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A ROBOTIC EXOSKELETON DEVICE FOR AUGMENTING WRIST MOVEMENT AND GRIP FUNCTION IN DEBILITATED PATIENTS

Chad V. Gilman
Robotics and Mechatronics Lab
Dept. of Mechanical & Aerospace Engineering,
The George Washington University
Washington, DC, USA
cvgilman@gwmail.gwu.edu

Pinhas Ben-Tzvi
Robotics and Mechatronics Lab
Dept. of Mechanical & Aerospace Engineering,
The George Washington University
Washington, DC, USA
bentzvi@gwu.edu

Gabriel Yessin
Department of Electrical & Computer Engineering,
The George Washington University
Washington, DC, USA
gyessin@gwmail.gwu.edu

Jerome Danoff
Department of Exercise Science,
The George Washington University
Washington, DC, USA
jdanoff@gwu.edu

ABSTRACT

Many diseases and conditions can cause reduced motor function in joints throughout the body. This paper identifies such health issues that affect the function of the wrist and hand in particular. After identifying these conditions, a concept three degree of freedom (two DOFs of the wrist plus cylindrical grip) robotic exoskeleton design is presented that is intended to augment a patient's remaining function and strength while remaining portable and lightweight. With this in mind, the device is intended to allow a patient to use and operate it independently, without the presence of a therapist. The mechanical design of the exoskeleton is described in depth, along with details of potential actuation methods. The main idea for control of the device is to detect small torque values as a patient attempts a movement and in turn predict what the intended outcome would be if the patient were at full strength. After processing this information the robot would assist the patient in facilitating the anticipated movement. This is in contrast to alternate control methods, which rely primarily on electromyography (EMG) to detect signals to muscles that control certain movements. Electromyography can be unreliable because many of the conditions that cause debilitated function also cause an interruption or break in these signals.

INTRODUCTION

Medical events that affect the hand and wrist can range from catastrophic, in the case of a cerebrovascular accident (CVA), more commonly known as a stroke, to non-life threatening such as a fracture. In many cases patients are left with at least temporary loss of function in their extremities. When a condition debilitates the hand and wrist, it affects the ability to function normally in everyday activities. Much of the use of our upper extremities involves using our hands in grasping and manipulation achieved through a combination of wrist and finger movements. Consequently, any condition that reduces activity of the hand and wrist can lead to weakness and atrophy of the upper extremities. The robotic-assist device can have two main benefits. First, by grading the level of assistance needed, the device would enable enhanced rehabilitation because it would be used throughout the day as opposed to being limited to therapy sessions. Second, the device would augment function for those with long-term or permanent loss of normal joint function.

1. CONTRIBUTING CONDITIONS

Numerous medical events can contribute to weakness or disability in the wrist and hand. Some of the conditions that could benefit from a robotic-assist device are described and detailed in this paper.

1.1 Cerebrovascular Accident (CVA)

A CVA or stroke can be one of two forms, ischemic and hemorrhagic. Ischemic stroke is the category in which a blockage occurs, preventing appropriate blood supply from reaching a region of the brain. Hemorrhagic stroke, as implied by its name is caused by hemorrhage or blood vessel rupture. The build-up of blood within the cranial cavity puts pressure on brain tissue, causing damage. When the brain is injured, a multitude of functions, from speech and sight to the control of the limbs can be affected. Stroke is a very prevalent event that affects more than 795,000 people [1] per year in the United States with over one fifth of that group not surviving the episode. The enormous rate of stroke occurrence per year has led to more than 5 million survivors [1] living in the US today, many of whom have impaired hand function on at least one side of the body.

1.2 Spinal Cord Injury (SCI)

SCI, an injury to the spinal cord or branching nerves, can also result in full or partial paralysis of the limbs. The spine contains twenty-nine vertebrae which are divided amongst four regions: cervical (seven vertebrae), thoracic (twelve vertebrae), lumbar (five vertebrae), and sacral (five vertebrae, fused in adulthood). Each vertebra is commonly referred to by the first letter of its region and number in descending order (i.e. head to toe), for example “C6”. In regards to hand and wrist impairment, injuries that affect said areas occur between C5-T1 (four vertebrae) while injures to the C4 vertebra and above affect arm, shoulder, and respiration. An injury to any of these upper vertebrae results in a form of what is known as tetraplegia, more commonly known as quadriplegia.

The American Spinal Injury Association (ASIA) classifies impairment due to a spinal cord injury into five categories (A-E) [2] as described in Table 1.

Table 1: ASIA Impairment Scale

Category	Severity	Description
A	Complete	No motor or sensory function is preserved in the sacral segments S4-S5
B	Incomplete	Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.
C	Incomplete	Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.
D	Incomplete	Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.
E	Normal	Motor and sensory functions are normal.

These levels are in part determined via what is known as Muscle Grading or the Manual Muscle Testing Scale [2] (Table 2), which determines a patient’s ability for different movements. Approximately 262,000 people [3] live in the United States who have survived and are suffering from the affects of a spinal cord injury. 30.1% of these individuals suffer from incomplete quadriplegia [4], which would be one of the groups where a robotic wrist and hand assist device is believed to have merit in improving quality of life.

