement and its connection to the driving pulley is now described in a new paragraph of section 4.3. Figure 4 has been modified to include the drive pulley and its connection to the tendons, we sincerely hope that explanation given is clear.

Comment N°6

Is position control possible?

Answer

Although we have no information on the cable material, the trials show large deformations on the line when a force is applied, thus it is not possible to apply an open loop position control between finger and the pulley. Even without this problem, the mechanism is used to control several links with one motor and allowing to wrap the object, this makes it impossible to correlate the pulleys rotation with the fingers position.

We are currently working on a closed loop control strategy for the prosthesis positioning system, the mechanism will be aided by cameras and an image recognition.

We encourage the reviewer to watch the following videos that show ongoing progress currently not integrated in the prosthesis

- https://youtu.be/_LUEIDgRges Here it can be seen how the camera distinguishes between the two hands, and only gives the order to grip the sphere when it touches the gloved hand, which resembles the prosthesis.
- https://youtu.be/sU-eRY4moaw In this video the algorithm only gives the order to grip when the sphere touches the "prosthesis" represented by the glove, when the sphere is close, but without contact, the order to "grip" is not given. It should be noted that the algorithm operates in real time.

Comment N°7

In design of the prosthesis, it is difficult to fix the tendon with appropriate tension because of the limited design space. Please explain how you solved this problem.

Answer

The reviewer is right, the assemble process was difficult and required much patience to put all strings through the channels with very limited space. The complete sequence of assemble is difficult to describe, sub-assemblies are made and later integrate to the prosthesis. Subsequently the two ends of each cable bust be secured. We begin with tying knots in the distal section of the hand, at this stage we can adjust the correct length of all the tendons enabling the desired movement response.

When this is complete, the tendons must be connected to the drive pulleys, the first step is to secure the flexion tendons to the pulley, then we energize the actuators and apply tension to the flexion tendons allowing to tie knots in the extension tendons more easily.

We hope this information is useful for the reviewer, this section it is difficult to explain in depth, we hope that the mentioned sequence might give you an insight of the assembly procedure

<u>**Comment N°8**</u>

There is no information about the used tendon. Please explain the material, diameter, and allowable stress of the used tendon.

<u>**Answer**</u>

We appreciate the observation made by the reviewer, the tendon is made of a monofilament strand with a diameter of 0.5 mm, the manufacturer does not mention the material or the allowable stress. The maximum force supported is rated at 14,6 kg. When considering the section area, the calculated tensile strength is 730 Mpa. This information is now incorporated in the text, excluding the calculated tensile strength.

<u>**Comment N°9**</u>

There is no specification about the used actuator. Please explain the torque, rpm, and rated current.

<u>**Answer**</u>

The actuators are servomotors, the following table is now included in the text, including the requested specifications:

Finger	Little, middle, and annular	Index and thumb
Quantity	1	2
Servomotor model	LH2018M	MG996R
Stall torque (kgf*cm) at 6V	20	11
Running current A	-	0,9
Stall Current A	-	2.5
Speed at 6V degrees/seg	315	430

Servomotors were driven at 5V.
According with the reviewer's suggestion we have included this information in table 6 located in section 4.2.

Comment N°10

How much is the payload of hook motion in Figure 14(b)?

Answer

We appreciate that the reviewer has taken the time to analyze the details of the presented device. We tested the capacity to lift weight with the hand, it was possible to hold 3 kg, with more weight added the tendons broke. This information is not presented in the text as we do not account for specialized instrumentation to perform this kind of measurements. The paper focuses on the design and implementation/construction of the proposed device.

https://youtu.be/F8F93_5Q_so This video shows a 3kg weight lifting capability

Comment N°11

I'm curious about the overall picture of the aluminum profile in Figure 11. What is the weight of the aluminum profile and how much is the gripping force?

