Design of the exoskeleton as a rehabilitation system

J.Tuliński[*,1], **D.Jasińska-Choromańska**[**,1]

[1] Institute of Micromechanics and Photonics, Faculty of Mechatronics, Warsaw University of Technology, 02-525 Warsaw, Poland, ul. Św. Andrzeja Boboli 8

The presented paper concerns development of a parallel kinematic structure of a palm fingers exoskeleton as a prospective solution for common design difficulties encountered in typical serial-kinematics exoskeletons for the fingers rehabilitation. The performed state of the art review showed that in spite of over 40 years of development of exoskeletons, considered to be particularly useful as programmable medical devices, there is not achieved the acceptable level of safety and usability.

1. Short introduction to exoskeletons

The term “exoskeleton” is widely used in the strictly technical field of robotics and biomechanical devices, but it originates from the animals biology. The main feature of exoskeleton is the fact that is some kinds of external skeletons it plays double role, i.e. supports and protects the body of an animal.

The exoskeleton is a powered, artificial appliance. Quite accurate description could contain information that exoskeleton is a powered device mounted outside a human body with the main purpose of increasing operator's strength and endurance. Thus the exoskeleton may be designed in order to support any particular limb.

2. Medical purpose exoskeletons - two ways of development

Assistance in the field of daily living activities - is for a partially disabled person, who retains small percentage of movements control ability. The disability is not eligible to be lessened. The device main task is to supply the user with the difference between the strength necessary to perform basic daily activities and the strength of the patient's muscles ability.

Physical rehabilitation - statistical user of a rehabilitation exoskeleton is partially disabled person, whose health status shows, that the disability, after proper treatment, is eligible to be lessened. During the rehabilitation process, where after an injury the previous health level is regained, rehabilitation equipment is widely used.

3. Existing designs - a starting point of the development

The state-of-the-art review showed a number of common drawbacks among existing fingers' exoskeletons. The five following were selected as the most common and the ones that procure the highest level of difficulty for users: hinges placed between fingers, necessity of manual adjustment, one way active movements, backwards springs, fixed axis of joint's rotation. The drawbacks were chosen as a starting point for the design of a new kind of a fingers' rehabilitation exoskeleton.

4. Proposal of a flat (2D) parallel structure exoskeleton

The proposed design, shown on Fig. 1, is a 2D parallel mechanism. There are presented three parallel stages combined in series. For each of a finger's joint there is one independent lever powered by two Bowden cables. The triangular structure of the two cables and the lever is combined by the three 1R joints, therefore by independent linear displacements of the two Bowden cables the third part of the mechanism - that is the lever makes rotation around virtual axis of rotation.

There is no mechanical connection between consecutive levers other than two Bowden cables per lever. One of the mentioned common drawbacks is that artificial hinges between levers were eradicated. Therefore, the entire design is not only simplified, but also there is no necessity for any manual adjustment parts like common adjusting screws etc. Rigidity of the Bowden cables enables to eradicate presence of backwards springs. Both active movements: flexion and extension are enforced by respectively: elongating and shortening Bowden cables in the area of the parallel structure. Majority of the known designs, due to a usage of flexible cords, support only one active movement.

[*] Corresponding author: j.tulinski@mchtr.pw.edu.pl
[**] danuta@mchtr.pw.edu.pl

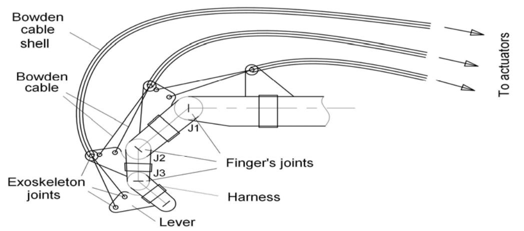

Fig. 1 The proposed mechanical structure of the exoskeleton

The trajectory is computed as a series of points in space. An inverse kinematics task [1] is used, where input data are angular positions of particular finger's joints (Distal, Proximal and Base Knuckle [2]), and output data are actuators' positions. The algorithm supplied with the angular position of the particular finger segments performs the four following steps (Fig. 2) in order to obtain required actuators displacements. Computations concerning only one joint (Base Knuckle J1) are presented. The first step - there are three input values: angular displacement of the finger joint ($J1_{ROT}$), and radiuses of the Bowden cable joints (R_{HI}, R_{LO}). Values (1–4) are the outputs of the first step. There are Cartesian coordinates of the Bowden cable joints.

