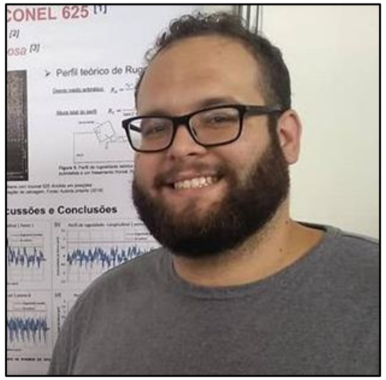
A concept design of an adaptive tendon driven mechanism for active soft hand Orthosis.

Bruno Lourenço [1, 2]



Vitorino Neto [1]

Rafhael de Andrade [1]

[1] Laboratory of Robotics and Biomechanics, Department of Mechanical Engineering, Universidade Federal do Espírito Santo, Brazil;
[2] PET-Mecânica UFES, Department of Mechanical Engineering, Universidade Federal do Espírito Santo, Brazil.

I. Introduction

Motivation

Mobility deficits in the hands, generate a negative life impact [1]. Hand paralysis has many causes, of which we can highlight stroke and spinal cord injuries (SCI) how two huge causes. In fact, stroke is the third source of disabilities in the world, and is estimated that occur up to 500,000 new SCI worldwide every year [3][4].

Reports by world health organization conclude that the worse effects, difficulties in treatment and rehabilitation occur in low and middle-income countries [3,4].

Demands

This reality demands support in the scope of rehabilitation and assistance to accomplish tasks. The regional rehabilitation program of the Pan-American organization says the only 2% of the 85 million people with some disability have your rehabilitation necessities attended in Latin America [5].

I. Introduction

Hand orthosis

Active upper limb orthoses are developed are in vast majority rigid exoskeletons. Perform properly daily live activities with comfort for long periods, lightness and low-volume are fundamental characteristics, which are generally achieved by soft-exoskeletons [10-12].

In view of a wide range of hand sizes hand orthosis have problems to the correct fit, requiring the development of a completely new device for different hands [11,13–15].

Proposal

Our work presents a soft exoskeleton concept to address these shortcomings. The proposed mechanism was thought to be compact, light in weight, and able to fit with different hand sizes. The number of degrees of freedom can be expanded or simplified to reduce costs and capable reach multiple clinical demands.

II. Methods

Biological Inspiration

Hand anatomy inspired the device development to attend biomechanical constraints [12]. The finger framework is composed of three distal, middle and proximal bones, these bones designate its finger phalanges. They are connected by ligaments and driven by three tendons to perform extension/flexion movement [16]. Figure 1 shows this configuration.

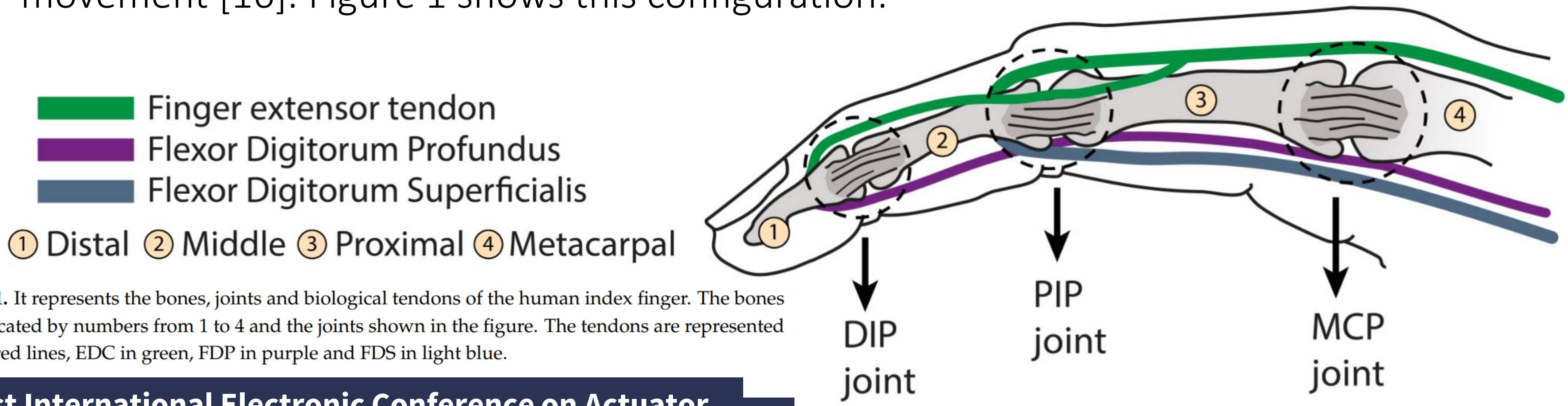


Figure 1. It represents the bones, joints and biological tendons of the human index finger. The bones are indicated by numbers from 1 to 4 and the joints shown in the figure. The tendons are represented by colored lines, EDC in green, FDP in purple and FDS in light blue.