Table 2: Numerical Value Muscle Grading Scale

Grade	Ability Level
0	Total paralysis
1	Palpable or visible contraction
2	Active movement, full range of motion, gravity eliminated
3	Active movement, full range of motion, against gravity and provides some resistance
4	Active movement, full range of motion, against gravity and provides some resistance
5	Active movement, full range of motion, against gravity and provides normal resistance

1.3 Wrist Fracture

A wrist fracture can refer to a break in one or more of eight bones in the wrist (carpals), or the ends of the forearm bones (radius, ulna). A wrist fracture is actually the most common type of fracture for people aged 65 and under and second only to fractures of the hip for those over 65 [5]. About one in every six emergency room visits is due to a fracture of the wrist [5].

Osteoporosis, which is a disease that reduces bone density and the presence of proteins, affects approximately 75 million people in Europe, the US and Japan [6], and about 250,000 of these people in the US alone suffer from wrist fractures every year [7].

When a fracture of the wrist occurs, common practice is to immobilize the joint, usually with a cast, regardless of whether the injury required resetting, surgery or no action. When a joint is immobile for a long period of time, the muscles used to activate it can atrophy, leading to below normal function by the time the fracture has healed. Other issues with prolonged immobilization are an increase in soft tissue stiffness and the buildup of scar tissue within the joint. All of these issues can usually be reversed through therapy that will force the joint to be moved through its range of motion. With access to a robotic device that a patient can wear throughout the day, the time to regain normal ability might be significantly lessened. A secondary benefit would be that with the movement assist that the device provides, a patient’s quality of life would be improved during rehabilitation because of an improved ability to carry out regular tasks.

2. BACKGROUND

Other devices and current research exist that are intended to aid in the movement of the wrist and/or assist in grip function. One of the devices, the MIT-MANUS [8] has achieved some clinical success and is in use in rehabilitation facilities. However, one of the main drawbacks of the MIT-MANUS and similar devices is their lack of portability [9-17], which limits use of these robotic systems to therapy sessions.

In some instances a robotic system is not portable simply due to its structure. This is usually done on purpose, as a stationary device can be designed on a rigid platform, therefore allowing for complete support of a patient's debilitated limb. While this allows for the size and weight of a design to be relatively unrestricted, portability becomes fairly impossible. Other considerations, such as control method can affect the portability and design of a device.

2.1 Electromyography

EMG, a method for detecting electrical signals associated with neuromuscular signaling is used as the system input for a few wrist assist robots [12-14,18,19]. The main focus of the research involving the devices introduced by Khokhar et al [18,19] was to test the validity of using EMG signals to control wrist moments. This was also part of the research of Gopura et al [12-14] who states that EMG signals are only reliable when the signals are strong. For example, persons neurologically impaired by stroke would inherently be unable to provide a strong, consistent signal. Therefore using EMG is not suitable method of control for severely weakened or neurological patients. Using EMG would also require electrodes on or in the muscles and extra equipment to process and analyze the signals. Finally, in order for the electrodes to pick up signals properly, their placement is critical.

2.2 Continuous Passive Motion

Some rehabilitation robots can operate using continuous passive motion (CPM) [20], which is essentially a set of predetermined commands used to exercise a joint. In this type of setup, there is no external input needed to control the device. The actuation system is simply pre-programmed to carry out a series of movements. The use of a CPM setup is often prescribed after a patient has undergone a major joint surgery, such as reconstruction or artificial joint replacement. It can also be used to shorten recovery time after a fracture. The main benefit of CPM is to counter the development of joint contractures that can increase recovery time or lead to a more permanent loss of range of motion. By using CPM, a joint remains active, blood flow is promoted, and the elasticity of ligaments is maintained or improved.

The most common CPM setups are those pertaining to the knee. However, these conventional devices are stationary and commonly require patient's use for up to 6 hours per day while remaining in a supine position [21]. There are various CPM devices available for a number of joints, including the hand and wrist, but none can provide the 2 DOFs needed for the wrist and fingers while maintaining portability.

The mobile device proposed and described in this paper would be able to provide CPM for those recovering from wrist fracture as well as an active autonomous control for those recovering from or living with other issues.

2.3 Movement Replication

Some robotic assist devices use the movement of an opposite healthy joint as the input for control [15-17]. Essentially, via angle measurement sensors, the posture of the healthy joint is replicated using the robot attached to the unhealthy joint. This type of control has benefits as the patient has more control over his or her rehabilitation; however it also has drawbacks. The main disadvantage of this control is that a patient must still schedule time to use the device, as normal activities are practically impossible, especially in the case of hand and wrist therapy since both sides of the body are in use. Even if a patient could use a device with this type of control to enable the unhealthy hand or wrist to complete a task, he or she would be more likely to just use the healthy hand to perform the task than to control the robot.

3. MECHANICAL DESIGN

The work presented in this paper deals with functions of the wrist and fingers. For simplification of the initial design, the fingers are restricted to allow motion in only one DOF, essentially replicating cylindrical grip function.

