Intelligent Sit-to-Stand (iSTS)

A Major Qualifying Project Report: submitted to the Faculty of the WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science by:

Steven Chelak
Colton Chung
Brittney Pham
Sophia Puch
Miriam Sayegh

Date: April 28, 2022

Approved:

____

Professor Sakthikumar Ambady, Ph. D., Advisor (BME)

Professor Ahmet Can Sabuncu, PH. D., Advisor (MME)

Table of Contents

Authorship

All members contributed equally to the development and execution of the project.

Section	Author
Acknowledgments	Brittney Pham
Abstract	Sophia Puch
1.0 Introduction	Colton Chung
2.0 Background	Steven Chelak, Brittney Pham, Sophia Puch, Miriam Sayegh
2.1 Who is affected?	Steven Chelak
2.2 Sit-to-Stand Movement	Brittney Pham
2.3 Treatments/Rehabilitation	Sophia Puch
2.3.1 Devices on the Market	Miriam Sayegh
3.0 Project Strategy	All
3.1 Clinical Research	Brittney Pham
3.2 Design Ideation	All
3.3 Design Optimization	Sophia Puch
3.4 Stress Analysis Simulation	Miriam Sayegh
4.0 Design	Brittney Pham and Miriam Sayegh
4.1 Prototyping Process	Brittney Pham and Steven Chelak
4.1.1 Materials	Brittney Pham
4.1.2 Building the Prototype	Brittney Pham and Steven Chelak
4.2 Professional and Ethical Responsibilities	Brittney Pham and Miriam Sayegh
5.0 Methodology	Colton Chung
6.0 Results	Steven Chelak, Brittney Pham, and Miriam Sayegh
7.0 Analysis and Discussion	All
8.0 Conclusions	Miriam Sayegh
9.0 Recommendations	Miriam Sayegh
References	All
Appendices	Brittney Pham and Colton Chung
A: Sample Interview Questions	Brittney Pham
B: Sensor Code	Colton Chung

Acknowledgements

We would like to thank our Advisors Professor Sakthikumar Ambady (Biomedical Engineering Professor) and Professor Ahmet Can Sabuncu (Mechanical and Materials Engineering Professor) for guiding and supporting us throughout the project.

Next, we would like to thank Lisa Wall (Lab Manager III) and Robert Kirch (Lab/Research I Engineering) for helping us with orders and 3D printing parts throughout the project.

We would also like to thank Todd Keiller (Director of Intellectual Property & Innova) for helping us file for Intellectual Property (IP) rights.

Lastly, we would like to thank everyone from Fairlawn Rehabilitation Hospital, Jamie Cormier (Physical Therapist Manager), Danielle Rizzuto (Physical Therapist), and Taylor Shaver (Occupational Therapist) for giving us feedback on our device throughout the project.

Abstract

Each year, nearly 32,000 elderly die as a result of fall injuries. About 41% of the falls that the elderly experience in their old age is a result of poor transition from sitting to standing. Many elderly patients find themselves in need of strength retraining in sit-to-stand muscles as a result of these falls or in an effort to prevent these falls, and their own experiences with leg injuries, stroke and sarcopenia. These sit-to-stand transition movements could be greatly improved by exercises that focus on building strength in the lower body and core as these muscles are utilized most in maintaining balance. Such devices exist in the rehabilitation and physical therapy market, but there is a gap in these devices which prevents the patient from tracking their progress and seeing quantitative results for strength improvement. This MQP develops a mechanical and sensor-loading sit-to-stand (STS) device for rehabilitative use. The device is designed with cross-functional handlebars to allow the patient to achieve a standing position using a variety of holds. Each handle set provides a different level of assistance, allowing both the physician and patient to set the rigor of their exercise throughout treatment. Using the sensors installed on the device platform, the patient and caregiver are able to track the healing progress and modify the exercise regimen accordingly. Testing of our device indicated that users could adapt their rehabilitation process based on the different handlebars and that the sensors are a good measure for tracking the patient's progress in rebuilding their muscle strength.