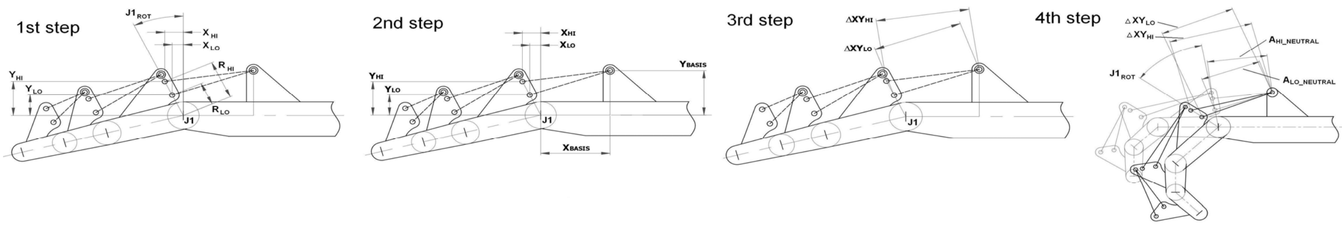

Fig. 2 The graphical presentation of the subsequent steps of the applied inverse kinematics task algorithm with the respective variables shown.

$$X_{HI} = R_{HI} \cdot \sin(J1_{ROT});\; Y_{HI} = R_{HI} \cdot \cos(J1_{ROT})\;;\; X_{LO} = R_{LO} \cdot \sin(J1_{ROT});\; Y_{LO} = R_{LO} \cdot \cos(J1_{ROT}) \quad (1–4)$$

The second step - Cartesian coordinates distances between Bowden cable joints. The output results (5–8) are the distances between both Bowden cable joints (upper and lower) and the double joint where Bowden cable outer shells are.

$$\Delta X_{HI} = X_{BASIS} + X_{HI}\;;\; \Delta Y_{HI} = Y_{BASIS} - Y_{HI}\;;\; \Delta X_{LO} = X_{BASIS} + X_{LO}\;;\; \Delta Y_{LO} = Y_{BASIS} - Y_{LO} \quad (5–8)$$

The third step - rectilinear distances between Bowden cable joints. Using the distances between Bowden cable joints and collinear joints where Bowden cable outer shells are attached described in rectangular coordinate system, the shortest - rectilinear distances between the mentioned joints are computed. Upper (9) and lower (10) Bowden cable distances are:

$$\Delta XY_{HI} = (\Delta X_{HI}^2 + \Delta Y_{HI}^2)^{\frac{1}{2}}\;;\; \Delta XY_{LO} = (\Delta X_{LO}^2 + \Delta Y_{LO}^2)^{\frac{1}{2}} \quad (9, 10)$$

The last step of the inverse kinematics task consists of using difference equations (11 and 12) for each of the actuators. The results (AD_{HI}, AD_{LO}) are the differences of the Bowden cables lengths between joints (ΔXY_{HI}, ΔXY_{LO}) in a current position and the cables lengths in the positions regarded as a neutral ($A_{HI\_NEUTRAL}$, $A_{LO\_NEUTRAL}$).

$$AD_{HI} = \Delta XY_{HI} - A_{HI\_NEUTRAL}\;;\; AD_{LO} = \Delta XY_{LO} - A_{LO\_NEUTRAL} \quad (11, 12)$$

With the above mentioned results (AD_{HI}, AD_{LO}), the last task to compute for the current exoskeleton position, is to determine values of the actuators control signals, required for actuators to achieve the desired position.

5. Conclusions

The research showed that in spite of over 40 years of exoskeletons development most of the designs have a number of common drawbacks. A proposed 2D parallel kinematics structure does not only supersede the known drawbacks encountered in conventional, serial structure devices, but also is likely to do not introduce any new inconveniences for the end users.

References

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[2] Bochenek A., Reicher M., "Human anatomy", PZWL, 2006