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Abstract: A system to evaluate several facets of hand function for neuroprostheses-mediated tasks is proposed. It includes a platform that serves as a test bench, sensors for dynamometry, electromyography, sensorized glove, and interactive objects. The system methodically locates and assesses the motor points along the forearm, evaluates stimulation-induced fatigue, measures digit motion and forces exerted during ADL grasps, and evaluates nerve excitability to advance electrode designs. While the system is exclusively designed for neuroprostheses-mediated grasp, it can also be extended to generic grasp and object manipulation-based research.

Keywords: forearm; sensor glove; electromyography; Functional electrical stimulation; hand function

INTRODUCTION

Transcutaneous stimulation serves as a viable intervention to restore upper limb functions [1]. Thus, evaluating the neurophysiological function mediated by transcutaneous stimulation will aid in developing better devices, their optimization, and the assessment of the meditated recovery. This study presents a system to evaluate several facets of hand function for neuroprostheses-mediated tasks.

The forearm's tightly packed musculature makes the identification of optimal motor point and electrode configuration an arduous task [2,3]. Furthermore, more than one stimulation site and electrode configuration can elicit a similar response. Hence, targeting the forearm muscles to identify, localize, and characterize the motor points and their electrode configurations must be carried out like a methodical process, wherein the assessment setup must facilitate fasting scanning times and standardization of outcome [2–4].

During external stimulation, its influence and the resulting muscle contraction can be quantified based on the contact forces exerted using a dynamometer under isometric conditions [5,6]. Similarly, studies have used dynamometry to measure wrist torque and prehensile grasp forces [7,8]. Although they are suitable for larger forces such as wrist torque or isometric digit forces, they are not suitable for low-level grip forces that involve object manipulation tasks.

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Similarly, quantitative investigations on hand function can be summed up into four categories. Firstly, finger movements and grip force are studied to evaluate fine motor control [8,9]. Secondly, the relation between grip force and the load is studied by assessing the grip necessary to counteract the physical load while holding an object [10,11]. Thirdly, to study unconstrained manipulation, dynamic gripping is assessed. Lastly, the force-generating capacity is assessed by studying the power grip [12]. To facilitate such measures while performing manipulation tasks, both kinetic and kinematic aspects of digits and the objects being grasped must be evaluated [10].

Studies have measured the position and forces of digits and fingers using a measurement system that mounted load cells [7,13]. However, these systems were static, facilitating assessments only for prefixed hand or forearm orientations. As an alternative to such static assessment systems, sensorized gloves can promote robust and dynamic measures while performing manipulation tasks. Sophisticated systems included the use of fiber optics-based sensors, motion capture devices, such as the Vicon [8–10], and inertial measurement sensors, which gave the position and orientation of each digit in a 3D space used [10,11,14–16]. Still, these devices are cumbersome, need constant calibration, and are technically challenging to operate in a non-laboratory-based setting. However, incorporating lightweight, compact sensors with robust measurement outcomes and low power consumption can make them ideal for hand function assessments.

With the above motivations, the main objective of this study is to present a system for assessing several aspects of electrical stimulation while facilitating hand function tasks. Thus, the objective of this system includes:

- To feature an XY-gantry system that localizes motor points under three forearm orientations.
- To include dynamometry and electromyography to assess muscle contraction.
- To facilitate the assessment of nerve excitation by eliciting a twitch response.
- To include a sensorized glove for kinetic and kinematic measures of hand function.

