Manual Material Handling Lift-Assist System for Occupational Exoskeleton

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NORTHERN ILLINOIS UNIVERSITY

Manual Material Handling Lift-Assist System for Occupational Exoskeleton

A Capstone Submitted to the

University Honors Program

In Partial Fulfillment of the

Requirements of the Baccalaureate Degree

With Honors

Department Of

Mechanical Engineering

By

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DeKalb, Illinois

May 14th, 2022
Capstone Title (print or type): Manual Material Handling Lift-Assist System for Occupational Exoskeleton

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Department of (print or type): Biomedical Engineering

Date of Approval (print or type): 05/07/2022

Date and Venue of Presentation: 05/06/2022 for the Senior Design Demonstration Day at the NIU Convocation Center

Check if any of the following apply, and please tell us where and how it was published:

✔ Capstone has been published (Journal/Outlet):

https://www.niu.edu/ceet/experiences/senior-design/index.shtml

*Senior design abstract and poster will be available in May 2022

☐ Capstone has been submitted for publication (Journal/Outlet):

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FINAL REPORT

Manual Material Handling Lift-Assist System for Occupational Exoskeleton

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ABSTRACT
It is no secret that lifting heavy objects is one of the premier causes of workplace injury, and the modern worker needs help to remain healthy. Workers need something they always have with them that makes their work safer as well as easier; our solution is an active lift-assist exoskeleton. The proposed exoskeleton design includes a military backpack exoskeleton frame, on which two actuators pull cables attached to end effectors that the operator will be holding. This system can adjust to conform to a wide variety of operator sizes, without restricting any of their range of motion. This leads to the design being lighter, less complex, and allows a greater range of motion than most conventional exoskeletons. A cable branches from the portion of the frame by the shoulder down to the end effectors for load transfer. It is controlled through wireless communication between the end effectors and the rest of the frame. The team resulted in
a completed prototype design proven by simulation to withstand the loads required. Future steps will include testing real world use which includes battery-life, comfortability, and lifting capability.

1 INTRODUCTION
1.1 BACKGROUND:

The existence of robotic exoskeleton has its roots firmly planted in the 1960’s when the well-known company, General Electric, began working on a device that was intended to increase the strength of the user for lifting heavier objects. This device was known as the Hardiman. The Hardiman was never fully developed due to the technical limitations of the time, but it does stand as a testament to how long we as a society have been attempting to create exoskeletons. It took a few more decades for exoskeletons to become available to the public. In the early 21st Century, exoskeletons were primarily used for medical or military applications, but have since been starting to gain popularity in industrial applications [7]. These industrial applications are what this report will focus on, specifically related to a device that will aid in material handling and lifting to prevent injury.

1.2 PURPOSE:

The purpose of the project is to redesign and update the already existing exoskeleton arm by implementing an active cable and actuator system. The reason for the active system is to assist in lifting and protect from material handling. The redesign will require the use of a controller type device within the handle using Bluetooth to reduce wiring. This controller will give workers a simple way to control the arm, change grips, and switch arm attachments or whole backpacks. When the device is finished it should be able to lift at a minimum 50 pounds
using the cable system controlled by the wireless controller and be compatible with the existing exoskeleton backpack frame. The claim is that this exoskeleton arm and backpack combination will keep current workers healthy while also making their jobs easier. One unusual part of this project is that this could become a normal device that people, and workers wear every day.

1.3 PREVIOUS WORKS:

Previous work is based on the earlier research and development conducted by Dr. Simon Kudernatsch and Dr. Hasan Ferdowsi where preceding iterations have been completed with similar intentions to the current project. This is also based on previous work done by the military and other exoskeleton companies.