Table of Figures

Table of Tables

1.0 Introduction

Many elderly people experience difficulty sitting and standing on their own and need assistance from other individuals, such as caregivers. “About 34.2 million Americans have provided unpaid care to an adult age 50 or older in the last 12 months” (Family Caregiver Alliance, 2016). This includes one of our group members' grandfather. His inability to get up independently has confined him to a wheelchair, needing assistance 24/7 to get from place to place. These unfortunate circumstances could have been possibly avoided, if easily accessible means were available to strengthen his leg muscles at earlier stages.

The inability or difficulties of entering a standing position could stem from a variety of health complications. Commonly, individuals that suffer from weakened leg strength are unable to stand up on their own. Some of the primary factors which contribute to leg muscle and bone degradation are age, physical inactivity, and injuries.

In elderly demographics, sarcopenia is one of the main conditions that leads to a loss of muscle mass. It is a common age-related condition where an individual suffers from involuntary deterioration of muscle mass and function. Muscular strength begins to decrease at the age of 50 and the degeneration accelerates when a person turns 65 (Baumgartner, *et al*, 1999). Weakened leg muscles increase fatigue and the likelihood of a fall. This could lead to serious hospitalizations and expensive medical bills (Centers for Disease Control and Prevention, 2017).

Immobilization and inactivity of a limb can lead to bone loss and muscle atrophy. This primarily occurs during extended bed rest (Rittweger, *et al*, 2005). Bone loss increases fragility and leads to numerous health disorders. Muscle atrophy decreases power and stamina in the limbs. It is directly correlated with bone loss and further complicates rehabilitation in lower limbs. This could lead to permanent impairments for an individual.

There are devices on the market that help individuals enter a standing position. These devices range in price; some are affordable for all consumers to be used in their homes, while others can only be purchased by hospitals and rehabilitation centers. Most devices on the market however only help patients into a standing position and do not actively exercise the patient's STS muscles as they achieve the STS motion. After conducting background research and talking to our stakeholders we revised our client statement to ensure the best possible outcome for the patients. The initial and revised client statements can be seen in the following subsections.

1.1 Initial Client Statement

There is a need for an assistive device to help bedridden and/or injured patients and the elderly to strengthen their leg muscles. The goal of this project is to "Design an assistive device to help strengthen leg muscles through controlled sit-ups". The device should

1. Assist the patient back into a standing position if he/she is unable to regain posture on their own.
2. Allow the patient to set the rigor of the exercise regimen based on their muscle strength.

1.2 Revised Client Statement

There is a strong need for an assistive device to help bedridden and/or injured patients and the elderly strengthen their leg muscles so that they can perform movements such as getting up from their seats or standing up on their own. The goal of this project is to design and construct an assistive medical device that helps patients achieve a standing position from a sitting one *and simultaneously exercises the patient's leg muscles*. The device should:

1. Safely assist the patient to enter a standing position if he/she is unable to regain posture on their own while using the device.

    a. This sit-to-stand motion must be stable and controlled throughout use of the device.

2. Allow the patient to set the rigor of the exercise regimen based on their muscle strength.

2.0 Literature Review

The following section will highlight important concepts our team researched during our literature review. This section will address demographics affected by weakened leg strength, treatments and rehabilitation for leg muscles, current devices on the market, and the biomechanical analysis of the sit-to-stand motion.

2.1 Who is affected?

The most prevalent demographic affected by muscle atrophy, and consequently the inability to stand up from a sitting position, is the elderly. Roughly 5–13% of elderly people aged 60–70 years are affected by sarcopenia. This range more than doubles for individuals over the age of 80. Gradual muscle loss is natural in adults, as muscle growth halts around the age of 30, but for older adults that are affected by sarcopenia, this muscle atrophy occurs at accelerated rates, leading to eventual disability and a bedridden life (Baumgartner *et al*, 2004). In theory, anybody can become bedridden if their leg muscles receive zero exercise for an extended period of time. A 2014 study sponsored by NASA had a volunteer lay in bed for 70 days without ever standing up. When the volunteer attempted to stand at the conclusion of the study, his blood pressure plummeted, and he nearly fainted. It took him several weeks to regain his balancing ability and walk normally (Iwanicki, 2015).

