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Research and Design of Supportive Exoskeletal Aides for the Physically ChallengedAn Initial Investigation Into The Fundamentals And Rudiments Of Building A Full Body ExoskeletonMark

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Research and Design of Supportive Exoskeletal Aides for the Physically Challenged

An Initial Investigation Into The Fundamentals And Rudiments Of Building A Full Body Exoskeleton

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Abstract: The purpose of this study is to provide methodology for designing exoskeletal prostheses targeted to specific pathologies associated with: Cerebral Palsy; Limb Deficiency; Spinal Pathologies; and Functional Limb Pathologies

This study will extend to whole body exoskeletal structures. The project will be performed in conjunction with Shriner's Hospital for Children in Springfield, Massachusetts; M.I.T. Bio-prosthetic Group; and finally, Massachusetts General Hospital Orthopedics Group.

Further work will be done designing the necessary components for the project in Solidworks utilizing a 3D mannequin. The parts will then be fabricated using a CNC machine, first making them from foam insulation, then from wood and finally from aluminum.

The Design Problem

So how does one go about building an exoskeleton? First, it is necessary to determine the materials that will be used, the placement of the joint pivot points and the various methods that will be necessary to simulate the joint movements. Additionally, considerations about the materials to be used must be addressed. Weight and material strength are at opposite ends of a continuum. Price and ease of machining are also commonly competing considerations.

As this project is simply a first exploration of the design challenges of building a usable, wearable exoskeletal frame the additional requirements of adding power and controls are beyond the scope of this project.

In order to design an upper torso exoskeleton it is first necessary to examine and model the existing structure. **Figure 1** shows the reference axes in each of the major joints in the arm in an attempt to model the movements of the arm.

Another challenge is identifying the actual physical location of the pivot point corresponding the theoretical pivot point given by the reference axes. The difficulty of this can be seen in the fact that each joint includes an amount of translation along with the rotation that it travels through.

It is easiest to see this translation in a knee joint (**Figure 2**). The progression of pictures, a-c, shows how the axes change position with respect to the femur. If the knee joint acted similar to a door hinge, as we commonly picture it, then the axes would have remained static as the joint was flexed.

If both, translation and rotation, are not accommodated the device is doomed to fail to function as intended and likely to cause repetitive stress injuries for the operator.

The next challenge is to observe and model the angle offsets that exist between each joint. For example, it would be easy to assume that the sagittal planes normal to Axis 1 and Axis 4 (**Figure 1**) would be parallel to each other, but that is wrong. In reality, the plane normal to Axis 4 is rotated approximately 10 degrees inward toward the centerline of the body (**Figure 3**).

All this observation and modelling has now led us to the capability of building an arm that can replicate the motion of the human arm, but it is not practicable to build a mechanical arm and, essentially, drape it over the human arm. Attempting to place a ball joint next to an actual shoulder joint will actually limit the range of motion of the exoskeleton's shoulder assembly.

My Design Plan

The objectives of this research were: to study the biomechanics involved in the motions of the joints involved; research exoskeleton theory, structure and mechanics; and to conceptualize designs to build an unpowered full torso, upper and lower limb exoskeleton of my own.

The Frame

In any self-contained exoskeleton design there must be a frame from which all the limbs originate. Working within the constraints of an effectively non-existent budget and too little time to hand fabricate a lightweight frame of an appropriate size with ergonomically correct straps. The realization that an "Alice" pack frame was almost tailor made for all of my needs was a huge breakthrough.

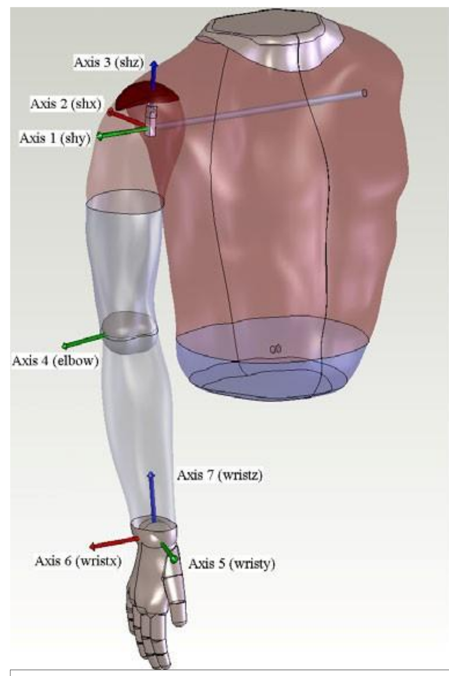


Figure 1. *Assignment of Euler Y –X–Z axes for the Vicon system. Human model from BodyWorks (Zetec Limited, New Zealand).*