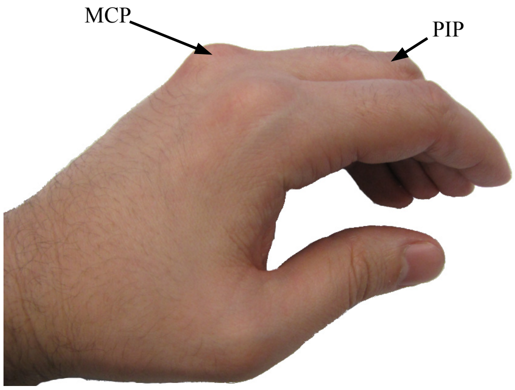

Figure 1: Selected Hand and Finger Joints

Flexion is isolated to the metacarpophalangeal (MCP) joints of the fingers while the proximal interphalangeal (PIP) (see Fig. 1) joints are to be kept at 45^{o} of flexion.

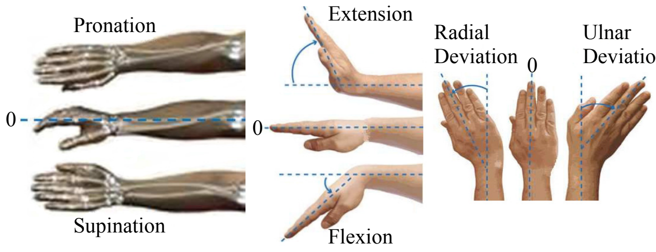

Figure 2: DOFs of the Forearm and Wrist [12]

Wrist functions (see Fig. 2) included in the design consist of flexion/extension (pitch) and radial/ulnar deviation (yaw). Pronation/supination (roll) of the wrist is actually a function of the forearm and is not included in this design. While the incorporation of as much function as possible is ideal, the 3 DOFs included in the design are most important when considering fine manipulation of objects. Therefore, pronation/supination assist will not be included in the device. A secondary consideration is to keep the device as compact as possible because portability is one of the main novel factors of the design.

3.1 Mechanical Components

The mechanical design of the robotic wrist exoskeleton is made up of nine main components, not including the various fasteners and other necessary hardware. Fig. 3 shows a three-dimensional (3-D) model of the design as it would be constructed for use on a patient's right hand.

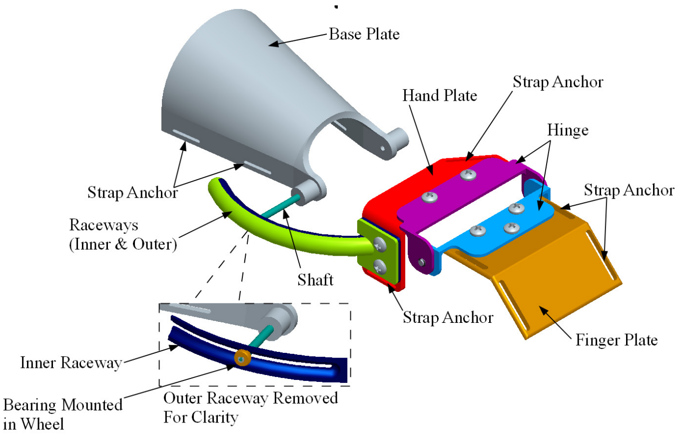

Figure 3: Detailed Mechanical Design

The Base Plate would be mounted on a patient's forearm. A threaded shaft is connected to the Base Plate and extends into a raceway made up of two components. Mounted on the shaft and contained within the raceway is a bearing which is fitted inside a modified sphere or wheel. The raceway can rotate about the wheel to allow for wrist flexion/extension, and the wheel can roll throughout the raceway to allow for radial/ulnar deviation. By combining the 2 wrist DOFs in this manner, the axes of rotation still cross through the center of the wrist, allowing for a reasonably accurate representation of the joint's normal function. A second benefit of this type of configuration is that the total number of components needed to replicate the 2 DOFs is lessened, leading to a lighter and more streamlined device. The Inner and Outer Raceways are then fastened to a hand plate that sits on the back of the hand. These components make up the elements needed to replicate wrist functionality in the design.

On their own, there is some concern that the wrist replication components may not be rigid enough to allow for precise movements. This concern is alleviated because the device is intended to be used by a patient with a fully intact skeletal structure, and this structure is what the exoskeleton replicates. Therefore, when the device is attached to a patient there are two mechanical paths that can facilitate the same motion, increasing rigidity.

For the replication of grip function, via rotation at the finger's MCP joints, one side of a custom hinge pair is fastened to the Hand Plate and another side to a Finger Plate. This Finger Plate would sit on the dorsal surface of a patient's fingers.

For left hand use, the only component that would need to be changed is the hand plate. It is currently designed for an ergonomic fit with the right hand. A mirrored version of this component would be needed to fit the left hand. All other components are designed symmetrically and would simply just need to be switched and re-assembled on the other side of the Base Plate.

