Title:
STRAHAND: Hand Exoskeleton for Rehabilitation Purpose

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Keywords:
hand exoskeleton, rehabilitation, CAD modeling, rheumatoid arthritis.

DOI: 10.14733/cadconfP.2023.46-50

Introduction:

Rheumatoid arthritis is one of the most common disease in elderly people. Most of them struggles in doing basics activities, like grasp an apple or grab cutlery, and need rehabilitation procedures to reactivate their hands motion. A useful solution in this way can be the use of a glove that thanks to his pneumatic action is able to help the squeezing movement of the hand.

The idea behind this project is twofold: to give the patients a direct support along their daily activities and in the meantime to help them regain the lost mobility and independence. The world population is ageing very quickly [7], causing a social trasformation. However new opportunities, a longer life caused an increase incidence of diseases, such as rheumatoid arthritis. It affects in particularly women (3 times more), and the number of cases increases with the age. The main critical issues related to this desease are the heating of the interested zones, together with pain and also difficulties in movements that require strength in hands. [6]

Rehabilitation is defined as management of the consequences of disease. In patients with rheumatoid arthritis (RA), the consequences of the disease such as pain, deformity and loss of physical function have been recognized since its earliest descriptions. As none of the current therapies for RA are capable of inducing long-term remission in all persons, patients are likely to continue to experience disability due to their disease in the future. In last years different methods have been introduced to the treatment of RA; in this paper we will focus the attention of one of the most used: Exercise Therapy.

The objectives of exercise therapy in patients with RA are restoration, preservation or increase of joint range of motion, muscle strength or cardiovascular condition. About 70/100 of patients with RA are involved in any type of exercise. Range of motion (ROM) exercises are intended to maintain or improve joint range of motion and flexibility and can be executed either active, assisted or passive.

- Active angular movement of the joints by the patients themselves is thought to be important for maintaining range of motion. If patients are too weak or otherwise unable actively to move their joints, assisted ROM exercises may be carried out, with the patient moving the joint through its maximal ROM and the therapist assisting with the terminal stretch.

- Assisted ROM exercises can also be performed with automated machines for continuous passive motion (CPM). These latter techniques are used, for example, after knee joint arthroplasty. In a systematic review of CPM after total knee arthroplasty, it was shown that, in the short term, a faster gain of range of motion can be attained in comparison with the control treatment; however, the effect on functional ability remains unclear.

- Passive ROM exercises are undertaken by a physical therapist, and are indicated for joints that are incapable of moving and at risk for development of contractures, with the aim of stretching peri-articular structures.

Several mechatronic devices for rehabilitation have been developed, facing many challenges of different natures. We decided to summarise them here.

- Comfort. A painful or annoying device will be unlikely used with perseverance and desire. Especially for rehabilitation, a hand exoskeleton should be comfortable for the user [3]. These devices have to be worn for long periods. One cause of discomfort is the misalignment between the orthosis and the human hand. It can damage skin and tissue [2].

- Lightness. Even though there are examples in the literature of lightweight devices [5], they are still a limited number. During the development process of an exoskeleton, lightness must be considered a high priority [4].

This research aims to develop a pneumatic portable hand exoskeleton for rheumatoid arthrisis patients. This solution meets the users' needs and addresses the current open challenges in the literature. A further objective consists of coupling the prototype with engaging exercises to reduce the high therapy abandonment rate.

STRAHAND:

The development of the STRAHAND device has seen the experimental approach as a primary aspect of the whole process. Some features must be taken into account in order to improve the comfort of patient in the use of our device, following several sources from the literature and personal experience; among them the following are the most important:

- placement: the device should be placed on the dorsal side of the hand to permit the interaction with the environment

- weight: do not overpass approximately 500g on the hand. It is a rehabilitative device. The patient (usually elder with motor impairments) should undertake repetitive exercises for several minutes without feeling pain or fatigue. It is also important to avoid hyper-extension of the phalanges.

CAD and Additive Manufacturing of the Exoskeleton:

Based on the users' needs, STRAHAND has a pneumatic soul that, through deformable elements connected to the dorsal side of each finger, allows their movement. The pressurized air from the compressor is delivered through a single air-inlet tube. A sorter is present at the height of the dorsal part of the hand: it permits the ramification of the single air-inlet tube to the 5 finger-connected delivery pipes. For each finger, at the knuckles height starts the extendable tube that enable the flexion/extension movement of fingers, avoiding hyperextension. The conducts are fixed to the glove structure in multiple points, in order to limit the pipe's unwanted movements. Lastly, on the wrist, a sorter permits the passage from 1 flux in entrance to 5 fluxes (one per finger) in exit. STRAHAND aim is to help the patient in the grabbing mechanism of objects, so it works on the finger's flexion movement.

We designed all CAD components using Autodesk Inventor® Professional 2022 [1]. STRAHAND is composed of several elements obtained by additive manufacturing (AM). The flexible ones lead and accompany movements of the human hand and have to adapt to its deformation. Others require more strength, for example, to fix the extendible pipes, and are rigid.

Fig. 1: Final shape of STRAHAND.

Looking at Figure 1, it is possible to notice that the core element of the assembly is the elongable tube. It spans all the user's finger lenght and is fixed to the hand by 3 different supports: a cap on the finger end, and two rings on phalanxes. Velcro is applied under the rings, in order to adapt STRAHAND to the specific user hand size, that can change the position of the joints to meet their needs. In the dorsal part of the hand 5 pneumatic joints are present, letting the passage to a smaller tube diameter; the smaller tubes are then collected into a sorter; from the sorter we are able to pass directly to the compressor.