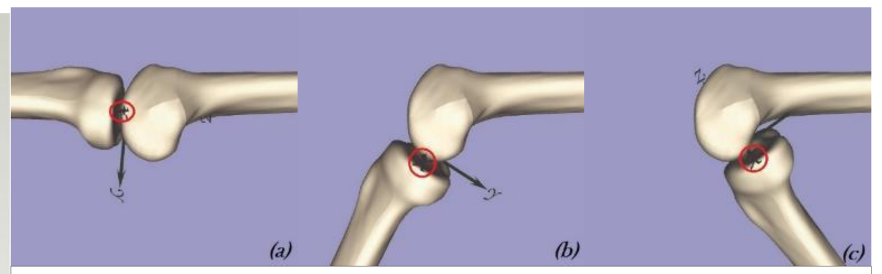


Figure 2. *In this figure, the knee joint is modeled showing how the rotation axis of the tibia moves as the joint is flexed and extended.*

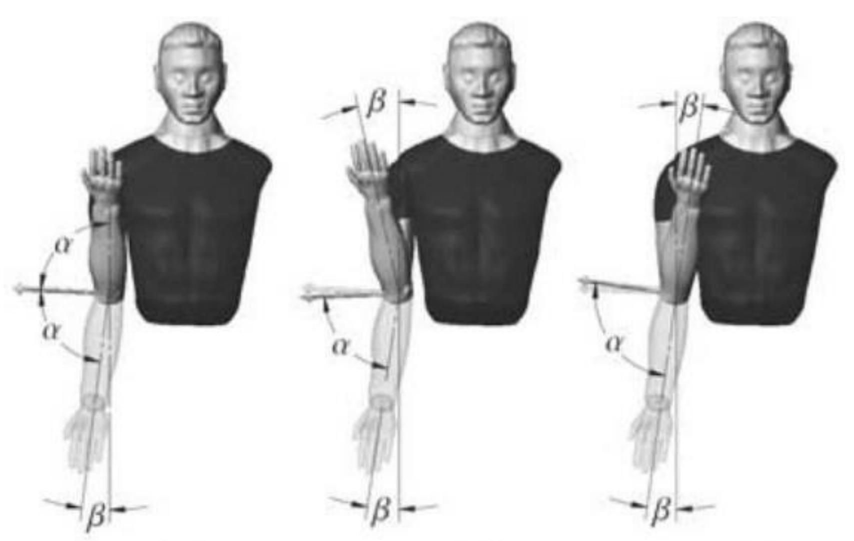
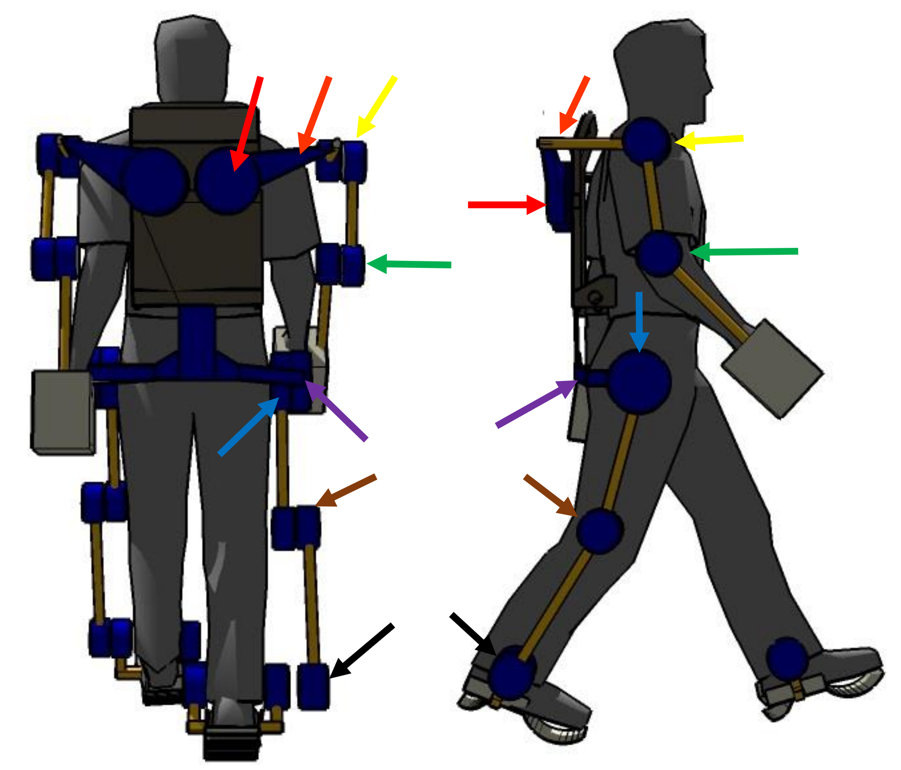
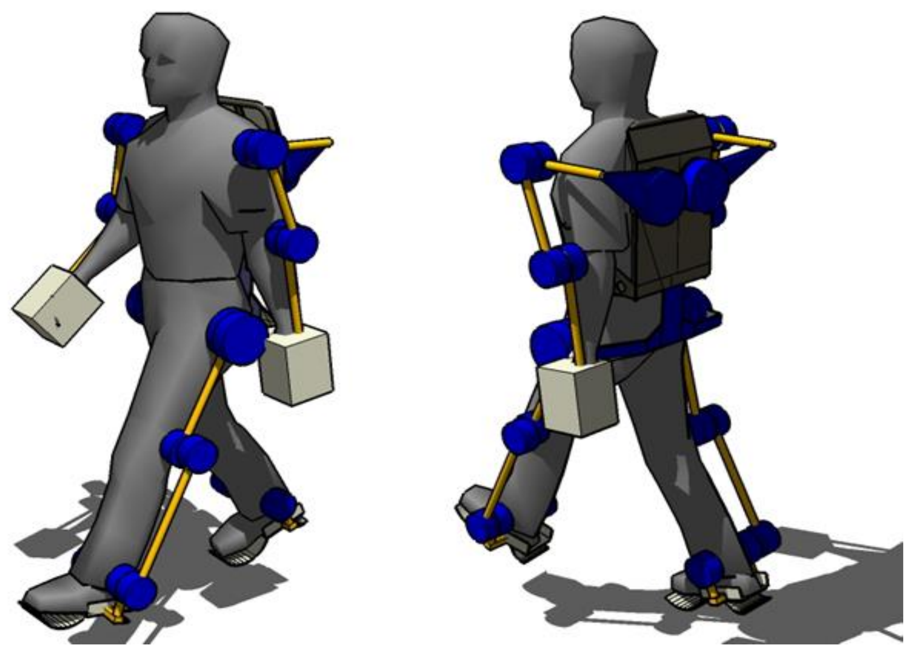


