WRISTSENSE: A MOTOR-ACTIVATED MULTI-FUNCTIONAL WRIST ORTHOTIC TO ASSIST INDIVIDUALS WITH SPINAL CORD INJURIES WITH ACTIVITIES OF DAILY LIVING

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ABSTRACT

Many individuals with mid-cervical spinal cord injuries (SCI) rely on wrist supports or orthotics in order to keep their wrists stabilized to grant them more functional ability. However commercially-available wrist supports principally provide support to perform limited activities of daily living (ADL) with cuff attachments. We developed and tested a motor-activated wrist orthotic system, the WristSense, which uses a two-tier gesture recognition approach to assist individuals with SCIs to perform a larger range of ADL. The WristSense was used as a PowerPoint presenter to allow individuals with SCI to present without much hassle. WristSense can be adapted by adding a variety of actuated tools to expand the ability of wearers to perform various ADL.

INTRODUCTION

There are approximately 12,500 new cases of Spinal cord injuries (SCI) every year in the United States alone and approximately 44% of these individuals have injuries in the C3-C6 region of the spinal cord. Daily manual activities such as unlocking doors with keys, swiping credit cards are extremely difficult for individuals with mid-cervical SCIs due to paralysis in the hand muscles preventing grasping and releasing and paralysis or weakness of wrist flexors and extensors [1].

In order to stabilize a flaccid wrist, wrist orthoses or splints can be used to maintain the normal position of the hand and wrist [2]. Wrist orthotics have often been used in rehabilitation of individuals with SCI to allow for the correct positioning of joints in the wrist, in order to maintain optimal muscle tone and structure[3], [4]. With the addition of a pocket in the palm cuff, mid-cervical quadriplegics are able to insert dining utensils, pencils, pens, toothbrushes, or other tools to accomplish certain activities of daily living (ADL) independently. However, these devices only provide support without much functionality. Other devices which use mechanical actuators or ratchet systems are bulky and cause fatigue to the individual [5]. Common ways to control actuators on these systems include speech recognition and gesture recognition [6,7].

WristSense focuses on expanding the functionality and usability of fixed wrist braces through the use of reliable gesture recognition systems which combine the use of gyroscopic and electromyography (EMG) signals [8,9].

PROBLEM STATEMENT

We found from speaking to our primary user, an individual with a C4/C5 SCI, that traditional wrist supports (Figure 1) can be enhanced or improved to add greater functionality to quadriplegics with little/no hand function.
A light-weight, wearable wrist orthotic was created using 3D printing and Arduino based electronics with sensors to perform various functions based on the recognition of different gestures performed by the user.

METHODS AND APPROACH

Wearable Orthotic

The WristSense consists of two parts: a rigid 3D printed plastic body made of ABS filament and wrist straps made of a semi-flexible material (Semiflex™). A Makerbot® 3D rapid prototyper was used to develop the body of the WristSense. The WristSense is designed to provide comfortable support and adheres to the design of current orthotics by including a wrap-around framework to support the sides of the hand to secure the correct positioning. Figure 2 shows the evolution of the design of the WristSense as both 3D models and physical models. It is designed such as to allow individuals with different wrist sizes to wear it comfortably with the use of the adjustable 3D printed strap. Changes were made to the prototype based on the feedback received from our primary user who uses a wrist brace on a daily basis. The design of the WristSense was improved to allow maximum comfort and longevity of use.
**Electronics**

WristSense holds an EMG sensor (Advancer Technologies®) with electrodes attached to the surface of the wrist and an IMU (SparkFun Electronic®), which is connected to a microcontroller unit (Arduino® Micro). WristSense incorporates a laser pointer and allows the control of a PowerPoint slide presentation. The electronics are powered by one small, rechargeable battery. WristSense is designed to be lightweight, weighing around 160 g which is slightly lesser than the standard commercially available wrist splints.

![Figure 3: Schematic for the electronics of the WristSense](image1)

**Gesture Recognition Methods**

To minimize the occurrence of false positives, a two-tier gesture recognition approach was implemented to control the WristSense. The first tier is an EMG sensor which detects a fine gesture allowing the activation of the second tier. The second tier is an Inertial Measurement Unit (IMU) which detects one of four gross gestures to perform the desired task.