II. Methods

Concept

Figure 2 represents three artificial tendons, and their main points of attachment on the index finger.

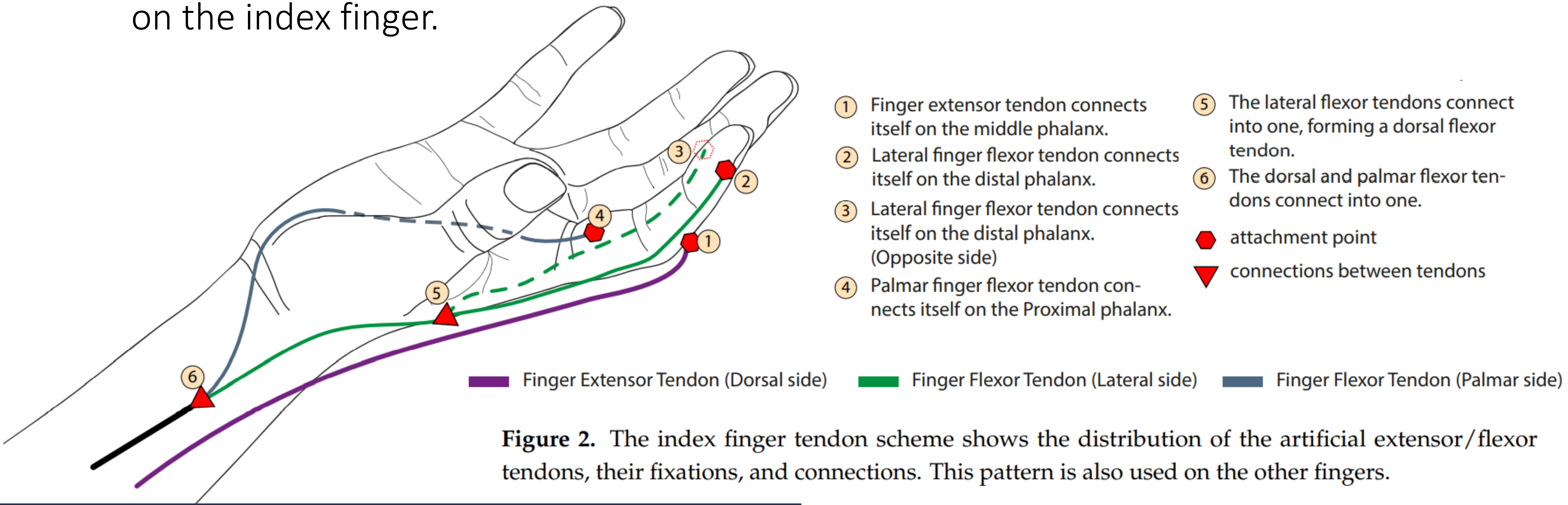


Figure 2. The index finger tendon scheme shows the distribution of the artificial extensor/flexor tendons, their fixations, and connections. This pattern is also used on the other fingers.