1.3.1 EXISTING PRODUCTS:

Exoskeletons today are used mostly in applications where the user requires support when lifting. Lifting will put stress the most on the back, hips, and shoulders. These passive devices are strapped on to the wearer and a strap is put under the object being lifted and supports the back and shoulders. StrongArm Technologies has a great example of a passive exoskeleton system which is used for lifting support [2]. A more high tech and more complex product is the Rhino Assembly Eksobionic Eksovest, part number 106759, produced by EksoBionics, Richmond CA, USA. This supports the arms much more than the previous products as it assists in lifting 5-15lbs per arm [1]. EksoBionics also has an active system called the EksoNR which is centered around the rehabilitation of people that need support in the lower extremities and the spine [3]. Ekso Bionics is not the only company to have created an active exoskeleton. A good example of a novel design comes from Bioservo’s Ironhand (N7NEM75S, Bioservo Technologies AB, Kista, SVE.) This is a soft exoskeleton glove that assists industry workers
with gripping items by stimulating mechanical tendons in the glove to a degree determined by pressure sensors in the fingers. It also utilizes machine learning to adapt to specific habits for each worker [4]. An active assistance full-body exoskeleton that is designed to a similar goal as this project is the Sarcos Guardian XO, produced by Sarcos Robotics in Salt Lake City Utah, USA. The 150 pound full-body exoskeleton is intended for use by workers to prevent injury and safely allow the lifting of heavier loads. None of the weight of the suit is felt by the wearer, and it allows for a full unrestricted 24-degrees of freedom. The suit allows the wearer to safely lift up to 200 pounds without straining, regardless of individual strength, and allows for a normal average walking pace of 3 miles per hour. Use case examples include loading and unloading of boxes in a shipping and receiving setting or manipulating parts during an assembly process. The Guardian XO provides a good idea of an exoskeleton designed for assistance in material handling [5].

1.3.2 PATENT SEARCH RESULTS:

When searching for exoskeletons in the uspto.gov search engine many of the search results show exoskeletons being used for rehabilitation or healthcare. Movement assistance which could incorporate the entire body to help someone who has had an injury, for example or surgical exoskeletons for surgeons to assist in their tasks during surgery. If lift assist, exoskeleton is searched many less results are present. They are mostly full arm exoskeletons with biological joint attachments with use not always specified. Then, some different surgical exoskeleton patents also with full arm and joint designs. Nothing was found that came close to what we have designed that had been patented but similar passive systems and the above-mentioned devices had to have been patented.
1.4 Overview

The project aims to redesign and update the already existing exoskeleton arm by implementing an active cable and actuator system. The reason for the active system is to actively assist in lifting and protect from material handling. The redesign will require the use of a controller-type device within the handle and Bluetooth to reduce wiring. This controller will give workers a simple way to control the arm, change grips, and switch arm attachments or whole backpacks. When the device is finished it should be able to lift at a minimum 50 pounds using the cable system controlled by the preferred wireless controller and also be compatible with the existing exoskeleton backpack frame. The claim is that this exoskeleton arm and backpack...
combination will keep current workers healthy while also making their jobs easier. The cable design instead of a full mechanical arm was chosen to keep the range of motion of the operator as if they were not wearing the exoskeleton.

2 PROJECT DESIGN

The design was completed by the team with assistance and guidance from the faculty team. This section will go more in depth for each subunit of the device and provide some specifics of design, manufacturing, and size of each subunit.

2.1 OPTIMAL DESIGN

2.2 SUBUNITS
2.2.1 ACTUATION STATION

The actuator units provide lift assistance using motors in a cable system which is attached to the end effectors. The actuation unit uses a custom planetary gearbox driven by an Eaglepower 90 kv brushless direct current motor on either side of the body to wind up or release a cable on the corresponding side. The use of brushless motors is part of the design constraints and allows for lightweight, reliable, efficient, and low noise actuation. These motors can supply about 4.5 Nm of torque at their maximum voltage of 36 volts. Since these motors will not be immediately providing this maximum torque under the load they will be subjected to, a gear reduction is needed to increase the torque available from the motors under load. This gear reduction will be supplied by the planetary gearbox. This gearbox is 3-D printed out of polylactic acid (PLA) filament. The actual gears within the gearbox are all printed at a 100 percent infill, which means they are entirely solid plastic, whereas the rest of the components are printed at an infill percentage of 50. The rationale behind this decision was to provide more strength to the
components of the gearbox that experience the most stress during loading by increasing the amount of material that is bonding the layers of the print together. While it is difficult to determine the exact reduction needed without testing the motors, a 5:1 reduction is a great standard single stage reduction which should give enough power to lift the 50 lb goal. Lifting a 50 lb box with two of the motors taking fifty percent of the load off the user means each motor will need to do about 111 Nm/s of work. The target linear lift speed for this load is 2 m/s which is about the average speed a person lifts at. To achieve this lift speed the motors will need to move at about 420 rotations per minute (rpm). This 111 Nm/s of work at 420 rpm requires about 2.5 Nm of torque from each motor. With a 5:1 reduction the 3600 maximum rotations per minute of the motors is reduced to 720 rpm, still meeting the 420 rpm requirement. The torque of the motor will be boosted to 22.5 Nm, which could potentially be enough to assist with lifting when put under the 50 lb load requirement. Unfortunately, this calculation does not factor in inefficiencies within the gearbox. In order to guarantee the system will be more than capable of lifting the load, a second stage has been added to the gearbox design, so there is now a gear ratio of 25:1. With this increased torque comes decreased rotations per minute, with it becoming a mere 144rpm. As this design is a proof of concept, it was decided that the speed of lifting requirement would rather be sacrificed than the load requirement. Given a larger budget, higher quality motors could be purchased, as well as more precise gearboxes, potentially allowing this system to function with a single stage, 5:1 gear reduction. The gearbox output is connected to a spool which when spun, either pulls or releases a Kevlar cable which is fed up to the shoulder unit inside a Bowden casing, and then down from the shoulder unit to the end effector. The actuation unit also includes an encoder to monitor the motor position, a motor controller, a microcontroller unit, and a rechargeable battery to power all the electrical components. To
monitor the position of the motor, an encoder will be attached to the motor to feed positional data to the motor controller unit, which will control the behavior of the motor. The motor controller will be an ODrive V3.6, a high-performance motor controller rated for up to 56 volts. This control loop will be influenced by the microcontroller unit on the end effector, which will be transmitting data via Bluetooth on the status of the user-controlled button on the end effector unit. The rechargeable battery will be a large lithium-ion battery to power the motor controller, microcontroller unit, and motors.