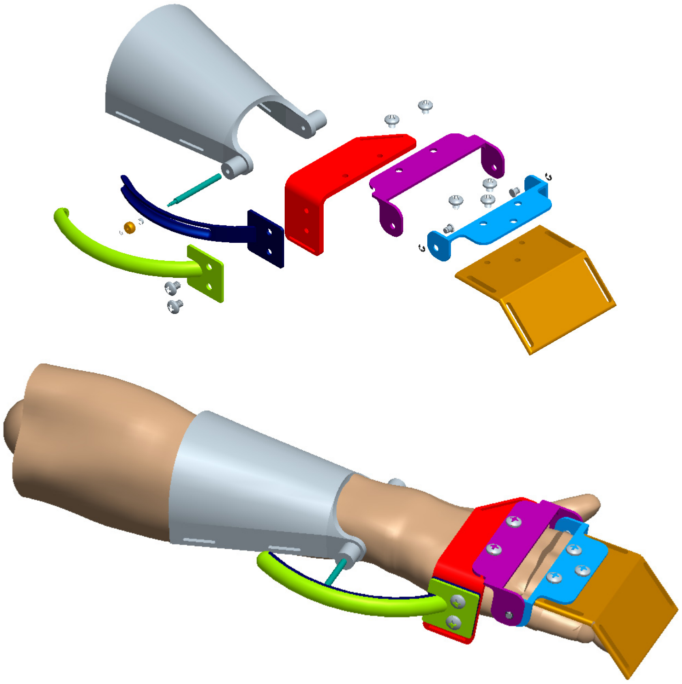

Figure 4: Exploded View of the Mechanical Design and an Example of a User's Right Arm and Hand Integrated with the Robotic-Assist Exoskeleton

The Base Plate, Hand Plate, and Finger Plate all have anchoring points for either elastic or Velcro straps. The straps would connect the Base Plate to the forearm, the Hand plate to the dorsum of the hand, and the Finger Plate to the fingers.

3.2 Actuation Methods

For the actuation of the exoskeleton DOFs, several methods were considered. From the outset, it was decided that the design should contain as few components as possible at the location of the wrist and finger movement. Doing so means less mass that a patient would need to support while using the device, as well as a design that takes inspiration from human biometrics. To achieve this, all electronics and computer processing elements are to be included in a small backpack type enclosure with either wires or cables running down the length of a patient's arm to the exoskeleton.

The first method considered was rigid actuation system using linear actuators mounted on the Base Plate for wrist motion and the Hand Plate for grip opening and closure. It was soon realized that to make this setup work for wrist functionality, the actuators would need to be able to move with the orthogonal wrist DOF. At least one previously developed wrist exoskeleton design incorporated this type of actuation [18], but was later redesigned [19]. The incorporation of an actuation system like this one would unnecessarily complicate the design. Because of this, alternate actuation methods were investigated, especially pertaining to wrist actuation.

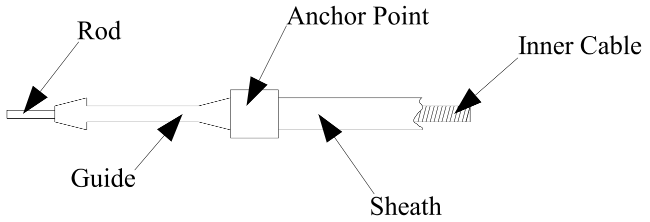

Figure 5: Push/Pull Cable Detail

The second method investigated was the use of push/pull cables, one end of which is detailed in Fig. 5. Cables of this type are commonly found throughout the automotive industry for various applications. One of the benefits of this system would be the need for only one cable per DOF, unlike the pull/pull method discussed later that would require up to 2 cables per DOF. These cables are constructed with a flexible sheath containing an inner cable that is able to translate. The end of this inner cable is attached to a rigid rod that is contained within a rigid guide. The cables can be anchored at the point where the guide meets the flexible sheath. Once it was discovered that the ends of these cables are rigid, it was seen that the same problems with wrist movement that were encountered with linear actuators would occur. Essentially the anchoring points would have to be connected to pivots, once again further complicating the design.

The final actuation method explored was the use of cables where only a pulling force is used. The type of cable used for this application would be a Bowden cable. These cables are well-known because they are the type of cables used on bicycles for brake activation and gear shifting. Like the push/pull cables described above, a Bowden cable consists of an inner translating cable surrounded by a sheath. The cable would be anchored at points on each end of the sheath. The benefit of a cable like this is that the translation of the inner cable on one end will always be replicated on the other end. This is possible because the section of the cable between the anchoring points can be placed in an infinite number of orientations without affecting the desired net end-point displacement. This will be especially important for control of the proposed exoskeleton because if one end of the cable is attached at the user's back and the other at the wrist or fingers, the orientation of the cable as a whole will change constantly during rotation of the shoulder and elbow.

After consideration of these actuation methods, the next design step will be to integrate a pair of Bowden cables into the mechanical design to actuate each wrist DOF and either a spring loaded Bowden cable or a linear actuator to activate finger motion. A spring loaded solution would be adapted for the fingers because it is necessary to mount components on the top of the hand in order to allow a patient's grasp to be unencumbered when using the finalized device.