The components have been printed using Sharebot One and Sharebot Next Generation. This procedure assures good precision and a creation of quite complex shapes. In order to provide suitable files to the printers, we used two slicing softwares: Slic3r for the Sharebot Next Generation and Continuum for Sharebot One. Including various tests that we have made and the final selected shapes, it took approximately 16 hours and 30 minutes for the production of all the models.

Final assembly:

STRAHAND is the union of multiple components. To better examine it, Figure 2 shows a drawing of the system with annotations. It includes the hand exoskeleton, pneumatic elements, fixing parts and joints.

- Connector system (x5): each of them receives the 4 mm tube from the sorter and keep the elastic tube in position through an apposite joint. The coating tube is kept in position by means of a cable tie, placed around the output part of the connector. Between the input and the intermediate part of the connector system, is placed the 3D printed part which fix the whole system in the right

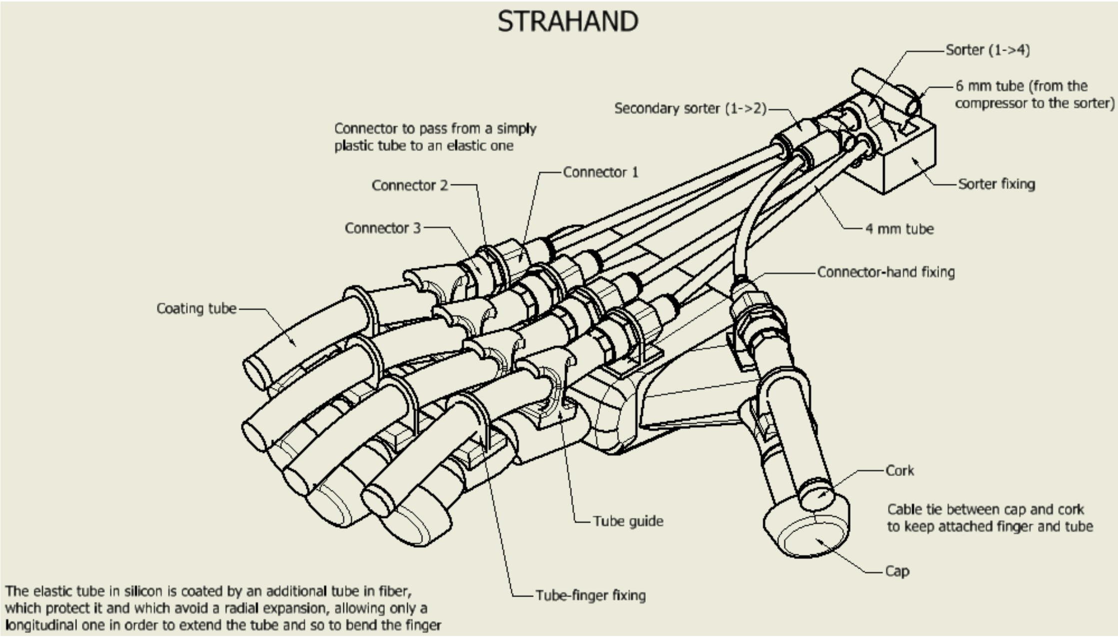

Fig. 2: STRAHAND assembly.

position on the hand

Moreover, every fixing element is connected to the glove by means of velcro, in order to permit to each patient to adapt the dimensions of STRAHAND to his own hand dimensions.

When we developed the project, we designed it under ideal conditions: if there isn't any loss, the compressor keep pushing and this may result in damage of the tubes or of the components. However, even if we set 10 bar in the fingers as compressor target, due to losses and pressure drops, the pressure will never reach this value, but it will stabilize around 3 bar. So, the valve sistem original designed is abandonend because not necessary, but also harmful (additional weight and cost).

Calibration:

In the project also a part of testing has been covered: by trivial and error procedure we tried some different solutions for every problem that we faced: for example different types of fixing systems and caps have been developed before converging to the final shape. Several tests on the glove itself has been performed too; the ideal pressure for STRAHAND work is about 3.5 bar; it is a pressure that assures a good elongation of the flexible tube, permitting the right exercise for the patient. All of the fingers are homogeneously deformed, showing a very accurate and fast dynamics. Also the release of the pressure is optimal for our application, infact is as fast as the inlet process. Though the compressor that we have purchased, even if assured a fixed and controlled pressure (for example 3.5 bar up to a maximum of 10 bar), has a poor flow with respect to our needs, and is not able to guarantee the right feed to our glove. A bigger and more powerful one has been used for the tests involving the completed exoskeleton.

Conclusions:

This work describes a rehabilitation system for the hand designed to assist patients during their rehabilitative therapy towards the process of regaining their autonomy. Improving the hand capabilities permits performing activities of daily living and interact with the environment. STRAHAND shows itself as a simple, agile and reliable exoskeleton. Anyway, this must be considered as a first prototype from which several improvements can be implemented, starting from its main drawbacks: the use of a rechargeable lung would make the exoskeleton perfectly autonomous and easy to carry ot, with no limitations due to the compressor. The automation of the control instead, comprehends the use of an Arduino board to control an electro-valve, that can manage the air flux and control the opening/closing of the device. Rehabilitation and object grabbing would be much easier.

Acknowledgement:
A special thank to the team of Airmatic SRL, Lecco, for the great contribution to the development of the first prototype, and the supplying of the pneumatic components.

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