The team was able to visit Fairlawn Rehabilitation Hospital (detailed in Section 3.1.1) to learn about the hospital's patient demographics and rehabilitation techniques. There are several reasons, in addition to becoming bedridden, that a patient may need to visit a rehabilitation hospital. A person who has suffered an injury may need to redevelop strength in their leg muscles the same way in which a bedridden patient would. Additionally, patients recovering from surgery are often too weak to sit up and will need to stay at a rehabilitation hospital until it is safe for them to return to their daily routine. The hospital staff also explained that brain injuries like strokes and paralysis can leave patients needing intense physical rehabilitation, the same way that an injury directly to the legs might. The patient population at rehabilitation hospitals is generally composed of adults that are expected to stay for only a couple weeks and recover enough to go home during that time. Unlike long-term care facilities, rehabilitation hospitals focus more on getting their patients back into a state of wellness and less on improving their condition (Cormier, Rizzuto & Shaver, 2021).

2.2 Sit-to-Stand Movement

The sit-to-stand movement is one that is essential for the body to function, especially in the elderly and the disabled. The inability to perform this simple task may result in impairment in daily life activities, institutionalization, and even death (Janssen, *et al*, 2002). Understanding the complexity of the STS movement is crucial. They reviewed 160 studies on the STS movement from textbooks and articles to reports and presentations. Out of 160, they found 39 of them "addressed the effects of determinants on the STS movement using an experimental design" and used quantitative instrumental analyzing techniques. Through their studies they found three prominent definitions of the STS movement:

1. Without losing balance, the movement of one's body's center of mass upward from a sitting to a standing position (Roebroeck *et al*, 1994)
2. "A transitional movement to the upright posture requiring movement of the center of mass from a stable position to a less stable position over extended lower extremities" (Janssen, *et al*, 2002; Vander Linden *et al*, 1994)
3. Four phases of STS:
    a. "Phase I (flexion-momentum phase) starts with initiation of the movement and ends just before the buttocks are lifted from the seat of the chair.

b. Phase II (momentum-transfer phase) begins as the buttocks are lifted and ends when maximal ankle dorsiflexion is achieved.
c. Phase III (extension phase) is initiated just after maximum ankle dorsiflexion and ends when the hips first cease to extend; including leg and trunk extension.
d. Phase IV (stabilization phase) begins after hip extension is reached and ends when all motion associated with stabilization is completed" (Janssen, *et al*, 2002, 867; Schenkman *et al*, 1990)

Unlike Schenkman *et al* (1990), Millington *et al* (1992) uses three phases to describe the STS movement. Millington *et al* (1992), studied the STS motion of ten healthy subjects, five male and five female, aged 65-76 years old. The participants were positioned in a standard wooden chair with no armrests and a seat height of 43cm. A force platform was embedded at their feet and everyone was to start at a certain position each trial with their knees at approximately 90 degrees of flexion. At the start of each trial, the participants were asked to start with their hands resting on their lap, preventing them from pushing off the chair with their arms. After they started, they were free to move their arms freely. Speed was not controlled and the participants were free to rest between trials as needed. They evaluated the motion through kinematic, force plate, and electromyographic data. For analysis, they used "[k]kinematic data collected by video, muscle activity monitored by surface electromyography, and ground reaction forces analyzed by a piezoelectric force plate" (Millington *et al*, 1992).

Millington *et al* (1992) identified three phases, Phase 1, weight shift, Phase 2, transition, and Phase 3, lift, shown in Figure 1.

- <u>Phase 1:</u> **Weight Shift** is "characterized by flexion of the trunk and pelvis, resulting in a forward shift in the center of gravity" (Millington *et al*, 1992), which lasts for about 27% of the whole motion. The muscles involved in this phase are the erector spinae, near the middle of the phase and quadriceps (rectus femoris and vastus medialis), near the end of the phase to prepare for standing. The initiator muscle is still unknown.