II. Methods

Multiple Configurations

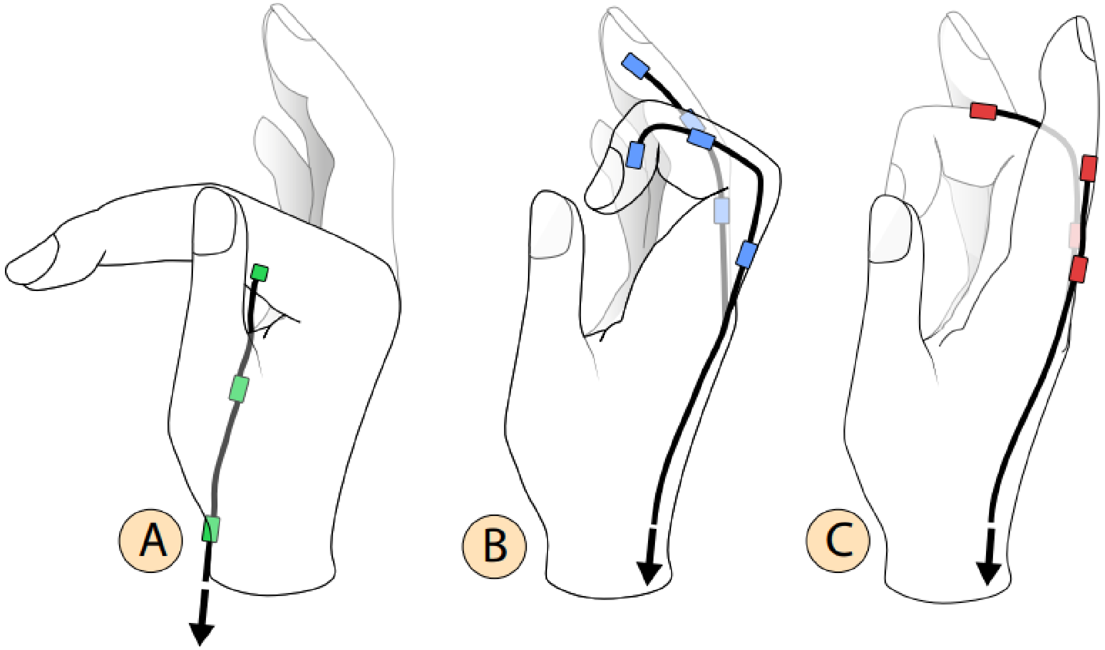


Figure 3. Independent motions of the finger performed by each artificial tendon, (a) Angular movement around MCP joint; (b) Finger contraction; (c) Finger extension.

This set can meet different rehabilitation and cost demands through a simple idea, the linear dependence (LD), and the linear independence (LI) of the movements. Flexion and extension movements are linearly independent. Figure 3 shows the LI movements given by artificial tendons.

II. Methods

Prototype

Figure 4 illustrates the proposed hand orthosis.

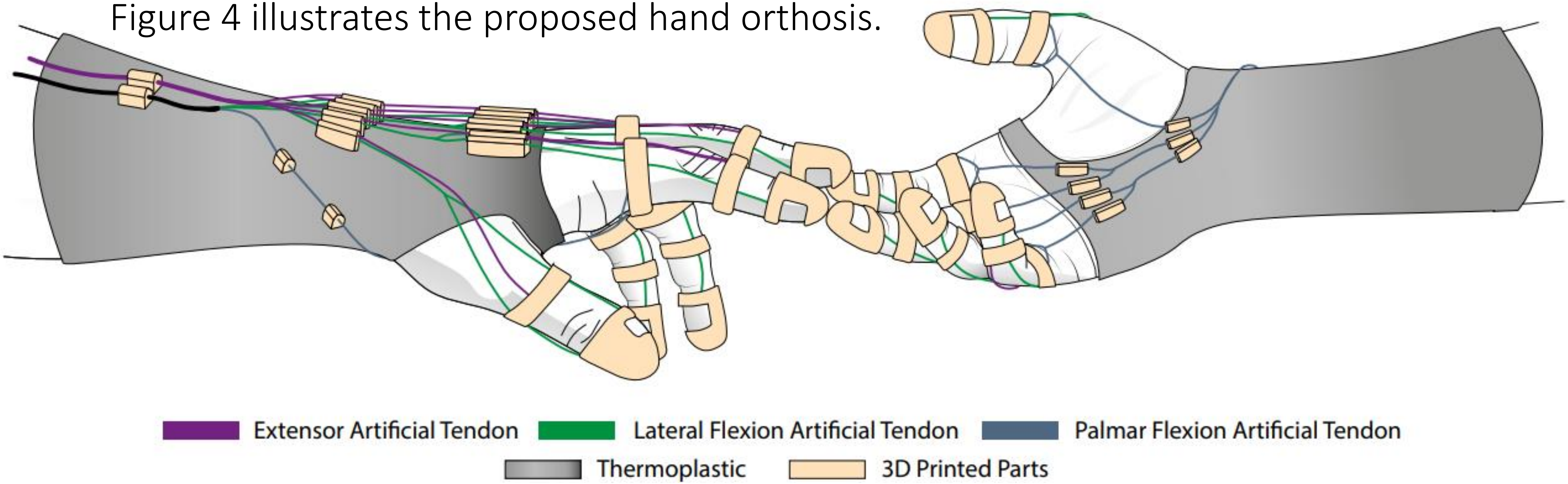


Figure 4. Independent motions of the finger performed by each artificial tendon, (**a**) Angular movement around MCP joint; (**b**) Finger contraction; (**c**) Finger extension.