3.3 Device Specifications

Table 3: Proposed Concept Attributes

Attribute	Human (Avg) [22-24]	Proposed Exoskeleton
Wrist Flexion Range	79.80°	60°
Wrist Extension Range	59.05°	50°
Max Flexion/Extension Torque	8.07 Nm	6 Nm
Radial Deviation Range	26.40°	20°
Ulnar Deviation Range	33.25°	30°
Max Radilal/Ulnar Deviation Torque	6.55 Nm	5 Nm
MCP Flexion	90°	60°
Max MCP Flexion Torque	N/A	TBD

Based on a review of the normal function of an average human's ability, requirements for the robotic-assist exoskeleton have been derived and summarized in Table 3. The values for the proposed design were chosen to be less in magnitude than those of an actual human's functional range because of safety concerns. This will prevent the occurrence of a movement surpassing the physical capability of the wrist joint, which, if not limited, could cause further injury to the patient. The raceway described previously already limits the radial/ulnar deviation range to the values reported in Table 3. Similar mechanical stops will also be added to the design to limit wrist flexion/extension and MCP flexion to the proposed ranges.

The required grip strength needed for the robotic-assist device has yet to be determined, but will be done so with later experiments. High crushing strength is not needed. We are anticipating acceptable function to range from picking up an empty 12 oz plastic cup (< 10 grams) to picking up the same cup filled with water (~ 200 grams).

4. KINEMATIC ANALYSIS

In this section two types of analyses are presented. The first shows the derivation of a velocity function that a motor would have to produce in order to allow for constant rotational movement at one of the robot-assist exoskeleton's DOF. The second analysis shows that via forward kinematics, the effective workspace of a patient's fingertips can be determined.

4.1 Velocity Analysis

When using a pull/pull cable actuation system, all of the proposed robotic-assist exoskeleton's DOFs can be analyzed similarly. Ideally, the rotation about each axis is a constant velocity. To achieve this, the motors activating the cables would have to operate at various magnitudes throughout the movement cycle. These varying magnitudes correlate to a translational velocity function at which the cable must be moved. By performing a kinematic analysis of the system, this velocity function can be determined.

The 3 DOFs of the system can be analyzed individually as three separate systems because each DOF has its own dedicated actuation components. To clarify, each DOF is independent of the other DOFs, as movement of one will not produce movements in the other. Therefore, the 3 DOFs will be analyzed using the same method by simply varying the inputs.

To demonstrate this, the determination of the velocity function needed to move the device from full wrist flexion to full extension is shown via Equations 1-7.

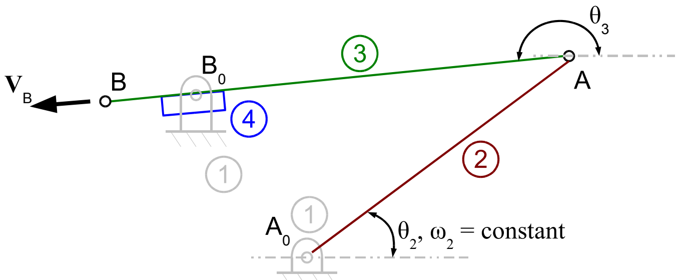

Figure 6: Kinematic Diagram for Wrist Extension

Fig. 6 shows a kinematic representation of the robotic-assist device while undergoing wrist flexion. Point A_0 is the location of the rotation for this DOF and is modeled as a revolute joint. Point A is the location where a cable can be connected to the Hand plate and is also modeled as a revolute joint. Point B_0 is the location on the Base Plate that this cable would be fed through. In reality this cable would bend at this location, but the cable can be modeled as rigid body that slides on a rotating block (body 4). Point B is the location at which the desired velocity function is determined for the analysis, but any point on the cable would yield the same result. Fig. 7 clarifies the location of these important points on the 3-D model. Refer to Fig. 3 and Fig. 4 for additional clarification of these components.

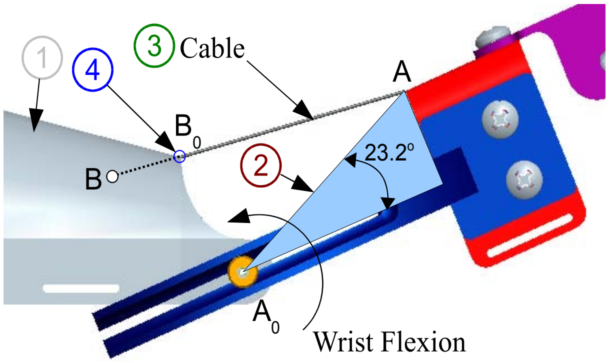

Figure 7: Wrist Flexion Kinematic Components shown on the 3-D Model

Using the complex number method of relative motion analysis, $\mathbf{V}_B$ in Fig. 6 can be determined. $\mathbf{V}_B$ is the velocity function mentioned previously that an actuation device (i.e. linear actuator) must operate at to generate a constant rotational velocity about the wrist.

$$\overrightarrow{A_0A} = |A_0A|e^{i(\omega_2 t+\varphi)} \tag{1}$$

where φ is the phase or initial value of θ_2.

$$\overrightarrow{AB_0} = |AB_0|e^{i\theta_3} = \overrightarrow{Z_{B_0}} - \overrightarrow{A_0A} \tag{2}$$

where $\overrightarrow{Z_{B_0}}$ is the position vector for point B_0 with respect to A_0.