- Phase 2: **Transition** is the most difficult and most important phase where several key events take place, such as controlling the center of gravity from a forward to upward motion. This phase "began with the initiation of knee extension (more than 0.5" of motion) and ended with the reversal of trunk flexion to trunk extension. A transition from shifting the weight forward to lifting upwards occurred during this phase" (Millington *et al*, 1992). Phase 2 lasted about 8% of the completed movement. The muscles involved in this phase are quadricep muscles, biceps femoris, gluteus maximus, rectus abdominis, erector spinae, and hamstrings. It is the most difficult phase due to the many operations needed, in a short amount of time.
- Phase 3: **Lift** begins with trunk extensions "while knee extension continues until full standing is reached" (Millington *et al*, 1992). During this phase vertical force increases, while muscle activity decreases. It marks the end of the STS movement and lasts for about 65% of the entire motion.

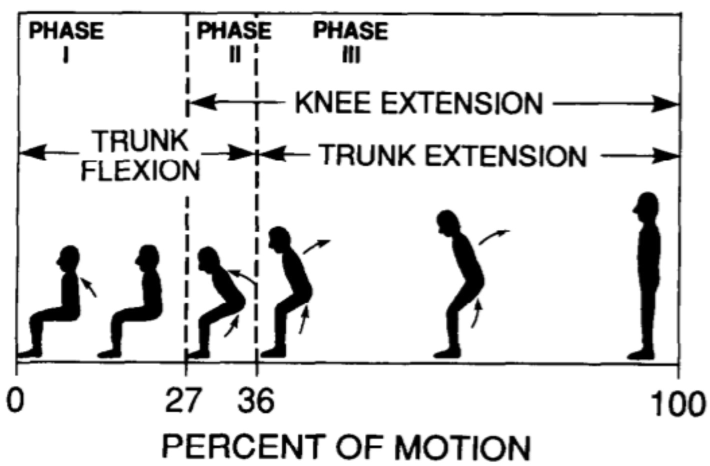


Figure 1: Millington's *et al* three phases of sit-to-stand motion (Millington *et al*, 1992).

The participants completed the motion in 1.62 to 2.54 seconds, with an average of 2.03 seconds. The lower body movement was similar in all cases no matter what the upper body movement was, a forward trunk lean followed by lift (Millington *et al*, 1992). Between young and elderly, it can be seen as a similar motion with only a difference in the trunk forward lean (Wheeler *et al*, 1985). For this project, we will use the rendition of the STS movement described by Millington *et al* (1992).

2.2.1 Sit-to-Stand Variables

Studies showed that failure to do an STS movement is directly related to different variables involved in the movement, such as the height of the chair seat, use of armrests, and foot position. If these variables are not counted for, it may affect the STS performance. With the increasing medical demand, more research is needed to completely understand these different variables. Through examining many studies (described above) and conducting their own research, Janssen *et al* produced their own conclusions through the use of force plates, video analysis, use of optoelectronic systems, goniometry, and accelerometry. The first major variable they looked at was seat height. Seat height can drastically change the difficulty to perform an STS movement, if the seat is too high or too low it can make it impossible to perform a STS. Janssen *et al* studied elderly people from community-dwellings and nursing homes with difficulties in STS movement (aged 64-105) and younger subjects with no known impairments (aged 25-36). In the elderly, a minimum successful seat height was 120% of lower leg length. A lower seat height resulted in an increase in angular velocity in the hip and repositioning of the feet in order to successfully stand. In the young, when the seat was lowered from 115% to 65% of knee height it caused a 100% increase in trunk flexion angular velocity to be able to stand. Seat height influences the hip and knee movements up to 50-60%, which can alter the body's center of mass, making one adjust their position/strategy to increase or decrease the moments needed, such as repositioning their arms and feet (Janssen, *et al*, 2002).

The second major variable that was looked at was the use of armrests. Armrests can influence STS by reducing the moments at the knee and hip by about 50%. The positioning of the hands and the height of the armrests play into the reduction in the moments, however, no study explored the relationship between the moments in the knee and hip, the hand positioning, and the height of the arm rests (Janssen, *et al*, 2002).