III. Results and Discussion

Kinematic model

Figure 5 and Table 1 show the analyses parameters.

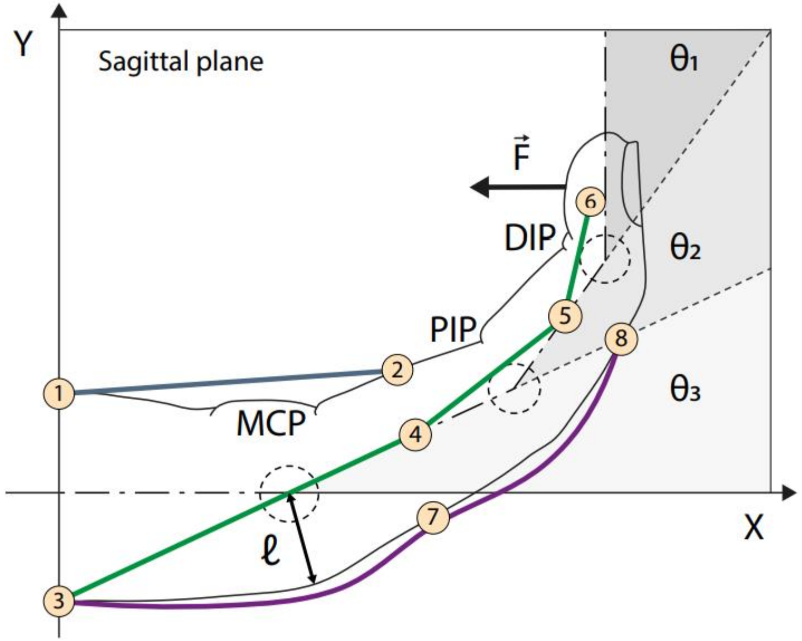


Figure 5. Kinematic representation of the model, showing the points considered along with the artificial tendons, joint angles, and the force at the fingertip.

