Development of a New Rehabilitation Device for Finger Extension Movement

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***Abstract*—This paper focuses on the development of a new device for hand rehabilitation that can perform the finger extension movement. The paper reports the basic ideas and outlines the development of the device design to perform also the finger closure movement.**

***Index Terms*—rehabilitation devices, finger extension**

I. Introduction

The global population aged 65 years or over numbered 703 million in 2019, more than twice as large as in 1980 when there were 382 million older persons worldwide. The number of older persons is expected to double again by 2050, when it is projected to reach nearly 2.1 billion. Nevertheless, a greater number of older people also means an increase in illnesses including cerebrovascular diseases such as strokes, which brings to physical issues like paralysis that can compromise everyday life. One of the most common problems after a stroke is the complete or partial paralysis of the hand. For this reason, it is necessary to develop rehabilitation systems and devices [1-2].

The target of this paper is to report the development of an easy-to wear and lightweight device whose basic ideas have been presented in a previous paper [3], which can perform the extension movement and can be used at home. The functional structure of this device is simple and represents an innovative solution in comparison with most mechanisms proposed in the literature. This paper outlines also the work in progress aimed at extending the capabilities of the device.

II. Basic Ideas of the Proposed Device

With reference to Fig. 1, the index finger can be modeled with a good first approximation as an open chain with link 0, the hand palm as the frame, and three movable links - links 1, 2 and 3 - that represent the three phalanges, connected by revolute joints centered at point O_1, O_2, and O_3, respectively representing the anatomical joints connecting the hand palm, the proximal, the medial and the distal phalanges. Link 3, the distal phalanx, has three degrees of freedom (DoF) with respect to the palm 0. Link 3 must move from the initial pose I, where the finger is contracted, to the final pose II, where the finger is extended. A simple way to move link 3 from I to II is by a finite rotation of rigid body. Indeed, this is possible by rotating link 3 about the point O_4 obtained from the intersection of the axes of the segments $\overline{PP'}$ and $\overline{O_3O_3'}$, where O_3 and P are taken as reference points of link 3, i.e. the distal phalanx. With reference to Fig. 2, the trajectories of points O_3 and P generated by a rotation about O_4 are two circumferences $\gamma^*_{O_3}$ and γ^*_P respectively centered at O_4. It is possible to perform this rotation by using a link 4, which - rigidly connected to link 3 - rotates about O_4. This solution has a twofold merit:

1) It allows a practical realization of a revolute kinematic pair between link 4 and the frame 0.
2) It leaves the space inside the ring free, where the finger is located.

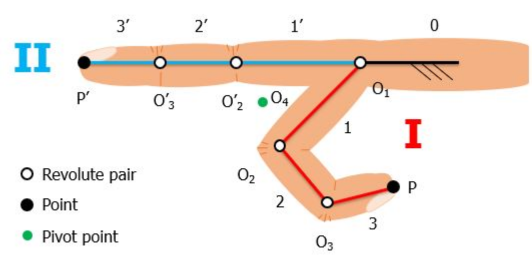

Fig. 1. Conceptual structure of the index finger.

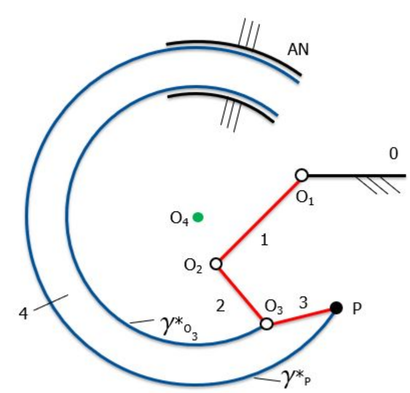

Fig. 2. Concept of the connection between annular ring 4 and finger distal phalanx 3.

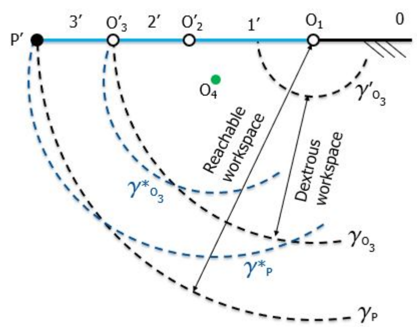

Fig. 3. Trajectories of the relevant points of the finger and the annular ring 4.