The third major variable was foot positioning. Stabilization strategy, described by Hughes *et al*, as lowering the moments (at the hip and knee) used for STS by repositioning the feet as a movement strategy. There are three positions that were described, posterior, preferred, and anterior positions. The posterior position showed a shorter movement time and a lower hip flexion and hip flexion speed, whereas the other two positions did not show much to decrease the difficulty of STS. Other variables that were studied were specialized chairs, backrests, speed, and arm position. These variables were not fully explored, however they either had a negative influence or no influence in STS movement in the studies that explored these variables (Janssen, *et al*, 2002).

The cause of differences in STS movement between individuals by “the result of increased age or of covariates such as muscle force, balance disturbances, neuromusculoskeletal changes, or changed motor control” is not yet clear (Janssen, *et al*, 2002). The three major variables, seat height, use of arm rests, and foot positioning, impact on STS movement was not studied together but one at a time, therefore their relationship with one another is not known. Further studies are needed to understand these variables' combined effect on the STS movement.

2.3 Treatments/Rehabilitation

Many elderly patients turn to different forms of exercise for restrengthening their muscles and as they get older their muscle mass and functionality deteriorates at faster rates. With this decline, strength training in the lower part of the body becomes crucial as our legs offer balance and support to the rest of the body. For the elderly, movements as simple as getting up from a chair and climbing stairs become difficult due to their muscles not being utilized throughout their daily lives. Low-intensity strength exercises such as ankle circles, hip marches, knee extensions, calf raises, and lunges can help them to rebuild some of the muscle they have lost over time. Focusing on exercises and repetitive movements such as these can also lower the risk of falling, as it builds on the patient's core strength and offers more support in the lower extremities to prevent falls from occurring. There are also many devices on the market that aid in rehabilitation, which will be discussed in the next section.

2.3.1 Devices on the Market

Sit-to-stand (STS) devices are often a key factor in many bedridden patients' rehabilitation process. STS is the motion of one going from a sitting position to a standing position. These devices are intended to be used by patients that have a level of mobility, but yet require some assistance to go from a sitting to a standing position. There are two alternative forms of rehabilitation through stand aid devices, such as passive devices and active devices. Passive devices can often be wearable, but their purpose is solely to aid the patient in achieving a standing position. On the other hand, active devices actively encourage the wearer to rebuild their muscles while the device is used, by encouraging them to use their muscles to perform the motions. Furthermore, a wide variety of features may be found in different device designs. These features may include, but are not limited to gait training, battery-powered components, safety features, and obstruction sensors. Depending on the type of sit-to-stand lift and its features, its price may range from $20 for a simple sling to over $6000 for an advanced electric device.

A cheap, passive STS sling design usually consists of a simple belt with a handle on each end. This design is meant to slide under the patient's back, and requires another individual to push the patient up by grabbing the handles. Although this design is very simple and affordable, it is often inconvenient for patients since it requires the assistance of a caregiver. This caregiver has to be strong enough to exert a certain amount of force to push the patient up. An example of such a device is the Vansun Patient Lift Sling (Figure 2), which costs roughly $21. This specific lift sling is designed to withstand a maximum weight of 300 lbs (Vansun, 2022).

Figure 2: Vansun Patient Lift Sling.

A more complex and structured design usually contains some form of mechanical feature and a rigid frame. Unlike cheaper devices, devices with stable framing have the potential to give the patient more freedom to go from a sitting to standing position and reduce extensive strain on the caregiver. Some devices that fall into this category are usually referred to as a Stand Assist device or a Stand Aid Device (Figure 3); these devices are usually used by rehabilitation centers to help patients move from one place to another. The Stand Aid or the Stand Assist devices usually cost about $700, and can be a passive or active device depending on the manner in which the patient and physical therapist uses it (Graham-Field Store, 2011).

Figure 3: Stand Aid Device.