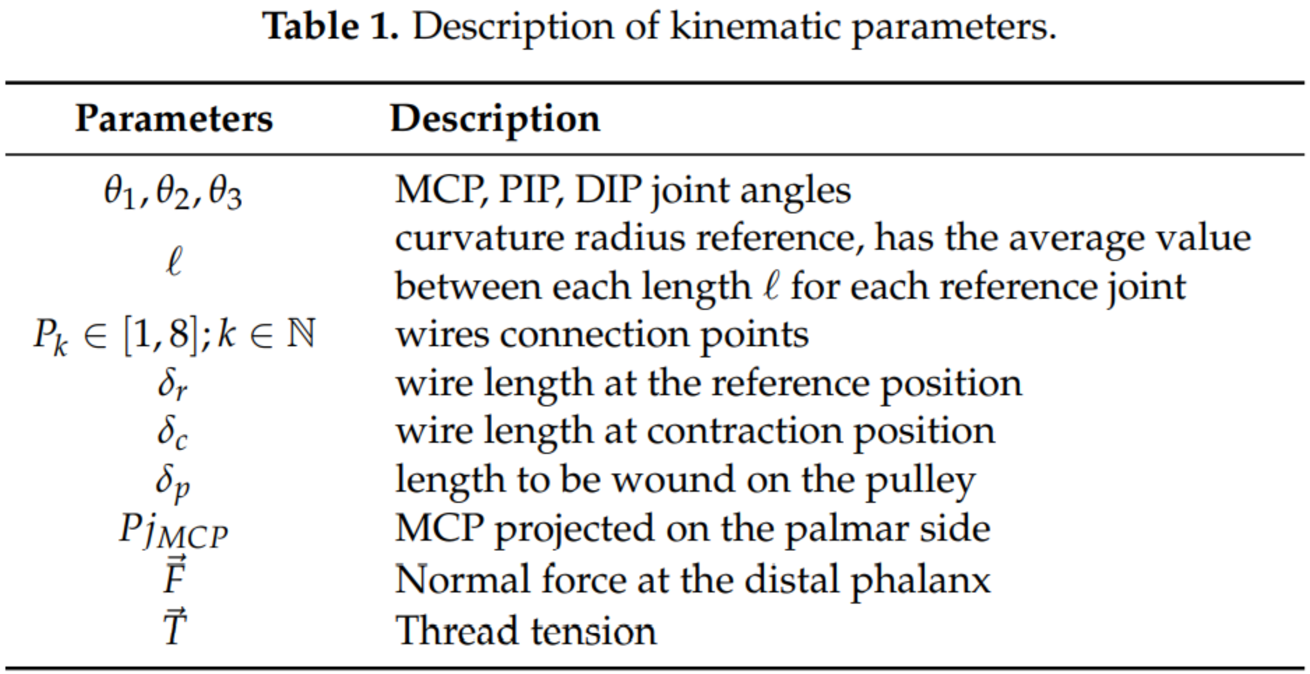


Table 1. Description of kinematic parameters.

Parameters	Description
$\theta_1, \theta_2, \theta_3$	MCP, PIP, DIP joint angles
ℓ	curvature radius reference, has the average value between each length ℓ for each reference joint
$P_k \in [1,8]; k \in \mathbb{N}$	wires connection points
δ_r	wire length at the reference position
δ_c	wire length at contraction position
δ_p	length to be wound on the pulley
Pj_{MCP}	MCP projected on the palmar side
$\vec{F}$	Normal force at the distal phalanx
$\vec{T}$	Thread tension

III. Results and Discussion

Kinematic model – wire slacks

Extensor artificial tendon (purple wire):

$$\delta_{r,\ EAT} = \overline{P_3, P_7} + \overline{P_7, P_8} \qquad (1)$$

$$\delta_{c,\ EAT} = \overline{P_3, P_7} + \overline{P_7, P_8} + \ell(\theta_2 + \theta_3) \qquad (2)$$

$$\delta_{p,\ EAT} = \ell(\theta_2 + \theta_3) \qquad (3)$$

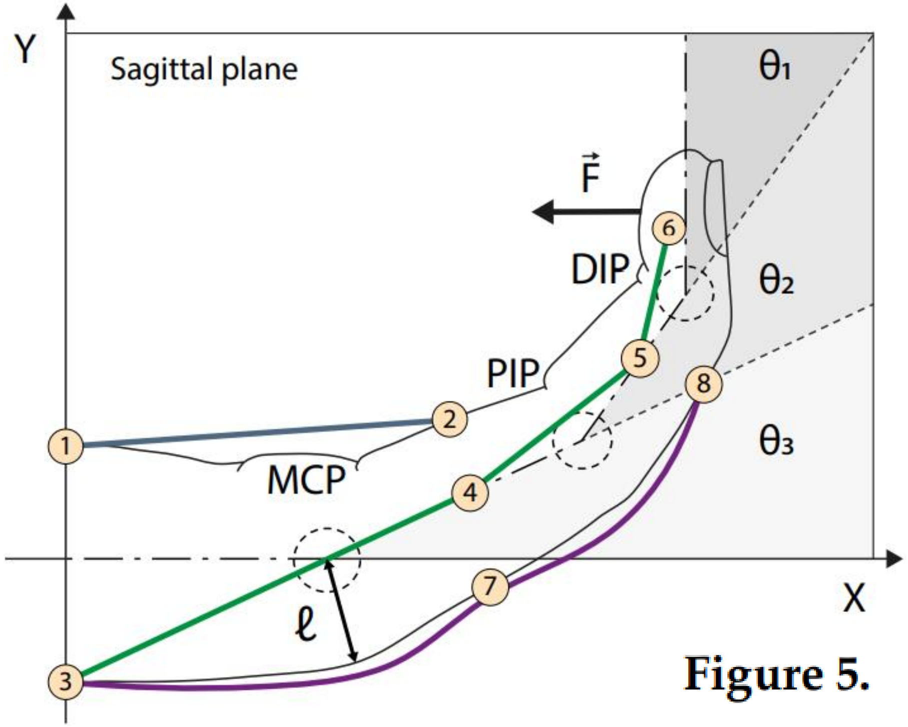


Figure 5.