![Figure 4: Latest prototype of the WristSense](image2)
**EMG sensor: System activation**

The EMG sensor (Figure 5) is a commercially available light-weight sensor which measures action potentials from adhesive surface electrodes placed on top of the *pronator teres* (muscle in the forearm). The sensor identifies a pattern of rapid supination-pronation of the wrist (double wrist twist) by the orthotic wearer, which then allows for appropriate activation of the IMU during a preset time period.

![Figure 5: EMG Sensor- Advancer Technologies Muscle Sensor V4](image)

**IMU: Gesture Detection**

The IMU (Figure 6) recognizes four distinct gross gestures: In-Out, Out-In, In-Hold and Out-Hold (Table 1, Figure 7). These gestures were chosen for their comfort and ease of execution by two individuals with cervical SCI. Each of the gestures allows the user to move along the slides or use the laser as described in the table below.

![Figure 6: Inertial Measurement Unit with 6 Degrees of Freedom](image)

**Table 1: Motion for each gross gesture**

<table>
<thead>
<tr>
<th>Gesture</th>
<th>Motion</th>
<th>Actuator Activated</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Out</td>
<td>Moving hand toward body (In) then away from body (Out)</td>
<td>Deactivates the laser pointer</td>
</tr>
<tr>
<td>Out-In</td>
<td>Moving hand away from body (Out) then toward body (In)</td>
<td>Activates the laser pointer</td>
</tr>
<tr>
<td>In-Hold</td>
<td>Moving hand toward body (In) and holding position (Hold)</td>
<td>Moves to previous slide (emulates left arrow key of keyboard)</td>
</tr>
<tr>
<td>Out-Hold</td>
<td>Moving hand away from body (Out) and holding position (Hold)</td>
<td>Moves to next slide (emulates right arrow key of keyboard)</td>
</tr>
</tbody>
</table>
Subject Testing

Nine subjects were asked to assess the reliability of the gesture recognition system and identify the number of times accidentally activating the EMG sensor (false positives) when wearing the WristSense when performing typical movements such as grasping, reaching and retrieving, etc. Of these subjects, two were individuals with cervical SCIs and seven were individuals without SCIs.

Cost of Materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino Micro</td>
<td>25</td>
</tr>
<tr>
<td>EMG</td>
<td>35</td>
</tr>
<tr>
<td>IMU</td>
<td>30</td>
</tr>
<tr>
<td>3D Printed plastic body</td>
<td>10</td>
</tr>
<tr>
<td>Batteries</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total Price</strong></td>
<td><strong>120</strong></td>
</tr>
</tbody>
</table>

RESULTS AND USER FEEDBACK

The number of accidental initiating the EMG command (double wrist twist) was determined by how many times the WristSense system was activated through various arm movements of subjects. The activation of the system was identified through a buzzer. As shown in Figure 8, some typical movements activated the system more often than others. It was observed that the three activities that caused the highest false positives were a pronounced, single twist (33%), followed by reaching the arms inwards (29%), and then reaching and retrieving (13%).

The WristSense was also identified as being easy to use and comfortable enough for our primary user to wear on a daily basis. However, there were some issues regarding the muscle sensor, when it was unable to identify any muscle activity.
Figure 8: Average percentage of false positives for entire subject population

**SIGNIFICANCE**

We want to employ the WristSense to ultimately activate or deploy various lightweight tools attached to the orthotic, like an automated "Swiss Army" knife. This would improve the usability of the traditional wrist brace and allow users to adopt them more easily. The WristSense can be used by individuals with SCI as well as those with Carpal tunnel syndrome. The modular nature of the device allows various attachments to be added and motorized to allow more independence. In this particular case, our user enjoyed the use of the WristSense as a PowerPoint presenter and a laser pointer with which he could explain his slides.

The pronator teres is often activated by either pure wrist flexion or wrist flexion coupled with mild supination [10], has a rather broad attachment to the elbow and is one of the stronger motors in the forearm [11]. The pronator teres muscle was chosen for activation of the WristSense in order to provide individuals with upper cervical spinal injuries the ability to control the system with voluntary gross gestures such as the double twist. Other voluntary motor gestures are also possible.

**FUTURE WORK**

Future work will involve the implementation of a machine learning algorithm to improve reliable gesture recognition, further decrease the false positive rate, and allow the system to adapt to individual preferences. Moreover, multiple muscles can be used as aggregated input sources to further validate that a gesture was performed and reduce the false positive rate. We are also considering using a different activation system as the EMG can be unreliable and may not necessarily work on all individuals. This work will also be extended by integrating various tools to the WristSense to assist wearers with different ADL.

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REFERENCES