On the other end of the spectrum, you can find expensive STS assist lifts. These lifts are usually electrically powered and function with a hydraulic system. A good example of an expensive STS lift is Hoyer Journey Sit to Stand Lift (Figure 4), which also falls into the category of passive sit-to-stand devices. Depending on where it is purchased, its price may range from $3,200 to $6,000. This lift is electrically powered, and holds up to 341 lbs. This lift is commonly advertised for its ability to accommodate a versatile group of patients with different body sizes, allowing it to be a perfect fit for senior centers and nursing homes (Joerns, 2022).

Figure 4: Hoyer Journey Sit to Stand Lift.

3.0 Project Strategy

This section will review the steps taken to develop the STS device, such as clinical research, design ideation, design optimization, and the final design.

3.1 Clinical Research

To gain a better understanding of the sit-to-stand movement, we conducted interviews with various stakeholders, such as rehabilitation hospitals. By interviewing rehabilitation hospitals, it will greatly help us to be aware of existing assistive sit-to-stand devices and exercises used in therapy, along with the advantages and disadvantages of each. This will not only help us improve upon the existing devices, but also understand the STS movement better by talking with physical therapists about its complex components. Some examples of a question we might ask to either the rehabilitation center or nursing home is, "What types of machines/equipment do you have in your facilities to aid in physical therapy for restrengthening leg muscles? What are features that you appreciate having in these devices? How would you recommend improving the current devices? What exercises/aiding technologies have been most effective in overall patient recovery? STS exercises?" Our full interview questions can be seen in Appendix A. By talking to rehabilitation hospitals, we can better understand our target audience, STS movement, existing assistive leg devices, and STS therapy.

3.1.1 Interview with Fairlawn Rehabilitation Hospital Personnel

Our interview was with Fairlawn Rehabilitation Hospital located in Worcester, Massachusetts. We had the pleasure of talking with physical therapist manager Jamie Cormier, physical therapist, Danielle Rizzuto, and occupational therapist, Taylor Shaver. Fairlawn is a rehabilitation hospital and treats patients that are over 18 years of age, however they mostly get patients nearing late adulthood and the elderly. Common reasons why patients are recommended to Fairlawn are injury, recent surgery, or have been bedridden too long. On average, patients spend two weeks at Fairlawn with at least three hours of therapy every day and are sent home ready for daily life. Fairlawn has 110 beds total, but on an average day about 90 are occupied and about 60 during the COVID-19 pandemic.

Through Cormier, Rizzuto, and Shaver, we learned more about the sit-to-stand movement. During STS, the most important step is the “nose over toes.” “Nose over toes” is something Rizzuto and Shaver tell their patients over and over again as most are not able to do this. It is where the patient will scoot to the edge of the seat and start to lean forward, positioning their nose over their toes, to start the lifting phase. If the forward lean does not happen, the patient will end up falling backwards. Sometimes the physical therapists will have the patients just practice this one maneuver using an exercise or yoga ball, which is a weight shift exercise. One clear misunderstanding of the STS movement is one only thinking about the standing up part, but what about the sitting down part? The sitting down part is equally as important to strengthen those muscles involved with it. If this part is ignored, one might always end up plopping themselves down to sit, instead of a controlled sit.

Some STS exercises utilized at Fairlawn are STS reps using the Stand-Aid (further explained in the next paragraph) or with a normal chair. They are able to vary this one exercise by allowing or not allowing parents to use their arms (no arms is harder), pushing or pulling with their arms (pushing is harder), changing the bed/chair height (lower height is harder), using resistance bands, and using dumbbells. Another exercise is the partial squat to stand.

During the interview we were able to see some STS devices that they had at Fairlawn. The first one was the Stand-Aid, where the patient is sitting in a chair or bed and is able to place their feet on a platform and pull themselves up. The caregiver is also then able to wheel them around with back supports, if needed. The physical therapists expressed that they use this device the most to help with STS reps. The pros were that it helps with exercising the leg muscles and it can be used with one person helping the patient. The cons were that it was not adjustable/does not accommodate every size, it does not help with the sitting down, and the edges were too sharp.