Palmar artificial tendon (pale blue wire):

$$\delta_{r,\ PAT} = \overline{P_1, P_2} \qquad (4)$$

$$\delta_{c,\ PAT} = \sqrt{(\overline{P_1, Pj_{MCP}})^2 + (\overline{Pj_{MCP}, P_2})^2 - 2(\overline{P_1, Pj_{MCP}})(\overline{Pj_{MCP}, P_2})\cos(\pi - \theta_3)} \qquad (5)$$

$$\delta_{p,\ PAT} = |\delta_{c,\ PAT} - \delta_{r,\ PAT}| \qquad (6)$$

III. Results and Discussion

Kinematic model – wire slacks

Lateral artificial tendon (green wire):

$$\delta_{r,\,LAT} = \overline{P_3,P_4} + \overline{P_4,P_5} + \overline{P_5,P_6} \tag{7}$$

$$\delta_{c,\,LAT} = \sum_{\zeta} \sqrt{(\overline{P_i,k})^2 + (\overline{k,P_{i+1}})^2 - 2(\overline{P_i,k})(\overline{k,P_{i+1}})\cos(\pi-\theta_j)} \tag{8}$$

For $(i,j,k) \in \zeta;\ \zeta = \{(3,3,MCP),(4,2,PIP),(5,1,DIP)\}$.

$$\delta_{p,\,LAT} = |\delta_{c,\,LAT} - \delta_{r,\,LAT}| \tag{9}$$

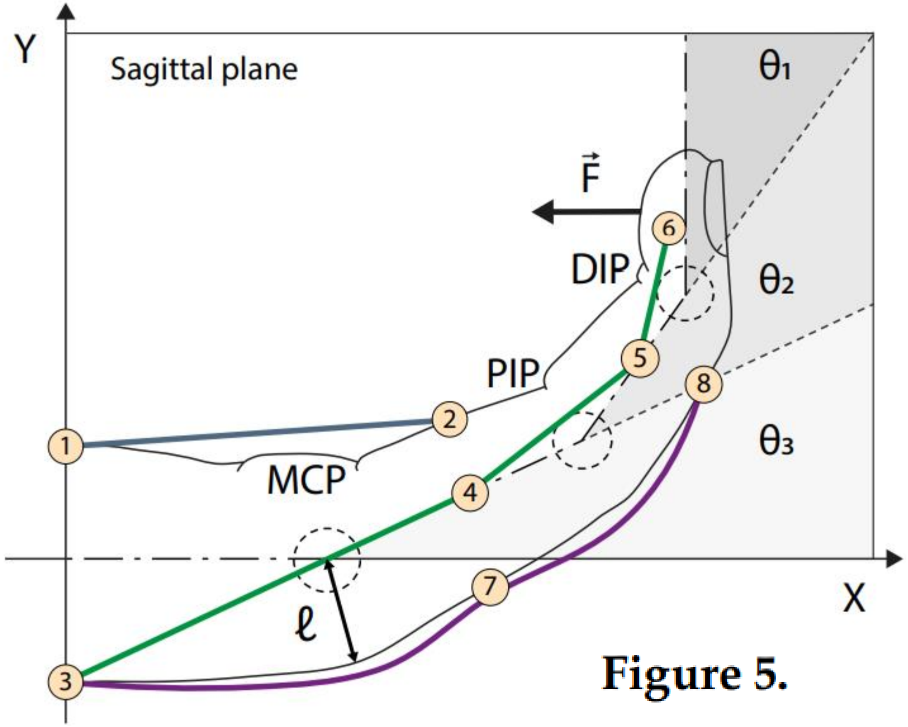


Figure 5.

III. Results and Discussion

Kinematic model – fingertip force

The resultant force will be provided by the applied tension at the Lateral Artificial Tendon, being perpendicular to the phalanx surface. Figure 6 shows the fingertip force.

$$\beta = \sin^{-1}\left[\frac{c}{a(\theta_1)}\sin(\theta_1)\right] \qquad (10)$$