Therefore,

$$|AB_0| = |\overrightarrow{AB_0}| \tag{3}$$

and

$$\theta_3 = \arg(\overrightarrow{AB_0}) \tag{4}$$

Then,

$$\overrightarrow{AB} = |AB|e^{i\theta_3} \tag{5}$$

and

$$\overrightarrow{Z_B} = \overrightarrow{A_0A} + \overrightarrow{AB} \tag{6}$$

Now, using numerical method, we can find $\mathbf{V}_B$.

$$\overrightarrow{V_B} = \frac{\overrightarrow{Z_{B,k+1}} - \overrightarrow{Z_{B,k}}}{\Delta t} \tag{7}$$

For this system, the following values are known based on the initial design:

$\mathbf{Z}_{A_0} = 0 + 0i$ mm
$\mathbf{Z}_{B_0} = -20 + 34.97i$ mm
A_0A = 76.16 mm
AB = 111.87 mm
ω_2 = 110 deg/sec
φ = -36.80° (-60° + 23.20°), the 23.20° is the angle between the raceway and A_0A as shown in Fig. 7.
t = 0 → 1 sec
k = 1,2,3,…,1000

Via a *Matlab* program utilizing Equations 1-7, a plot of the magnitude, and X and Y components of $\mathbf{V}_B$ was generated (Fig. 8). These plots show a visual representation of the velocity function needed to allow for constant rotational velocity at the wrist joint. In order to confirm the accuracy of the equations used to formulate the velocity function, a second simulation was performed utilizing *Pro/Engineer's Mechanism* application. In this method, a constant rotational velocity was applied at the point A_0. The components and magnitude of the linear velocity value of point B were measured throughout the simulation, generating a plot identical to Fig. 8, therefore confirming Equations 1-7.

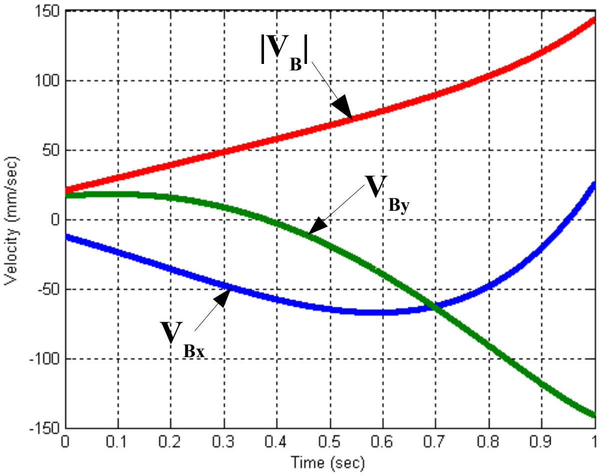

Figure 8: Linear Velocity Functions for Wrist Flexion

4.1 Workspace

The second analysis of the device presented in this paper is the determination of the effective workspace in the x-y plane. In this plane there are 2 DOF, while in the accompanying plane there is only 1 DOF (radial/ulnar deviation). The modeling of the radial/ulnar deviation DOF is straightforward as it can be represented as a simple side to side sweep within the range proposed in Table 3.

The determination of the robot's workspace is important because it allows us to know what affect each rotational displacement will have on fingertip position.

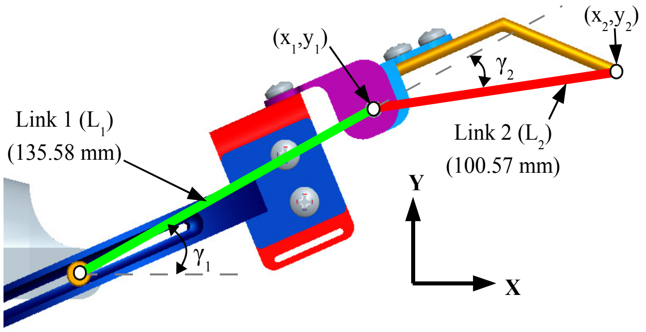

Figure 9: Kinematic Representation of System used to Determine x-y Workspace

The Cartesian position of the end of Link 1 and Link 2 can be determined using the following forward kinematic equations:

$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = \begin{bmatrix} L_1 \cos\gamma_1 \\ L_1 \sin\gamma_1 \end{bmatrix} \tag{8}$$

and

$$\begin{bmatrix} x_2 \\ y_2 \end{bmatrix} = \begin{bmatrix} L_1 \cos\gamma_1 + L_2 \cos(\gamma_1+\gamma_2) \\ L_1 \sin\gamma_1 + L_2 \sin(\gamma_1+\gamma_2) \end{bmatrix} \tag{9}$$

By once again utilizing *Matlab*, a visual representation of the workspace can be displayed in a plot, Fig. 10.

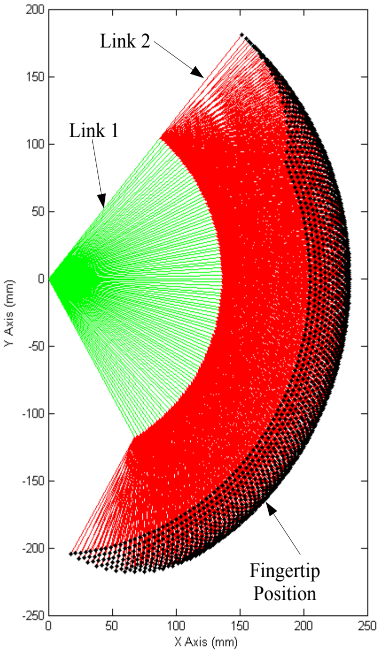

Figure 10: Worskspace of Robotic-Assist Exoskeleton in the x-y plane

The inverse kinematics of this system are not important for the types of control presented later and therefore are not calculated. This is because desired position will not be needed as a system input. The torque detected at each DOF will be transformed directly into a magnitude of displacement. Converting the measured torque into desired position with reference to the current position and then using this information as the input for motor control is an excessive and unnecessary step.