2.2.2 SHOULDER ASSEMBLY

The shoulder assembly’s purpose in the design is to redirect the cables from the actuators down to the end effectors, as well as redirect the loading from the operator’s arms into the exoskeleton frame. There are three main components that comprise the assembly: the upper shoulder bracket, the mounting plate, and the spine. Each of these components serve a specific function to aid in the effectiveness of the device.
The upper shoulder bracket is the main component of the shoulder assembly, and as such, its job is the most important. This design must support the load of whatever is being carried by the operator. This component will be cut out of aluminum on a waterjet for the main profile and then milled for the other features. The bracket has been designed with a counterbore and hole seen in Figure 1, at its far end, where the Bowden cable cover will end and the core cable itself will protrude through the hole and carry on to the end effector. The counterbore, at a diameter of 0.3 inches, is an interference fit with the outer diameter of the Bowden cable cover which has an outer diameter of 0.31 inches. This was done so the cover can be pressed directly into the bracket without the need for an external clamp. As it is an interference fit, it should fit snugly and prevent movement of the cover. The thru-hole has a diameter of 0.1 inches which is a clearance.
fit for the core cable which has an outer diameter of 0.085 inches, allowing free passage. The bracket is shaped as it is due to the necessity to bridge the gap between the plate upon which the brackets are mounted and the operator’s chest. As the frame will be worn as a backpack, the cables need to go over the operator’s shoulders before being attached to the end effectors, which in turn is the reason for the length of the bracket. The bracket is not a straight, cantilevered beam because under loading conditions, the bracket could end up deforming a great amount, instead it utilizes a built in support to support some of the loading the bracket will experience.

Figure 3: Mounting Plate

The mounting plate serves as a connecting piece for the shoulder assembly. It joins the shoulder bracket to the spine, and allows for the adjustment of the device to accommodate operators of different sizes. This component will once again be cut out of aluminum on the waterjet. The plate takes its shape from the necessity to have a shoulder bracket on either side of
the operator’s head, allowing the cables to extend down to each end effector. As people can be shaped very differently from each other, there is a need to allow each individual operator to adjust the span of the shoulder brackets. To accommodate this, the mounting plate has two sets of double slots, through which four bolts with a diameter of a quarter inch will attach to each shoulder bracket. Double slots were chosen for this design because they prohibit rotation of the shoulder brackets, as well as spreading out the contact points of the fasteners. To adjust the width of the shoulder brackets, all the operator needs to do is loosen the quarter inch bolts, and slide the brackets to the desired location. In a similar manner, the height of the shoulder brackets must also be adjustable. This was accomplished by having three holes for quarter inch bolts located along the center axis of the plate, allowing for fastening to the spine through the use of T-slot nuts. data for the size extremes of this design was taken from the ANSUR II study [6].

Figure 4: Spine
As previously mentioned, the spine is a length of T-slot aluminum extrusion. This component attaches the mounting plate and shoulder brackets to the backpack exoskeleton frame, allowing the load to be distributed through it. T-slot extrusion is widely used as it is commercially available along with a plethora of fastening devices which are very easy to move along its length.