$$\vec{F} = \cos\left(\frac{\pi}{2} - \beta\right) \qquad (11)$$

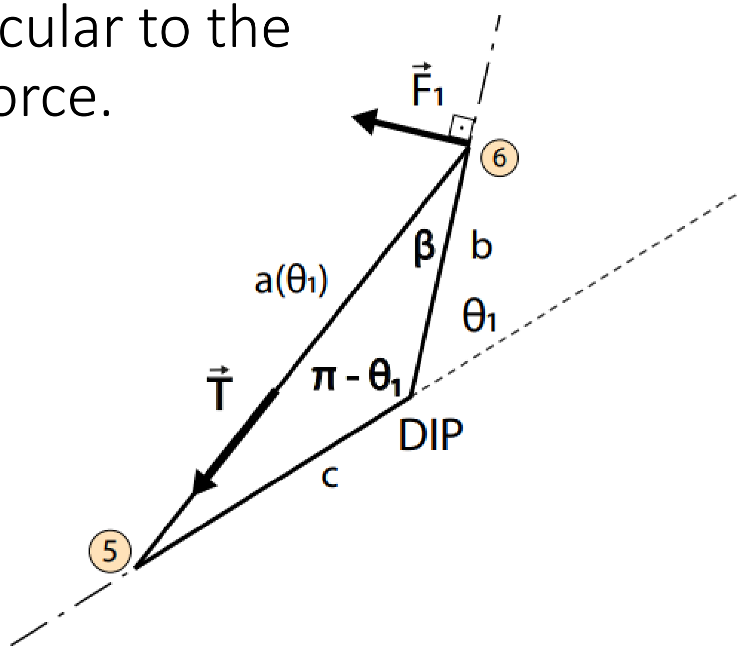


Figure 6. Fingertip force diagram, for a tension, applied to the LAT.

III. Results and Discussion

Kinematic model – fingertip force

We should pay attention to the kinematic coefficient alpha (**α**).

$$\beta = \sin^{-1}\left[\underbrace{\frac{c}{a(\theta_1)}}_{\alpha}\sin(\theta_1)\right] \qquad (10)$$

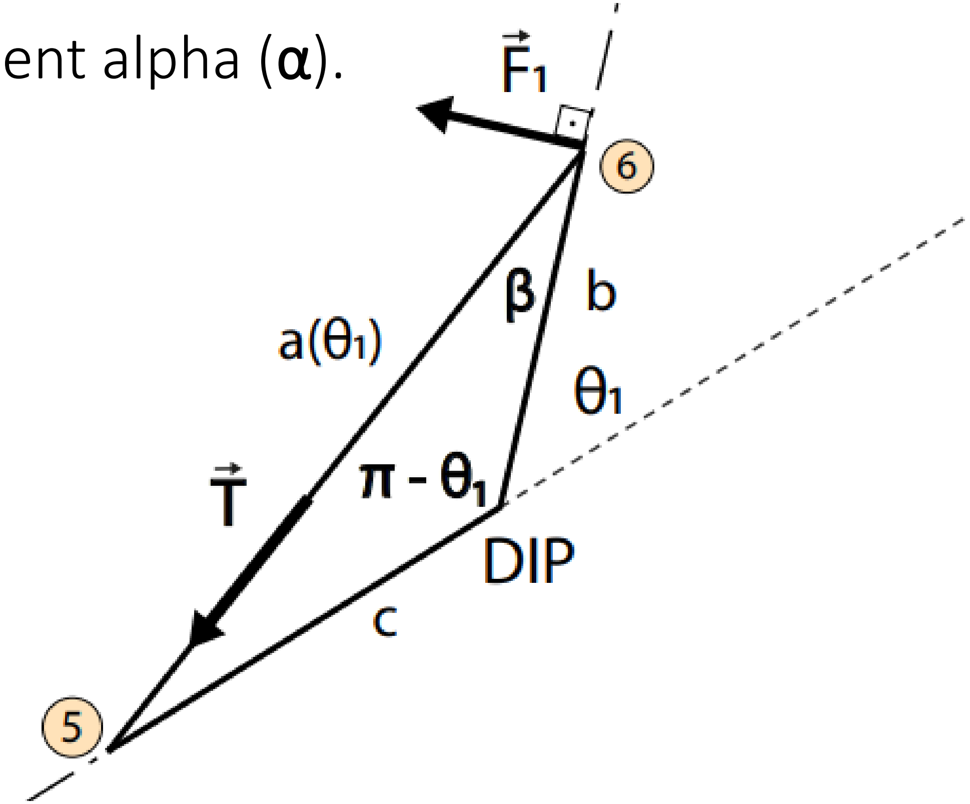


Figure 6. Fingertip force diagram, for a tension, applied to the LAT.