5. CONTROL

In terms of autonomous control, there are two methods that are being considered for the robotic-assist device. Both methods would detect torque values at the DOFs.

The first method would move the device in the direction relative to the measured torque and continue moving the device as long as an input is applied. The magnitude of the input torque at any moment would also be transformed into a corresponding rotational velocity output that would increase and decrease directly relative to the input. This method would be ideal for patients who still have the ability to move their wrist and hand about the full range of motion, but are not strong enough to move objects on their own with any regularity. The target group for this method would be those that have had a limb immobilized for a significant period and have suffered significant muscle atrophy or a CVA or SCI survivor who has started his or her rehabilitation. Fig. 11 shows a preliminary block diagram for this type of control.

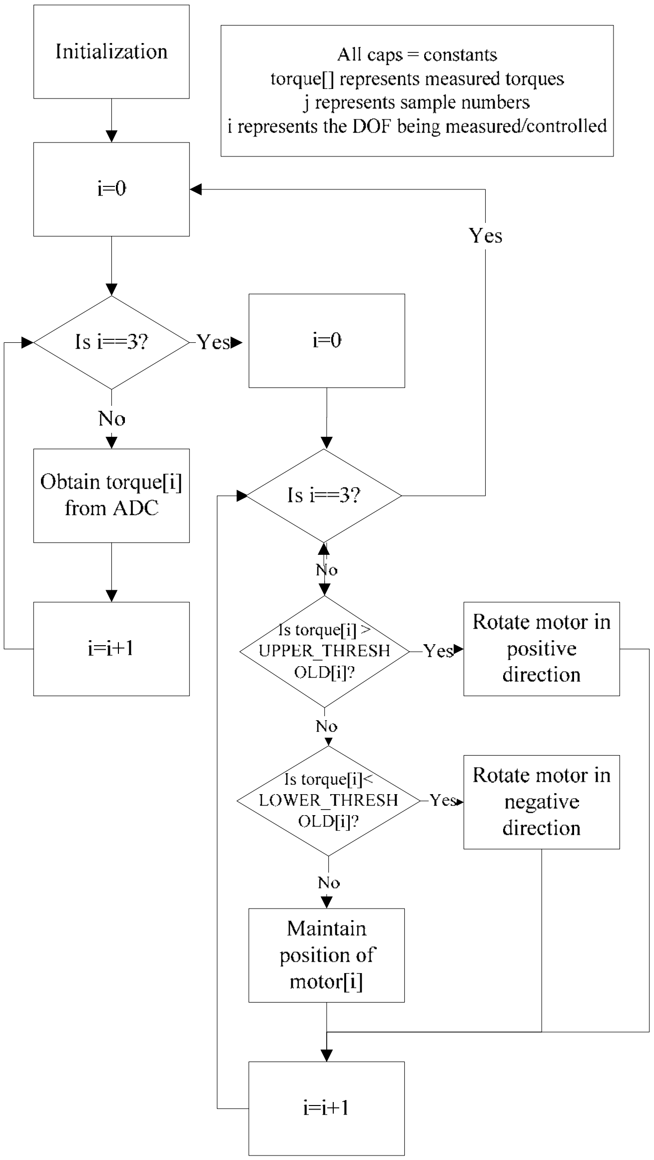

Figure 11: Simple Motion Assist Block Diagram

The second method targets more severely debilitated CVA and SCI patients. This method would suit individuals that do not have much fine control over their movements and can really only move in short directional bursts. The main difference between this control method and the one mentioned previously is that instead of the input torques being transformed into varying magnitudes of rotational velocity, the torque magnitude would be transformed into a displacement. In this method, the desired position is of more importance than the speed of motion. For this method to be successful, the control would ignore any new inputs until the preceding maneuver is complete and then once again accept fresh commands. Fig. 12 shows a preliminary block diagram for spastic movement Control.

