The SoftPro Wearable System for Grasp Compensation in Stroke Patients

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***Abstract*— This extended abstract presents a wearable system for assistance that is a combination of different technologies including sensing, haptics, orthotics and robotics. The result is a device that, by compensating for force deficiencies, helps lifting the forearm and thanks to a robotic supernumerary finger improves the grasping ability of an impaired hand. A pilot study involving three post-stroke patients was conducted to test the effectiveness of the device to assist in performing activities of daily living (ADLs), confirming its usefulness.**

I. INTRODUCTION

Robotic devices have been developed to give supervised assistance to patients with mild to extreme motor disabilities after neurologic injury [1]. In the context of the EU project SoftPro (`https://www.softpro.eu`), a consortium of universities and companies has investigated novel solutions for assistive robotic tools to be used at home by chronic stroke patients. In addition to classical exoskeleton approaches [2], we have introduced the concept of using wearable robots as assistive tools for restoring grasping capabilities in people with paretic arms. We have also designed an sEMG interface embedded in a cap called e-Cap for the system control and a wearable haptic interface called CUFF which provides force feedback from a wearable robotic finger. We attached all devices to the Assistive Elbow Orthosis, a light passive exoskeleton that assists elbow flexion, to enlarge the number of potential final users.

II. SYSTEM COMPONENTS

The Robotic Sixth Finger is a wearable supernumerary robotic finger created by the University of Siena (US). It is an extra finger that acts as a functional replacement of the thumb, and has been demonstrated to compensate missing grasping capabilities of stroke subjects [3]. In the integrated device, the Sixth Finger has the end-effector function. It is the device of the system that enables the stroke patient to grasp objects in combination with the impaired limb. The e-Cap is a human-robot interface embedded in a regular cap which is easy to wear and can recognize the movement of the eyebrows through real-time sEMG measurement of the frontalis muscle [4], [5]. The e-Cap consists of an sEMG acquisition chain composed of dry electrodes, a commercial instrumentation amplifier and a Teensy 3.2 microcontroller to sample the analog signal. For the dry electrodes, we proposed a solution which combines a reusable sticky plastic tape and non-gelled 3D-printed flexible TPU-based sEMG electrodes developed by University of Twente (UT) [6].

The e-Cap electronic board is equipped with a Bluetooth antenna with which it can communicate with the Sixth Finger. Finally, at the back of the cap there is a 3D-printed box for the battery. Being an sEMG-based interface, it requires a calibration before operational use. The trigger for the calibration was upgraded in comparison to previous versions [4], [5]. The physical switch was replaced by a copper touch button. The described system maps the Sixth Finger's current load, an estimate of the force exerted onto the grasped object, to the CUFF [7] – a device developed by University of Pisa (UP) in collaboration with Istituto Italiano di Tecnologia (IIT), which renders a real-time force feedback by squeezing the arm. The device is composed of the structural frame, two mechanical actuation units and the feedback interface. A fabric band is attached to both motors, in such a way that when actuated in a counter-rotating motion the length of the band is reduced, squeezing the arm. Each added device increases the overall weight that the stroke patient has to lift when grasping something. To address this issue, we consider the use of the Assistive Elbow Orthosis [8], a passive gravity balancing device developed by the University of Twente, featuring a 3D-printed spring which is designed to provide weight compensation to the

Fig. 1. The Robotic Sixth Finger (a) and its power supply and control system (b) developed by US has been integrated with the Assistive Elbow Orthosis (c) developed by UT and the CUFF (d) from UP. The CUFF has been modified to be completely wearable. Motion of the finger is controlled by a new e-Cap version (e) developed by US with novel 3D-printed electrodes by UT

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forearm of the affected limb. The device consists of a modified Wilmer elbow orthosis (Ambroise, Enschede, The Netherlands) which acts as the mechanical interface to the wearer, and a stack of nested springs that is mounted laterally onto the orthosis. The spring shape has been optimized to provide an angle-dependent moment at the elbow, which counteracts the moment caused by gravity acting on the forearm. The final prototype is shown in Fig. 1.

III. SYSTEM INTEGRATION

When the patient raises the eyebrows, the e-Cap recognizes the gesture by sEMG real-time processing and triggers the Sixth Finger to close, in order to perform a grasp. This trigger signal is sent via Bluetooth antenna to the Robotic Sixth Finger, that starts closing itself until it reaches contact with an object. Once the Sixth Finger is in contact with the object, the patient can decide to increase the strength of the grasp by keeping the eyebrows raised. The amount of force is proportional to the time the patient keeps the eyebrows raised, and the value of the Sixth Finger load is sent to the CUFF device. The current that flows to maintain the motor torque level, was used as an estimate of the force that the Sixth Finger is exerting on the grasped object. The CUFF renders the force feedback in real-time by squeezing the arm in a way that is proportional to the estimated force. Finally, to open the finger, the patient has to raise the eyebrows upward twice consecutively. This movement is acknowledged by the system by vibrating twice. The act of integration required modifications to all components. The e-Cap was upgraded by using non-gelled 3D-Printed flexible TPU-based sEMG electrodes. The connection between the Assistive Elbow Orthosis , the Sixth Finger and the CUFF was improved to increase the wearing comfort. The CUFF control library was modified to use an UART port instead of a USB com port. To use the UART port, additional hardware was necessary to allow communication via the RS-485 protocol used by the CUFF device. The CUFF was modified to increase wearability in the integrated system. It was difficult to wear the CUFF for this specific application, because the fabric strip of the device got stuck on the arm of patients while donning the system. Thus, we cut the fabric strip in the middle and sewed velcro pads to the ends of the fabric. In addition, a button was added to be used as a redundant means of control since some users reported problems using the e-Cap interface.

IV. PILOT STUDIES

We have conducted a pilot study on the usability of the integrated system involving three patients. Two subjects taking part in the experiment have been affected by stroke no more than three months before and one subject was in a chronic state. The device can be used by subjects showing a residual mobility of the arm. Patients received the system on their paretic arm, the left hand for two subjects and the right one for the other. Patients were asked to wear the system, familiarise with the controls and then use the system to execute a series of bimanual tasks common of ADLs: opening a bottle, removing the cap from a jar, and peeling an apple. The paretic arm and the wearable system were used to stabilize the objects. We perform a qualitative evaluation of the system asking the participants to answer the ten questions of the System Usability Scale (SUS) [9] after 30 minutes of use. A quantitative analysis using adapted evaluation scales starting from the ARAT and the Frenchay Arm test will be performed as future work. The patients scored 70, 95 and 90, respectively. This means that the integration was deemed useful and the resulting device easy to use. We also collected suggestions for further improvements of the system. One patient suggested to provide the ability of adapting finger length depending on the task. Two patients suggested to further reduce the encumbrance of the feedback device. Finally one patient suggested to add the ability of regulating closing velocity and applied force through knobs embedded in the control box at the forearm.

V. CONCLUSION

In this work, different technologies such as a supernumerary robotic finger, an sEMG input device using 3D-printed electrodes, a wearable force feedback device, and a gravity balancing arm orthosis were combined to generate a new device that can assist an impaired arm. The positive response of the subjects that participated in the pilot study indicates the need for robotic assistive devices. The collected first impressions of the users will provide the starting point for further development.

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