DESIGN OF A COMPACT AND PORTABLE HAND REHABILITATION DEVICE FOR STROKE-SURVIVORS

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INTRODUCTION

About 795,000 people experience strokes in the US, annually [1], with many suffering from the hand disabilities post stroke. The effects of such disabilities include weakened grip strength, lack of muscle coordination, and hand spasticity [2]. Although commercially available products like Saeboglove, Musicglove and Exo-Glove enable in-home hand rehabilitation, they have limitations that considerably prevent their broader usage: (i) they focus on specific hand functions, (ii) they require a considerable active range of motion to operate, and (iii) they are inapt for patients with hand spasticity [2]. Hence, a new compact and portable Hand Rehabilitation Device (HRD) is proposed that would rehabilitate the hand in a holistic manner. The HRD (US Patent Application: 62/413,130) is a fully actuated rotor-gimbal assembly, which when actuated imposes a gyroscopic torque on the user's hand. Unlike the current products, the developed gyroscopic torque does not demand the user's input.

METHODS

Based on a customer needs analysis and a competitive benchmarking, it was gathered that a device that imposes a torque on the hand would aid in rehabilitation. There are two kinds of therapies that can be implemented with such a device: one involving synchronization of the hand movement with the generated torque and another requiring the user to resist the torque. While the former relaxes the hand muscles and combats hand spasticity [2], the latter increases hand muscle strength and coordination [4]. It was decided that the HRD should produce a minimum 0.7Nm gyroscopic torque (the amount required to open a jar's lid – an activity performed during physical therapy) [5]. The mass of the device was limited to approximately 550g (mass of a commonly carried half-liter water bottle) so that the device does not strain the user's hand. Portability is another desired feature so that users can undergo rehabilitation anywhere and at any time.

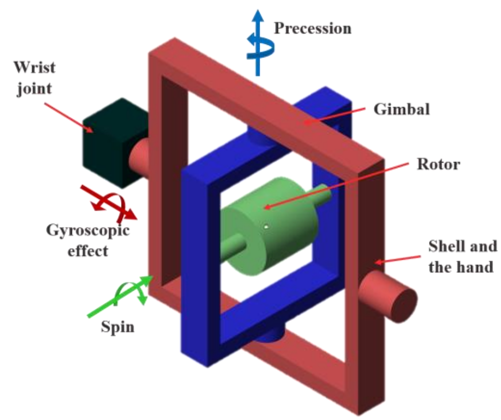

Figure 1: A schematic of the device

Consider Fig. 1 where red, blue and green components represent the user's hand, gimbal and the rotor, respectively. When the rotor spins about its axis and the rotor-gimbal assembly precess about the gimbal's axis, a gyroscopic torque is generated and acts on the user's hand. To understand the working principle, a proof-of-concept (POC) model and mathematical simulations were created.

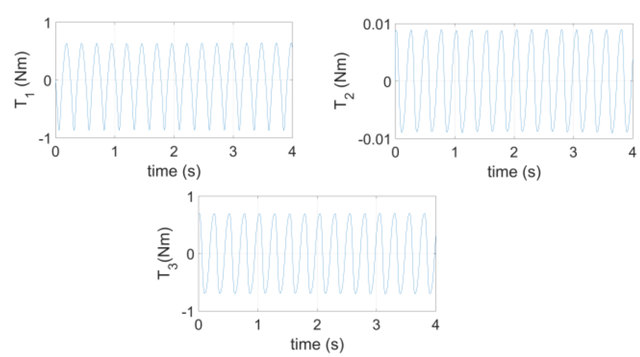

Figure 2: Theoretical torques achievable by the device for the specifications provided in Table 1. T_1 is the torque about wrist flexion and extension, T_2 is the torque about radial and ulnar deviations, and T_3

is the torque about pronation and supination of the wrist.

The POC consisted of a fully actuated rotor-gimbal assembly was constructed. It was observed that the hand was forced to move about the wrist in a circular manner when no restriction was posed against the torque. Additionally, imposed hand motion can be manipulated by varying the motion of the rotor–gimbal assembly. Further the mathematical simulations revealed that for given parameters of the device, such as inertia and mass, a torque of magnitude 0.8Nm was attainable. These simulations were used to select the design parameters of the device.

RESULTS AND CONCLUSION

The greatest challenge of the design process involved lessening the weight and size of the device. Owing to the size requirements of the embedded subsystems, the desired spherical shape could not be acquired and thus an oblong shape had to be adopted. The final product was designed to resemble an American football, so that it would appeal to the user and prospectively add a fun element to the rehab process. To make the device portable, the electronics were initially conceived to be embedded in the device. Since this idea conflicted with the need for compactness and lightness, the electrical systems are placed external to the device in a satchel that the users can wear. While the wires to the gimbal's motor are easily drawn through a hole in the bottom end cap, the wires for the rotor assembly are mechanically coupled to the motor's leads via a slip ring assembly. This enables the free precession of the rotor assembly without any entanglement of wires. To ensure symmetry in the design and to avoid rotary imbalances, the rotor and the gimbal housings were directly integrated with the permanent magnet rotor of the chosen brushless DC motors.

Currently, a dynamic analysis of the design is being carried out to determine the output torques, which will be followed by a biomechanical analysis to i) attest the safety of the device and ii) examine muscle activation patterns due to the output torque. Upon fabrication, the device's performance will be evaluated by investigating the relation between the muscle activation patterns and the hand functional recovery of stroke survivors. Fugl-Meyer hand function will be evaluated.

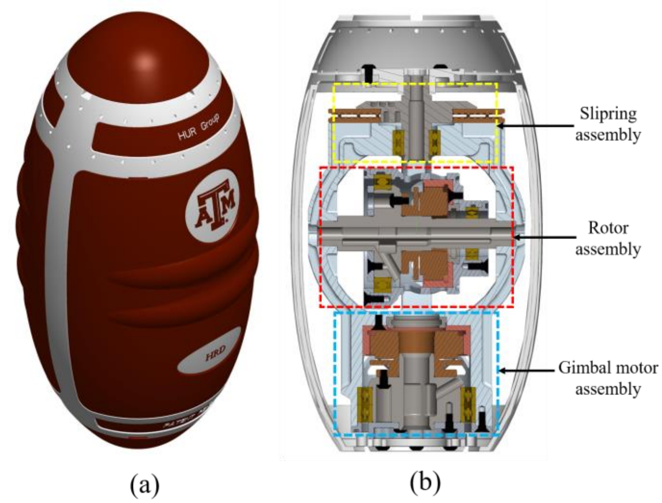

Figure 3: (a) Isometric view of the device (b) Cross-sectional view of the device with major subsystems highlighted.

Given the novelty of the device, more efficient and affordable hand rehabilitation for stroke patients is expected. In addition, the application of the device can be extended to other patients with hand function problems including patients with arthritis, Carpal Tunnel Syndrome, and those recovering from hand injuries/surgeries.

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