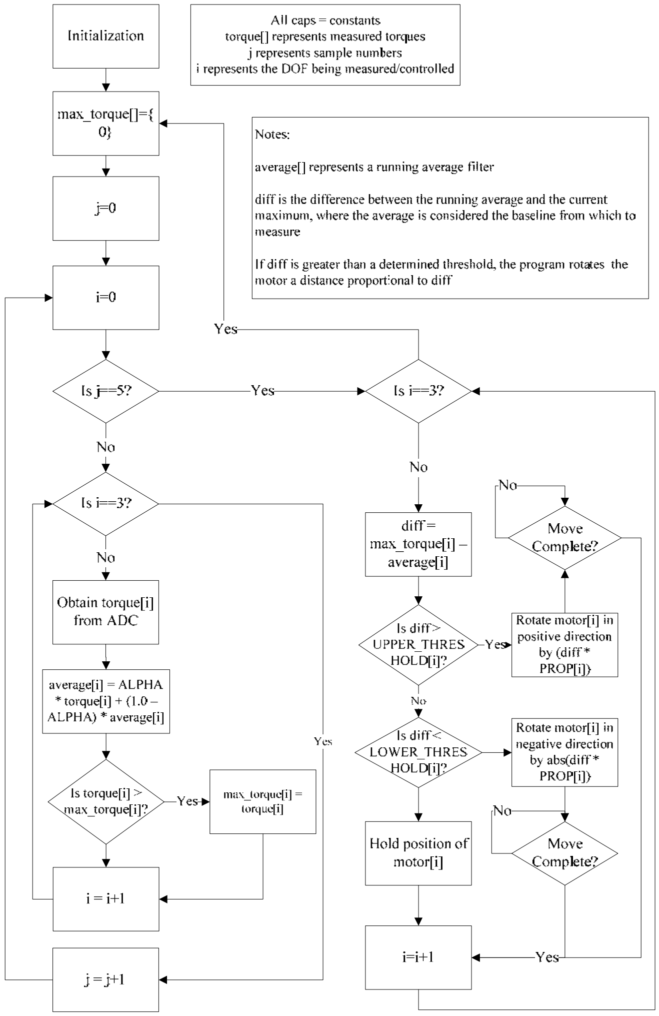

Figure 12: Spastic Motion Assist Block Diagram

Both methods discussed have significant benefits. Ideally, the robot assist-device will have multiple modes allowing users to switch between both methods along with a CPM option.

6. FUTURE WORK

Before completing the mechanical design and integrating actuation components, a few experiments are planned to enable us to have a better understanding of what the capabilities of the device need to be during certain tasks. To achieve this, the approach is to measure dynamic properties at the 3 wrist and hand DOFs that the robotic-assist exoskeleton replicates in a healthy volunteer. For example, some tasks may include picking up a cup of water and bringing to the mouth to drink, opening kitchen drawers and cabinets, and turning various types of doorknobs. The values that would be measured are angular velocity, acceleration and torque. In the ideal system modeled in section 4.1, rotational velocity remains constant throughout the movement, but in reality we expect to see at least some acceleration and deceleration at the beginning and end of movements. To be as accurate as possible the control system will have to account for nonlinearities such as these. This is why these types of experiments are so important, because as we acquire more data we can further educate the control system by having a large database to compare movements to when trying to autonomously determine desired displacement. The data collected will also help create set a performance specs needed for motors, sensors and other design components needed for a functional prototype.

After the necessary data is acquired, the next step in the design process will be to add an effective fourth DOF to the device that will enable a patient's thumb to be assisted in and out of the dexterous workspace enabling and allowing for more effective gripping ability.

Once the addition of the fourth DOF is complete, work will begin on integrating the actuation components into the design. This will include various end-attachment and guide points needed for cables as well as the electric motors and gear reductions that will facilitate the cable translations. Also to be incorporated into the design is the various sensors that will be needed to detect the torques needed for the control input. A redesign of the Hand Plate is under consideration to make the design fully symmetrical without the need for any modifications to use the device on both arms. In order to accomplish this, the Shaft, Wheel and raceways would most likely be replicated on the other side of the Base Plate.

After the mechanical design is complete, detailed algorithms will be developed for both control methods and will include comprehensive block diagrams for the system and will lead to the design of electrical schematics.

When these tasks are complete, a prototype of the robotic-assist device will be manufactured that will allow for real-time experimentation with the integrated sensors and verification of the control methods.

CONCLUSION

In this paper, a need was identified for a robotic wrist and grip function assist device after a review of significant conditions that are often associated with weakness or loss of function in the hand and wrist. Devices that are currently in use or are related to ongoing research were discussed, especially in reference to how they work and what inputs they use to facilitate movement. The benefits and drawbacks of these devices were considered and a decision was made to create a device that uses measured torque values as the inputs for control.

The mechanical design of a 3 DOF robotic-assist device was then presented that can move in cooperation with wrist flexion/extension, radial/ulnar deviation and MCP flexion. Three considerations for device actuation were presented. The most likely system to be implemented is one that consists of pull/pull Bowden cables for the activation of the wrist's DOFs and either a pull/spring cable setup or rigid actuation system for MCP flexion.

A simple kinematic analysis was derived resulting in a sample velocity function that the actuation system would have to output in order to achieve constant rotational velocity at a given DOF. Then, a second analysis was shown, displaying what the device's workspace would be with respect to the plane containing 2 of the exoskeleton's 3 DOFs.

Along with CPM, two possible control modes were discussed with the main difference between them being how the input torque magnitude is processed. The first method transforms this magnitude into a rotational speed that requires constant input, while the second method translates the torque magnitude into a displacement that only requires an input pulse.

Future work was then discussed, first detailing some experiments needed to acquire data that will be important to the structure of the control system to ensure accurate movement. Then, the work needed to complete the mechanical design and create control algorithms were presented that will lead to a prototype to be built to test the claims and benefits of the envisioned robotic-assist exoskeleton.

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