However, according to the geometrical dimension of the system, the trajectories of the points O_3 and P, when considered as belonging to link 4, that are $\gamma^*_{O_3}$ and γ^*_P, may extend outside the work space $\mathbb{R}^3$, as shown in Fig. 3.

Therefore, in a certain range of motion, the extreme positions of O_3 and P, when thought as belonging to link 4, may fall outside the work space of the same points when thought as belonging to link 3. In order to allow link 4 dragging link 3 from the pose I to the pose II, an elastic connection can be realized between the two links to absorb the difference between γ_{O_3} and $\gamma^*_{O_3}$, γ_P and γ^*_P respectively. The elastic connection could be realized physically by two springs, for instance one torsion spring and one extension helical spring, as shown in Fig. 4, which allow a relative motion between their attachment points J and L, P and M respectively thus providing, at the same time, corresponding elastic reactions at the interface between the two links.

However, the ring 4, during the rotation about O_4 of an angle equal to β would collide with the back of the hand. To avoid collisions, several particular constructive solutions can be adopted, two of them are depicted in Fig. 5. The solution in Fig. 5b could be feasible in case of design constraints at the price of a double bending of the belt, but solution in Fig. 5a is otherwise preferable.

With reference to Fig. 5a, the annular ring 4, along a proper arc UV (at least equal to that subtended by the β angle starting from the radius $\overline{O_4U}$), is formed by a number of individual sectors D_i, one adjacent to the other along the annular ring 4, connected only on the external side of link 4 by an inextensibleflexible belt 5, as represented in Fig. 5a. The belt during the rotation of link 4 (about O_4), takes a straight shape once it crosses the line $\overline{UT_2}$, and allows adjacent sectors D_i to rotate relatively to each other. The end of the belt is connected in F to the actuator, which controls the displacement of the belt, i.e. the rotation β of link 4. Link 4, in the O_3U arc, behaves as a single rigid body since the forces that act at its extreme interface $\overline{O_3P}$ with link 3 tend to close the ring 4, which therefore maintains the circular shape. The T_1T_2 arc of link 4 (see Fig. 5a), in contact with the frame 0, must have an adequate width to guide link 4 and to properly support the flexion moment produced on the link itself by the forces and torques of link 3. The connection between the annular ring 4 and the distal phalanx can be made with a simple thimble-shaped design, while its general dimensions depend on the size of the finger's phalanges.

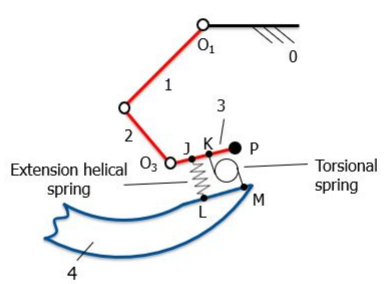

Fig. 4. Trajectories of the relevant points of the finger and the annular ring 4.

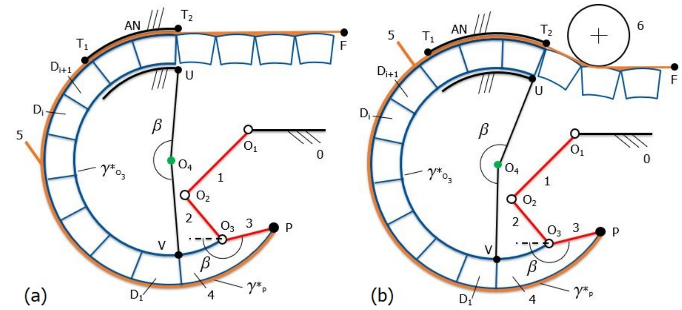

Fig. 5. Solutions to drive the annular link 4: (a) straight belt solution; (b) belt-pulley solution.

III. Work in Progress (New Development)

A protoytpe of the proposed device is in progress. Moreover, new ideas have been devised, which will be reported in a next paper, to extend the capability of the device to also perform the finger closure.

IV. Conclusion

In the future, the realization of a device prototype is considered to confirm the feasibility, reliability and to evaluate the efficacy of the device itself. More specifically, static, kinematic and dynamic analyzes will define the forces and speeds of the system, based on which the device will be designed. Moreover, it is worth mentioning that a proper design of the belt and connected sectors has been defined, in order to drive the link 4 also counterclockwise, that is to guide the closure movement of the finger.

References

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