The combination of these three components makes up the shoulder assembly as seen in Figure 4. This subunit has been designed to easily attach to the backpack exoskeleton frame by bolting on the spine, and feeding the cables from the actuation station through the shoulder assembly to the end effectors. The subassembly will undergo testing to ensure it meets all the design requirements. For this system that will consist of three different tests. The first of these testing procedures will test if the shoulder assembly can support having 25 pounds hanging from each shoulder bracket. In this case failure would be defined as any permanent deformation, any type of cracking, fracture, or shearing, as well as any slipping of either of the adjustable systems. The next test would be to mount the system on the backpack frame and ensure that the shoulder brackets can be easily adjusted to the proper width for each team member. Failure in this test is defined by interference of the operator’s neck, head, or shoulders with the shoulder brackets while performing normal movements. The last test is similar to the previous one, but will be for the height adjustment on the spine. Failure is defined by the system not being able to raise high enough to conform to avoid contact with the operator’s trapezius. This round of testing will be followed by improving the designs based on the test results, and then tested once more to ensure the designs are functioning as intended.
As seen in the finite element analysis (FEA) in Figure 5, when loaded with 50 pounds on the end of each shoulder bracket, much of the stress for the design is within the mounting plate’s slots. At double the design requirements of each bracket being able to hold 25 pounds, the maximum stress is only 185 megapascals (MPa), which is well less than the yield strength of 275 MPa. Upon loading the end of each shoulder bracket with 75 pounds, the stress within the mounting plate does exceed the yield strength, as it exhibits a maximum stress of 278.4 MPa. As this system only needs to be capable of lifting 25 pounds with each bracket, the FEA proves the design is beyond sufficient.
Figure 6: Stress analysis for a 50 pound load on the end of the shoulder bracket.
2.2.3 END EFFECTOR

The end effector is going to be the center for device control and communication to the motors and actuators mounted on the back. The design will have an ergonomic grip for comfortable holding the hand and a joystick to control the amount of assistance of the lifting. Contained within the end effector handle will be the grip attachment, grip attachment release, and the electronics required for the wireless communication to the motors and actuators. Manufacturing for this design will be largely 3-D printing of most of the end effectors with a polylactic acid (PLA) material. Part of the function of the end effector is to contain the electronic control and communication features. Several electronics will be needed in the end effectors to allow the user to control the device. The center of the electronic system in the end effector will
be the Arduino Pico ESP 32 microcontroller. This Arduino unit will have a built-in Bluetooth classic communication feature. Bluetooth classic will allow the microcontroller to wirelessly communicate with another microcontroller board on the actuator unit. This is to allow the user to input the joystick to wirelessly control the actuator output. The joystick on the end effector will be a position sensitive device, to control the amount of assistance the actuator on the corresponding side of the device will provide. The farther the stick is pushed up, the larger the force the actuators will exert to assist with lifting. A battery power source will be used to power the microcontroller unit and joystick. The battery will be rechargeable, and accessible through the end effector attachment with the grip unit, so it may be quickly swapped for a fresh battery. A level shifter may also be used to regulate the voltage level between the microcontroller unit and the button, if they need different amounts. It will also be necessary for the end effector to rotate independently of the grip attachments. This part of the device will be tested first with comfort and the ability to hold all necessary electronic components. After initial testing and redesigning, integrating the part into the completed device should be an easy task to complete.

2.2.4 GRIP ATTACHEMENT

Different grip attachments for different scenarios will be a great way to incorporate this design into many different industries and applications. The function for this piece is to grip, hold, and lift the material without the user needing to touch the materials. A variety of different grips will be designed for individual lifting needs such as a tacky grip or an L shaped bracket for lifting under objects. The grip will have the ability to rotate independently of the end effector. The grips will be manufactured from either steel or aluminum in their final forms. They can be manufactured using a water jet or lathe to acquire the desired part.
The grips will be tested via lifting different objects and visually seeing if the grip is able to support the load being lifted. Testing the friction created by the grip will also be a way to understand the necessity of a different material or design of the grip itself. Testing with different materials will also show the need for other grip types and narrow down what the design or roughness of surface will be required. As seen in Figure 6, the part of the attachment gripping will have tacky material in the area surrounding the bearing housing. Depending on the materials being handled cleanliness of the material after handling will be important so the change of grip will be necessary to achieve that.

The grip attachments are where the lifting occurs. Below in Figure 8 are two different designs for different uses. The flat plate is best suited for cardboard boxes or symmetrically shaped objects where the “L” grip is for items where it is best to lift from the bottom for more support. An unevenly loaded container would be great for this grip like a milk crate with liquid within the bottles the crate holds. The top hole of each grip is for the attachment of the cable and the larger bottom hole is for the bearing as you can see in the “L” grip which is containing the bearing. The smaller holes around the bearing are used for mounting tacky materials for grip when lifting. Both will utilize the tacky material for more confidence while lifting.
Figure 8: Example grip attachments
2.3 PROTOTYPE
Figure 9: Prototype manual material handling list-assist system for an occupational exoskeleton