Figure 3. *Showing the offset of the forearm with respect to the upper arm during movement.*



Figures 4 & 5. The Back and Right views showing the location of the joints facilitating full articulation of movement.



Figures 6 & 7. Isometric views of the exoskeleton

The Upper Limbs

The design I've chosen consists of two disks and a barrel hinge to comprise the shoulder assembly and a disk used for the elbow.

The first disk is in the frontal plane placed over the bottom of the shoulder blade (**Figures 4 & 5,** red). This will accommodate shrugging motion and the beginning of raising the arm in the frontal plane.

A "wing" rises from the frontal shoulder disk to the shoulder barrel (**Figures 4 & 5,** orange), outside the silhouette of the body. This barrel hinge facilitates the full raising of the arm in the frontal plane. The combination of these two elements should allow the full raising of the arm, allowing for a full "wing flapping" motion.

The shoulder barrel leads into the sagittal plane shoulder disk (**Figures 4 & 5,** yellow) which will allow 85 – 95 percent of sagittal range of motion.

A sagittal elbow disk will be used to allow for normal elbow range of motion (**Figures 4 & 5,** green).

In this plan, the upper arm is unrestrained, with the forearm strapped in and a handgrip grasped by the hand, the operator will be able to perform virtually all of the common arm motions. This allows for the hand and forearm to "drive" the motion of the arm and the combination of motion in the disks and barrel will allow the exoskeleton shoulder to follow the motion of the arm.

The Lower Limbs

Where the upper body was all about careful placement of joints to allow for proper freedom of movement to allow full comfortable range of motion. The lower body has simpler joint setups, but it has greater structural demands to endure the forces that each step inflicts on the frame. Another consideration is: if the lower back and hip joints are held too rigidly in place without the opportunity to flex and shift the load around, operator fatigue increases sharply causing back and joint aches.

While hip motion in the sagittal plane (**Figures 4 & 5,** blue) is an intuitively obvious necessity, what is just as necessary but less obvious is hip abductor movement. The hip abductor joint (**Figures 4 & 5,** purple) allows the knee to "turn out" and the operator to shift his/her feet slightly in the frontal plane making balance adjustments as needed.

Finally, a sagittal knee disk allows proper knee movement (**Figures 4 & 5,** brown), and a sagittal ankle disk (**Figures 4 & 5,** black), on either side of the ankle supports the foot of the frame.

Next Steps: Further work will be done designing the necessary components for the project in Solidworks utilizing a 3D mannequin. The necessary parts will be fabricated using the CNC machine, first making them from foam insulation, then from wood and finally from aluminum. Foam insulation will be used first in order to verify that the Solidworks files are valid for construction purposes, then the designs will be made of wood next because it is more durable than foam, yet cheaper than metal, and allows for test fits that would otherwise destroy the less durable components.

Additionally, over the course the next semester, I will be researching and designing the construction of the composite spring feet to be added to this exoskeleton design to create a full body exoskeleton system demonstrating a proof-of-concept understanding of exoskeleton construction.

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