Answer

The aluminum profile is a V-Slot linear rail 40x40 mm and 250 mm long, its weight is approximately 350 grams. Regarding the gripping force, we do not account with adequate instruments to perform these measurements, thus we did not include this information and focused on the dexterity of the design. Further tests will be performed in future work

Comment N°12

Please explain how the movement of Figure 14(a) comes out using movements in Figure 5.

Answer

Figure 14a) corresponds to a gravity grip achieved by the extension of the five fingers, as the hand does not need to wrap an object, the opening sequence is not relevant only the final position. Figure 5 shows the closure sequence in the flexion process, as the extension movement was not explained in the text, we are assuming it could have generated confusion.

Comment N°13

It would be nice to have a full picture including the actuators. Please explain the connection between the actuators and the tendon.

Answer

We thank to the reviewer for the interest and dedication required to review in depth our work. As requested, we have included some pictures with the full device and some pictures with details of the pulleys. If the editor and the reviewer consider it appropriate, we can include the pictures in the manuscript.

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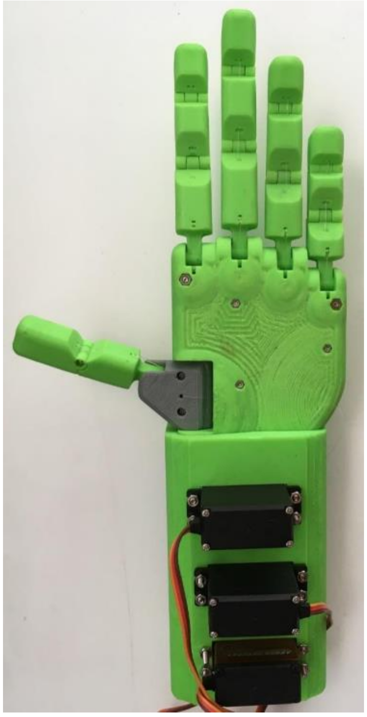
<tr><td></td><td></td></tr>
<tr><td>Dorsal view of the prosthetic hand prototype</td><td>Palm view for the prosthetic hand prototype</td></tr>
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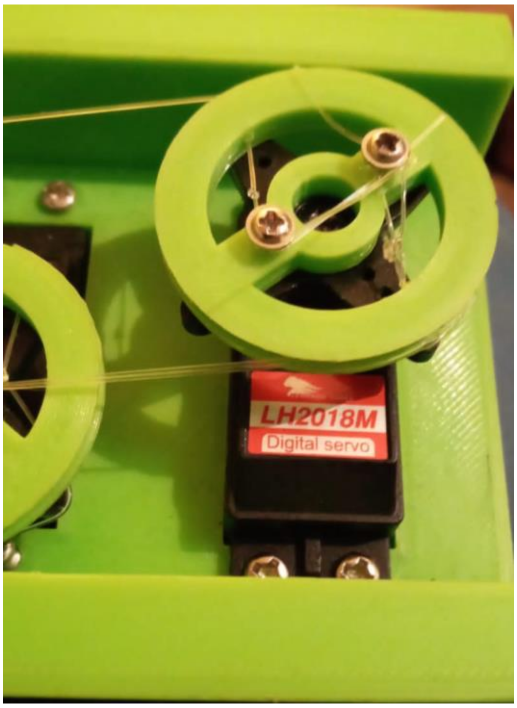	
Servomotor and drive pulley for middle, annular, and little fingers	Servomotors and drive pulley for index and thumb fingers

<u>Comment N°14</u>

Table2 title figura -> figure

<u>Answer</u>

We thank the reviewer for pointing out this issue. We have revised the document and fixed the problem.

<u>Comment N°15</u>

In Table2, the description of the mechanical differential is hard to see.

<u>Answer</u>

We thank to reviewer for pointing out this issue. We have revised the document and fixed this issue adding colors to the image.

<u>Comment N°16</u>

Overall, the description of the design is too short, and the description of the figure is too cursory. In the revised one, the description should be much more specific and in detail. I hope my comments are helpful to improve your paper

<u>Answer</u>

We are grateful for your comments, we believe the text has been greatly improved, we hope that the revised version meets your expectations.