*Component will be covered in greater detail in another image*

Pictured above is the completed prototype of the manual material handling lift-assist system. Figure 9 highlights thirteen components of the prototype which will be covered more in depth. Component 1 from Figure 9 is the Eaglepower 90 kv brushless direct current motor. The motors received were a slightly different version than the documented versions online, and thus required minor modifications to the gearbox to ensure a proper fit. Component 2 in Figure 9 shows the CUI AMT10E2-V rotary encoder attached to the end of the motor shaft, which measures the rotation of the motor and transmits the information to the ODrive motor controller through a direct wired connection. The encoders are mounted to the gearbox using two screws on the wings of the encoder mount to ensure it does not move during use. It is important that the encoders stay in place to accurately measure the rotations of each motor. Each encoder can measure up to 3000 motor rotations per minute and is supplied with five volts from the ODrive board. The encoders draw a steady current of only 6 milliamperes. The fourth component of Figure 9 is the motor mounting plate. It serves as a connection for the gearboxes, batteries, and motor controller to attach to the rest of the system. It was cut out on a waterjet from a sheet of 3/8 inch T6-6061 aluminum. Component five from Figure 9 is a Bowden casing connector, which functions to terminate the Bowden casing, component 6. The Bowden casing or tube allows the Kevlar cable, component eleven from Figure 9 to slide throughout its length, changing its direction without much friction. The Bowden casing is terminated at either end with the connectors, keeping it in place. The seventh callout from Figure 9 indicates the spine of the exoskeleton system. It is made from aluminum T-slot extrusion, which allows for easy fastening along its length. The spine of the system attaches the motor mount, as well as the shoulder mount, component eight, to the rest of the system, while allowing them to be adjusted to the
correct position along its entire length. Component eight, the shoulder mount mentioned earlier was waterjet cut out of the 3/8 inch T6-6061 aluminum as the motor mount, and it attaches the shoulder brackets, component nine, to the rest of the system while allowing the brackets to be adjusted back and forth along the slots to accommodate operators of almost any size. The shoulder brackets themselves are the end point for the Bowden casing and redirect the Kevlar cable down to the end effectors. They have also been cut out on a waterjet; however, they are made from a 2 inch thick block of T6-6061 aluminum. This manufacturing process took a substantial amount of time, and due to the nature of how waterjets cut, there is a small taper along their surface. After making these components, it was determined that for the next iteration of the project, they should be slimmed down to reduce weight as well as increase maneuverability of the system. Based on the simulations done in Figure 6, it is clear that these components are superfluously sturdy. Next up, component ten in Figure 9 indicates the backpack exoskeleton frame for which this project was designed to be mounted on. As previously mentioned, component eleven is the Kevlar cable that is being lifted up and down. Kevlar was chosen for this design as the braided metal cable frequently used for applications similar to this is abrasive and could potentially inflict serious injury on the operator in the event it snapped or got caught. The Kevlar on the other hand is only slightly abrasive, extremely strong, easier to manipulate, and less dangerous overall. Moving on, component twelve is the end effector. This component is what the operator will be holding onto, and each one contains some circuitry, a small battery, an ESP-32, and a joystick which the operator uses to tell the motor controller how the motors should be moved. The end effector can be seen with each half exposed and close ups of the grip attachments with a complete assembly. Attached to the end effector is component thirteen, which is the end effector grip attachment, which has a tacky surface to provide gripping
strength to the operator. This component has several designs that can easily be swapped in and out depending on the application. Next, the gearbox shown as component three will be broken down into its own components.

![Figure 10: Exploded view of the planetary gearbox, component 3* from Figure 9](image)

As can be seen, each gearbox consists of two stages, each of which has four planet gears which orbit around a central sun gear. The sun gears, components 20 and 22, turn the planet gears, component 17, which in turn are guided around in a circle by teeth on the interior of the ring gear, component 19. The planetary gears being driven around the ring gear causes the carrier assembly, made of components 18 and 21, to spin one time every time the sun gear spins five times. The stage two sun gear, component 20, is attached to the bottom of the stage one carrier, so it in turn drives the second stage around one time for every five times it turns. This concludes in the motor, component one, performing 25 full rotations for every full rotation of the output spool, component 16. To keep the gearbox running smoothly, all moving parts had silicone grease applied to them. This lubricant does not degrade the PLA like many other commercially available lubricants would. The Kevlar cable, or component eleven from Figure 9, is wound around the output spool, and fed through the spool cover, component 14 from Figure 10. The
amount of cable fed through the spool cover is regulated by a motor controller which gets positional data from the rotary encoder which is mounted on component 23.
From the figure above one can see the housing slots for all the electrical components on the inside of the end effector handle. The left is for the battery and the right is for the ESP32 and joystick plus associating wires. The figures above the two half of the end effector shows the two grip attachment designs. As pointed out in the end effector section each grip has its own preferred uses with many other designs for the future when the need is required for a different design.