METHODS

Firstly, a custom-made setup was devised to position/orient the forearm while the participants sat comfortably (Figure 1). Given the prolonged nature of experiments, adjustable and padded arm support further improved participant's comfort. The anthropometric information on the length of the forearm, length span of the wrist, and length of fingers was considered for the design of the test bench [17,18]. The setup also featured several adjustments that could improve the suitability of the user, as indicated by blue arrows in Figure 1. At the wrist level, a mechanism facilitates controlled pronated, supinated, and neutral positions, insert in Figure 1. The setup featured an XY-gantry that gave electrode positions about the forearm surface.
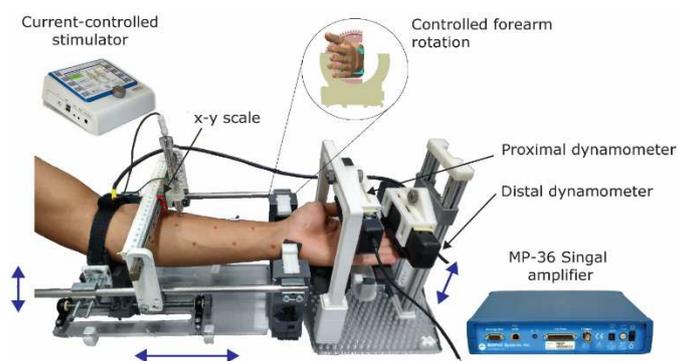

Figure 1. Hand function assessment system.

Secondly, the setup had two SS25LA Dynamometers (BIOPAC Systems, Inc., California) that evaluated the muscle response to subsequent stimulation. One dynamometer measured the forces exerted by the thumb and wrist and the other measured forces across the four digits. The positions of these sensors were adjusted to suit the user. Force measurements from these dynamometers sampled at 1 kHz were recorded using Biopac MP 36 (BIOPAC Systems, Inc., California). The Biopac

MP 36 amplifier also enabled electromyography (EMG) measures. The interactive objects represented the objects that were used in daily living [19,20].

Also, the external stimulation was delivered through a current-controlled stimulator, Rehastim™ (Hasomed GmbH). The stimulator had eight channels to deliver customized stimulation and supported various pulse generation modes. The stimulation parameters could be regulated, with amplitude up to 130 mA, pulse-width up to 500 µs, and frequency up to 50 Hz, using a PC via the ScienceMode2. A custom software interface was developed to control the hardware (Figure 1). Details of this software implementation are described here [21].
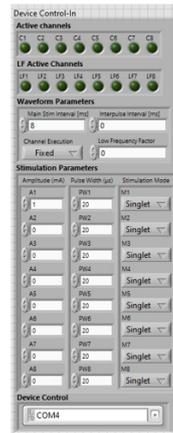

Figure 1. A LabVIEW-based software interface.

Thirdly, a sensorized glove facilitated the kinetic and kinematic measures of hand manipulation tasks. It consisted of a fabric glove with several sensors mounted using a 3D printed assembly (Figure 2e). The glove mounted flex sensors, force sensors, and IMUs that measured digit motion, fingertip forces, and hand orientation during activities of daily living (ADL)-based grasp, respectively.
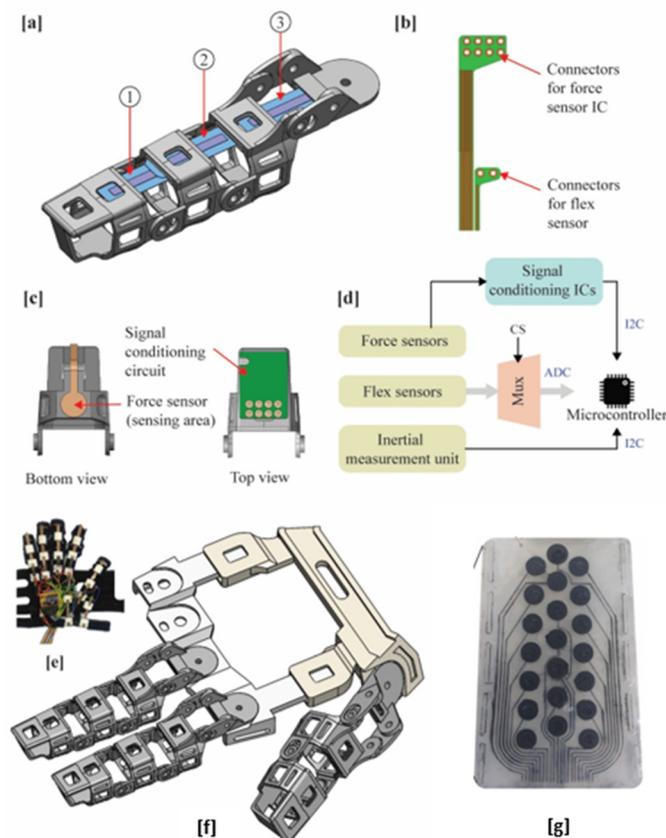
Figure 2. (a) Housing to accommodate the flex sensors across the finger joints, (b) Flexible printed circuit board to connect sensor elements, (c) Force sensor on the distal phalanges with sensing element on the palmar side and the signal conditioning circuit on the dorsal side, (d) block diagram for the electronics two versions of the sensorized glove, (e) fabric-based and (f) 3D-printed version, (g) electrode array-based sleeve.