III. Results and Discussion

Kinematic model – fingertip force

To represent this effect graphically (Figure 7), we plot equation 12. Equation 12 is Equation 11 with Equation 10, and the last term of Equation 8 merged on it.

$$\vec{F} = \cos\left(\frac{\pi}{2} - \sin^{-1}\left[\underbrace{\frac{c}{\sqrt{(\overline{P_5, DIP})^2 + (\overline{DIP, P_6})^2 - 2(\overline{P_5, DIP})(\overline{DIP, P_6})\cos(\pi - \theta_1)}}}_{\alpha}\sin(\theta_1)\right]\right) \tag{12}$$

III. Results and Discussion

Kinematic model – fingertip force

The graph was built considering the tension equal to 80N. The blue curve represents $\alpha 1$, and the orange $\alpha 2$.

$\alpha 1$: b = 0.5 mm and c = 1.5 mm
$\alpha 2$: b = 1.5 mm and c = 0.5 mm

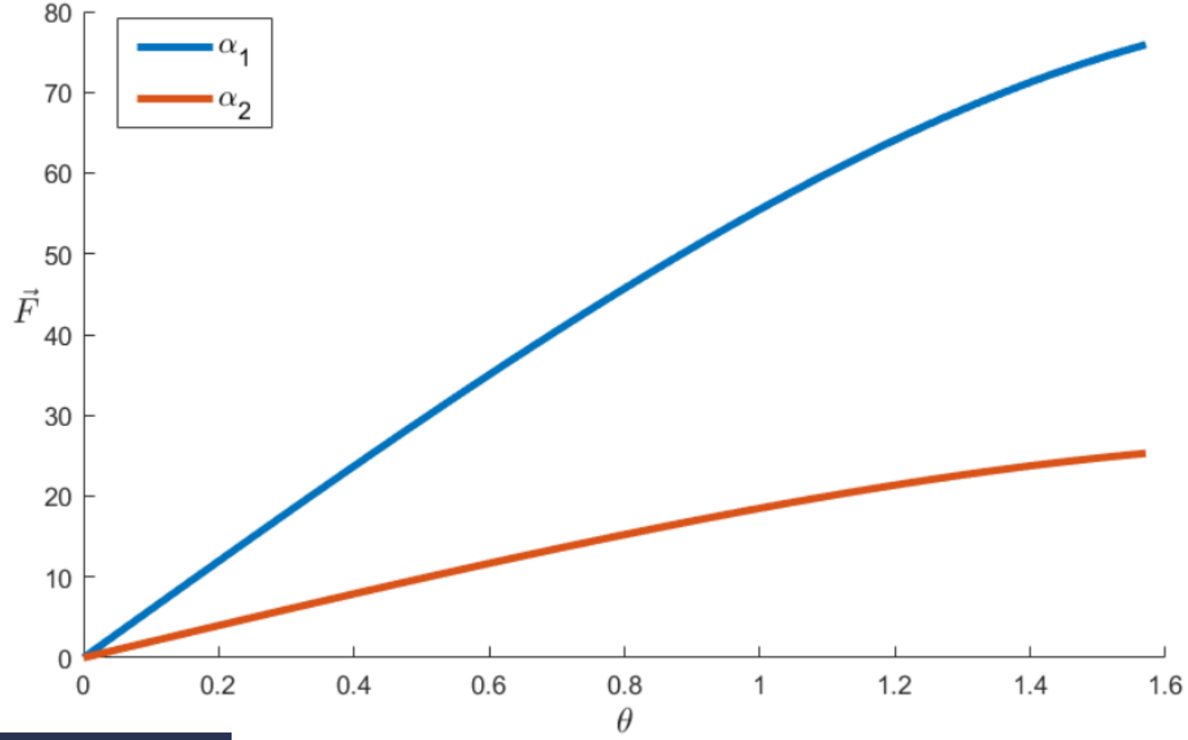


Figure 7. Evaluation of the kinematics coefficient α. The α_1 and α_2 refers to different orthosis positioning on the finger.

IV. Conclusions

- The artificial tendons of the concept look for complying with the biological constraints stimulating the natural tendons.
- It is expected that when using thermoplastics and additive manufacturing, the resulting prototype achieves lightness, low volume, and a customized design.
- The variety of possibilities for degrees of freedom is an advantage of this design, it can adapt to multiple rehabilitation and assistance demands.
- Thermoplastic moldability guarantees comfort, and adequate adjustments to the hands, forearms, and arms of different users.
- A kinematic model was considered to evaluate design parameters to develop the prototype.

Acknowledgments: This study was financed by FAPES (Fundação de Amparo à Pesquisa e Inovação do Espírito Santo).