3 REALISTIC CONSTRAINTS

3.1 ENGINEERING STANDARDS

The project aims to conform to the standards brought up by the ASTM F48 Committee for the Formation and Standards for Industrial Exoskeletons and Exosuits. This set of standards is used to guide the design of industrial exoskeletons and exosuits for human factors and ergonomics, task performance and environmental considerations, maintenance and disposal, security, and information technology, while utilizing agreed upon terminology [2]. This set of standards has yet to be fully explored and is changing frequently. With that in mind, the main goal of the standards is to ensure the safety of the operator, so the team will keep that as the most important design criteria while also attempting to conform to the ASTM F48 standards as best as possible. In addition to conforming to the ASTM F48 Committee’s standards, this system must also take into account ISO 13482:2014. It documents the standards for safety and design of physical assistance robots. This projects somewhat falls into this category, and while the standard covers a broader scope of topics, there are some that are directly applicable to this system. Another important set of standards to follow is ANSI A10.40-2007, which covers the standard process for reducing musculoskeletal disorders. This is one of the intents of this project, and as such, this process should be considered. Lastly, as with any device utilizing Bluetooth
communications, it must follow the IEEE 802.15.1-2002 standard which covers the proper way
to do so.

3.2 ECONOMIC CONSTRAINTS

The project will be built on a strict $1000 budget. This economic constraint was
considered in the selection of the optimal design by comparing multiple products and choosing
the most cost-effective solutions which also fit project design needs and other constraint areas.
Each component of the design that uses the project budget is compared to other similar
components and selected based on cost effectiveness and adherence to design constraints.
Selecting each component based on a combination of these two factors leads to a design which is
the most economically effective while remaining a quality solution.

3.3 ENVIRONMENTAL CONSTRAINTS

For environmental constraints regular manufacturing environmental impacts such as
unused material in the manufacturing process. The disposal of electronics and batteries will have
the largest impact on the environment as recycling these products can be difficult to properly
dispose of. Lithium, lead, and plastic will need to be correctly recycled in order not to damage
the environment.

3.4 SUSTAINABILITY CONSTRAINTS

This design features easily swappable end effectors as well as batteries. If either one of
these runs out of power, it will be easy for the operator to swap them out for a fully charged
replacement version. In addition, the design is made using materials which should not degrade
quickly in common warehouse applications. Considering this, the design should be able to
perform without degrading for a reasonably large amount of time.
3.5 MANUFACTURABILITY CONSTRAINTS

The manufacturability has been greatly improved since the last iteration of the design. Since there will be no arm structure then the design for that is not needed and the complexity of the manufacturing will be much easier. The end effector will be the most difficult to manufacture as it is the most complex in design. Using a lathe and water jet after 3D printed prototypes will be the primary method of manufacturing the parts required and possibly change of design for some parts.

3.6 ETHICAL CONSTRAINTS

The team has a moral responsibility to ensure that this device will function as described by the project statement because it concerns the safety of those who will be using it. The team has made many of the components adjustable to ensure proper fit for every operator. This will help ensure the system will not be used in an unintended and potentially dangerous manner.

3.7 HEALTH AND SAFETY CONSTRAINTS

Safety is the biggest focus of the project as this device will be on one's body and used to assist in lifting. The largest constraint for safety is a piece of clothing or hair getting caught on to the cable system and injuring the user. Another safety constraint is the possibility of the system failing while lifting and the extra load put on the user's body may also cause injury. Working with materials has always been a dangerous task and takes quite a toll on one’s body after a long period of time and this device seeks to improve safety and health within the material handling industry.

4 SAFETY ISSUES

Improving the safety of the operator during routine material handling and heavy lifting is the motivation behind this project, and as such it follows that the team is greatly concerned about
the safety of the design. The exoskeleton system has been designed to not include an arm mechanism to avoid limiting the range of motion of the operator, and instead only having a cable between the shoulder and end effector. In addition, this device will not be performing all the lifting force required to lift the objects. The operators will still be required to provide some lifting assistance. This decision was made to ensure the operators do not become weaker and more reliant on mechanical assistance. The rotating components connected to the actuators will have a cover on them, both to prevent detritus from getting into any of the components, but to also prevent the operator, or those around them from getting any body parts stuck or pinched by the actuators.