A second iteration of the glove was also developed, as described here [22]. The glove included unidirectional, resistance-based flex sensors (Spectra-Symbol, Salt Lake City, USA). Several flex sensors measured the flexion of five digits, the flexion of the wrist, the abduction of the thumb, and the extension of the wrist. Each digit had two flex sensors that measured the range of motion at its respective proximal and medial phalanges. The outputs were then normalized based on the ROM of their respective phalanges to give the percentage of flexion/extension between 0 – 100. The capacitance-based force sensors (Singletact™, Pressure Profile Systems Inc., USA) at the fingertips gave a pre-calibrated output that measured fingertip forces up to 50 N. Also, the IMU was mounted on the posterior side of the hand, which prevented any interruption to the user while handling or grasping objects. A DAQ device collected the outputs from all the sensors and processed them in LabVIEW 8.6 (National Instruments, TX, USA).

The ADL-based grasps were mediated by dynamic control over the forearm muscles using an electrode array-based sleeve. The sleeve had several reconfigurable 3 x 3 pads of Ag-AgCl-based disposable snap electrodes that covered the desired forearm regions. Seen-printed wearable sleeves were also used [23] (Figure 2g).

RESULTS And DISCUSSION

The assessment setup enabled to position/orient the forearm; this allowed motor point identification under controlled pronated, supinated, and neutral positions in [24,25]. Following motor point-based stimulation, to quantify muscle tension directly, isometric contact forces of the digits and the wrist were measured using the two dynamometers mounted to the setup. Moreover, motor points along the forearm surface were traced using a special motor point pen mounted on the XY gantry. The gantry system within the setup facilitated the localizing and assessment of the response of motor point-based stimulation.

Similarly, dynamometry was used to determine the muscle response to varying stimulation parameters [26]. Evoked force exertions were normalized based on the strength of isometric contractions using maximum voluntary isometric contractions (MVIC) [25]. Also, the influence of stimulation-induced fatigue was studied across the forearm muscle groups; here, EMG was used to quantify the onset of fatigue by measuring the fall in muscle contraction levels over time [26]. Furthermore, the sensorized glove, which mounted flex and force sensors, measured digit motion and force exerted during ADL-based grasps [22]. These electrophysiological evaluations can help identify stimulation waveform parameters for a desired target response and further optimizations on them can improve subject-specific outcome [27–30].

Lastly, the setup was able to position the forearm comfortably for extended periods, which enabled psychophysical, recruitment (muscle), and excitability measures to assess the stimulation performance for electrodes [23,31–33].

CONCLUSION

A hand grasp assessment setup is proposed to evaluate several aspects of electrical stimulation across the forearm muscles. The entire system and its elements were custom-built, which consisted of a test-bench platform with dynamometry and electromyography, a sensorized glove, and interactive objects. The test-bench platform featured an XY-gantry scale that was used to locate and assess the response motor point-based stimulation. Also, the sensorized glove-mounted flex sensors, force sensors, and IMUs that measured digit motion, fingertip forces, and hand orientation during ADL-based grasps, respectively. The system was exclusively designed for neuroprostheses-mediated grasp. Still, it can be extended to generic grasp and object manipulation-based research.

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