The second one was the RJ Walker, a gait trainer. Straps went around the patient's legs to hold them up in case their knees gave out. The height was also adjustable. It was expressed that they did not use this device very often for STS as it was training for walking. The last device was the NeruoGym Sit-to-Stand Trainer, where it had a harness around the patient's bottom which was connected to a counter weight to help the patient stand. The amount of weight applied is easily adjustable to accommodate different patients. Unfortunately, Fairlawn did not have this device at their location at the time.

It was important to the physical therapists that patients only use the rehabilitation devices for a certain amount of time and is slowly leaned off of the device into normal conditions. If not then the patient becomes too relied on the device and cannot do it on their own. It was also important that the patient's progress was able to be quantifiable to track their progress. Cormier, Rizzuto, and Shaver assured us that there was a market for our device as there are many situations that require STS rehabilitation as it is a necessary daily activity, such as patients that are bedridden, had strokes, brain injury, hip injury, partial or whole body paralysis, Parkinson's, or been through recent surgery (Cormier, Rizzuto & Shaver, 2021).

3.2 Design Ideation

In this section we go over the design objectives, functions, and means. We also explored some of the design alternatives for the assistive device.

3.2.1 Design Objectives, Functions, and Means

To determine the specific components of the device, one must first generalize the needs for the device. Here we broke our device into objectives we want the device to achieve, how the objective relates and will function in the device, and the means of how to achieve the objective. For example, if one was making a window, an objective could be that it needs to be see-through. The function would be one or many people are able to see through the window to the other side. The means would be that the material used for the window must be clear/see through. We identified 12 objectives we wanted the assistive device to achieve, defined the functions and means for each, and ranked them on a scale from 1-10 of importance (1 being the lowest priority and 10 being the highest priority), this can be seen in Table 1.

Table 1: Ranked design objectives, functions, and means.

Objective	Function	Means	Importance (1-10)
1. Easily transportable by hospital staff	Can move across many surface types with relative ease and fit through hospital doors	-Wheels -No need for transport -Lightweight materials -Restrict size	10
2. Device remains stable throughout use	Device does not move unintentionally when subjected to reasonable force vectors	-Durable materials -Lockable wheels -Anchor points	9
3. Affordable	Hospitals should be able to purchase it; If the device is cheaper, then treatment can be more affordable to patients	Utilize strong, but cost-effective materials to build the device	5
4. Durable	Device has a use life of 10 years	Materials resistant to damage and degradation. Functionality does not decrease over time.	8
5. Is able to exercise the leg muscles used in STS	Strengthens leg muscles; Utilize resistance to build tension in muscles and exercise them	Through resistance exercises	10
6. Comfort	-Device should be wearable for extended periods of time -Comfortable while in use	Utilizing soft and comfortable materials to build the device	9
7. Satisfies diverse clients	Device should take into account different weights, heights, and shape of patients	Adjustable components	9
8. Is able to assist the user in regaining a standing position in a natural way	-Helps user stand from a seated position in a natural way	-Unknown -Ensure that the device follows a natural STS motion	10
9. Compact	Can be easily stored	-Built at a limited size -Foldable	3
10. Aesthetically pleasing	Device is appealing to the user/eye	Maintaining a compact and neat design.	1
11. Easy to use and maintain	Helps technician/patient easily use/fix the device	Device uses simple components	10
12. Safe	Low risk to users and staff	Low risk materials and components	10

The objectives that ranked the highest in priority (sitting at a level 10 in weight) were portability, ability to exercise the leg muscles used in STS, ability to assist the user in a natural way, easy to use and maintain, and safety. During the first stages of brainstorming and after conducting the interviews with our stakeholders, we found **portability** to be a very useful trait to add to our device, which was why we ranked portability 10th in importance. Being able to easily transport the device from room to room posed to be very helpful to the patient and caregiver as it eased the load of both parties to a possible faraway location.