5 IMPACT OF ENGINEERING SOLUTIONS

The design has an impact in any context in which occupational material handling is a subject of importance. This includes countless numbers of high impact areas in the global economy and society. Any company which employs manual material handling to ship, assemble, or otherwise handle their products, is a place of impact for this design. This impact can take the form of a safer workplace, reducing worker injury and strain. Reduced worker injury and a safer work environment leads to happier employees, and increased profit for companies adopting the design. Workers would be less likely to need compensation or leaves of absence due to injury, which is a positive for both workers and their employers. A happier workforce has a large societal and economic impact, especially if the design is adopted by large companies to increase profit. The increase of corporate profit also has a profound effect on every scale of society and economy from a local to global level. The large impact on global economics and society will also impact the environment, which is often an afterthought. A happier population and healthy economy stimulate environmental change as well.
6 LIFE-LONG LEARNING

There were many subjects that the whole group was not entirely familiar with at the start of the project that now we are much clearer on or have learned. The use of gear reduction will be essential in making the chosen motors lift the weight we will be asking from them. While we all have a good grasp of gears, putting that into practice and troubleshooting will be a great learning experience. Using the engineering design method to design something new and be tangible is something the team be tested on in different ways to overcome the challenges that come with design. The project will be a great place to test CAD skills and use Solidworks to create unique designs for new parts. Electronically, there are several opportunities in the project for learning new applications of components and controlling the flow of current and voltage. Coding a microcontroller unit is commonly a learning experience due to the discrepancies between different microcontrollers as well as using them for a range of applications. Bluetooth communication is a protocol we have never coded. Learning to use encoders and motor controllers is another very large opportunity for acquiring useful experience in a major part of electronics and coding for robotic applications.

7 BUDGET AND TIMELINE
7.1 BUDGET

When it comes to the project budget, the team has been allocated a budget of $1000 by the Northern Illinois University College of Engineering & Engineering Technology. This budget will need to cover all expenses for the design team for the entire length of the project. This forces the team to be confident in the components, materials, and services that are ordered. Realistically, it is desirable to minimize the cost of the project if this design is ever to be used on a large scale, so it is obtainable by the end-user. There may be a possibility of extra funding from an outside source via Dr. Simon’s connections to the industry. To ensure the project will stay
within the budget, the team created a list of the major components needed for the project including estimated prices of each item, as well as a justification for why each item on the list is necessary for the design.

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Qty</th>
<th>Unit</th>
<th>Total</th>
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<tr>
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<td>3.7V Lipo Battery</td>
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<td>Nylon Flat Washers M3</td>
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<td>Analog Mini Thumbstick Breakout Board</td>
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<td>Mini 2-Axis Analog Thumbstick</td>
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<td>Mousepad with non-slip rubber base</td>
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<td>Kevlar Line</td>
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<td>Unit Price 2</td>
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<tr>
<td>T-Slotted Framing</td>
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<td>$7.50</td>
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</tr>
<tr>
<td><strong>FINAL TOTAL</strong></td>
<td></td>
<td></td>
<td>$1038.19</td>
</tr>
</tbody>
</table>

Building the new device without building physically on a pre-existing system means the budget needs to account for various mechanical and electrical components which are not being reused from another model of the device. New brushless direct current motors will be needed to actuate the cable system and are the driving force present in the overall design. These motors are high torque devices which can output the over 20 Nm of torque necessary to assist in lifting boxes of 50 lbs. Two will be needed, one for each arm of the exoskeleton. An ESP32 microcontroller will be used as the processor for control of the entire system since it has sufficient I/O and analog pins and is capable of wireless Bluetooth communication with multiple other modules. This processing unit will receive input and control the sensors, motor controller, encoders, and other electronic devices on the project. The ESP32 will also be used for communication between the other identical modules in the end effectors of each arm. An ODrive motor controller will be needed to control the two brushless direct current motors in a proper control loop. Rechargeable batteries are needed so that when the exoskeleton is worn for long periods of time the batteries do not need to be completely replaced and can be swapped for fresh
ones. As some parts of the exoskeleton will be 3-D printed components, roughly 2 kg of filament for 3-D prints is accounted for in the budget. In addition to the filament for printing there will likely be a need to machine parts from metal, which is needed for the actual brackets on the back piece of the exoskeleton. For moving parts, bearings will be needed to allow smooth rotation and encoders will be needed to record the rotating position of motors for the cable retraction. As an additional electrical component, the budget accounts for joysticks to be placed within the end effectors for user control of the device.

### 7.2 Timeline

This project has a timeline of 26 weeks, in each of which the team will be working on the tasks designated by the project’s Gantt chart seen in Figure 7. The project began in September of 2021 when the team was able to choose this project. Starting in October, the team formulated a project statement which includes the statement of need, an overview of the project, the constraints it must work with, technical and general specifications, and questions that came up during research. This is the groundwork that allows for further working on this project and coming up with a viable solution. Additionally in October, the team created a project proposal with early design ideas for the purpose of motivating upper management to give funding for the team. Following this, the team came up with and analyzed several unique alternative designs. At the beginning of November, the team had analyzed the optimal design and justified how it solves the problem the best. Next, the team created the first iteration of the computer aided design (CAD) models and utilized these models to perform some simulation tests. After these simulations, the models were be fine-tuned to reflect the results that were given. After this the focus shifted from theory in drawings and 3-D models to manufacturing. The team began manufacturing their design at the beginning of the Spring 2022 semester. Once it was
manufactured, the team assembled and subsequently tested the design. Next, the design was then modified to fix any flaws, and then the manufacturing, assembling, and testing process is repeated. This cycle repeated itself and carried on throughout the rest of the semester, until finally the team settled on the final design, and ordered any and all components that have been confirmed to be a part of the design along the way.

Figure 9: Project Gantt chart for Fall 2021 (top) and Spring 2021 (bottom)

8 TEAM MEMBER CONTRIBUTIONS

8.1 Erik Goes

Erik was focused on doing the mechanical design work that was necessary for the entire system aside from the end effector. The major components included in this were the shoulder assembly, actuation system, and all the various mounting points. For each of the designs that would see significant loading Erik analyzed different scenarios through simulation software to validate the designs before moving to the next step. In addition to design work, he also was in charge of the assembly and much of manufacturing for the project. After assembling, he also tested the
components to ensure they were working as intended. Outside of tasks related specifically to the design and manufacturing of the project, Erik was in charge of keeping the group organized, on task, as well as leading the presentations.

8.2 Daniel Guthrie

Daniel contributed mostly to the design and simulation aspect of the project. Daniel also contributed to writing all the essays and assignments we were given. Base design for the spool and cover was also done alongside the alteration of the end effector design. Assisting with meeting times and getting everyone on the same page as far as when we would be meeting. He assisted with the soldering of wireless parts and anything else someone needed assistance with.

8.2 Trevor Ward

Trevor’s tasks were focused on the actuation system and electronics in the end effector and backpack. Trevor searched for suitable motors, rechargeable batteries, microcontroller units, encoders, and motor controllers. Trevor also searched for wireless communication modules and determined the type of wireless communication that fit the project needs and was readily available. Tasks also included coding for establishing wireless communication and motor control. Trevor also helped to convey the project to others through contributing to writing and presentations which portrayed the actuation system.

9 CONCLUSIONS

The aim of the project is to create a system that can be mounted upon an occupational exoskeleton frame to prevent workplace injury due to the lifting of heavy objects. The proposed solution makes use of a pre-made backpack exoskeleton frame for mounting. The design will be made of four sub-units, the actuation station, the shoulder assembly, the end effectors, and the
electrical system. Using an active cable system which is wirelessly controlled from the end
effectors, the operator will be able to specify the amount of assistance required to lift the object.
The mechanical design and simulation indicate it is more than capable of withstanding the
required load of 50 pounds, which gets split to 25 pounds per side, and even has some room for
going over that requirement. Further testing of the current design will be needed to ensure safety,
comfort, and accessibility. The development, research, and designing concluded over the
semester shows that the final product will achieve all the goals and constraints given to the team
by the faculty.
10 REFERENCES:


11 ACKNOWLEDGEMENTS

A massive thank you to Dr. Simon Kudernatsch and Dr. Hasan Ferdowsi for allowing the team the opportunity to assist in their research and for their knowledge along the way.

Another big thank you to the team’s teacher’s assistant Justin Berdell for his recommendations for parts and knowledge of those said parts. Thank you to Northern Illinois University for offering the class and funding to each team.
12 APPENDIX

12.1 UPDATED SPECIFICATIONS

While the project initially aimed to lift a 50 pound object at a maximum acceleration of 2 meters per second squared, this was adjusted to be not quite as strict. Due to budget limitations the new goal is to lift as heavy an object as possible, up to 50 pounds that is, at the same maximum acceleration as before, as the motion of lifting should not be interrupted by the system. The goal of this project is to be a proof of concept, so the load being lifted is not quite as important as the actual process and motion behind lifting. For practical applications, there will potentially be a greater budget available, so the actuators could be swapped for more powerful ones which could attain both the motion and load requirements for the system.