The primary goal of this device is to **exercise the leg muscles used in STS**. Rehabilitation of these muscles is a crucial step to allow patients to begin standing on their own. The device must assist the user in a natural way to properly enter a standing position. The patients conduct a compound standing exercise to build strength in their muscles while increasing their coordination and balance.

The device should be **easy to use** for both the patient and any clinicians that may be assisting the operation of the device. This objective is critically important, as devices that require extensive training and have complex or time-consuming instructions for use (IFU) are often less appealing to consumers.

Safety is of the utmost importance when it comes to the device design. A general principle of engineering ethics is that safety must be held paramount, and all potential risks must be identified and mitigated to a reasonable level. Safety will be managed through the use of risk matrices, design failure modes and effects analyses (DFMEAs), and other in-depth measures. A final product must be FDA approved before market release in the United States.

The objectives we ranked at 9 were stability, comfortability, and diversity. Due to the portability of our device, it would be incredibly problematic if the device moves unintentionally due to outside forces, which is why we ranked **stability** at 9. To improve stability, the device needs to be made out of durable materials and/or have anchoring points.

The device must also be **comfortable** for the user during the operation of the exercise. Any discomfort could result in the patient repositioning themselves and using the device incorrectly. An uncomfortable device will also not be appealing to use for patients and discourages their rehabilitation. Our product's padding must be made from comfortable materials and the device needs to be adjustable to fit a variety of body types and heights.

The device needs to meet the needs of a **diverse** group of patients making it inclusive to most body shapes and sizes. While most devices on the market are accessible for patients with different heights and weights, our device should be able to maintain this accessibility and potentially improve on it. Currently, most STS lifts are capable of providing assistance to patients up to 300 to 450lbs, hence we expect our design to yield equivalent or better results. After talking to physical therapists, some devices may accommodate a larger weight load, however, the width of the device seems to not accommodate every size.

The overall structure and mechanics of the device also allows for users to move from a sitting position into a standing position in such a movement that they would have achieved **naturally with their own muscular movements**. With these practices, the patients are able to exercise the muscles they normally would engage when going from a sitting to standing position. This furthers their progress in rehabilitation, training them to build their own muscular resilience and independence from the device so that they could eventually wean off the device and utilize these same muscles on their own in rehabilitation.

The next objective our team discussed was the **durability** of the device. This objective was rated high in importance with a score of 8. Durability is directly related with the device's use life. Consumers will not purchase or trust a device with a potentially low number of uses. We must also ensure the device's functionality does not decrease over repeated use. This could lead to numerous safety concerns and failure of components.

Although this objective ranks low for our design, many hospitals and patient care facilities appreciate equipment that can be **easily stored and moved**. Offering the ability of our device to move would allow the device to be used by multiple patients in different locations. This would make the device appealing to many since it will be cost effective.

The **affordability** of our device was ranked low in importance with a score of 2. Our product will be marketed for nursing homes and rehabilitation centers, general consumers are not our main focus. The device must be reasonably priced for these establishments to purchase. Exorbitant prices could also drive away potential clients from our product.

The device should be **aesthetically pleasing** and ergonomic, making it more user friendly. The general appearance of the device can make a difference in how the patients interact with it. The overall aesthetic of the device can either attract or repel clients from using it. This objective is good to have and consider, but for the purposes of this project it takes lower priority than others.

3.2.2 Design Alternatives

After much analysis and discussion of the literature reviews and interviews, our group was faced with two options, improve upon an existing device or create an original idea from scratch. First our group came up with original designs for the assistive STS device. The first design, listed as Figure 5, is a lever seat system. This original design's system looks very similar to an office chair and has different components to it to aid with the STS movement. This chair will have a leg rest, and as the patient pushes down with their feet, the force exerted would in return push the chair up. The more downward force applied by the patient, the higher the seat will rise. The seat is also mounted on springs that as the patient takes their body load off of, it would release and tilt the seat forward allowing for further assistance to the patient. Finally, similar to an office chair, the back will be loaded with springs and as the patient takes their weight off of the back, it would slowly give them a push forward. The backrest and seat would simultaneously lift the patient out of the chair using a rotational motion.

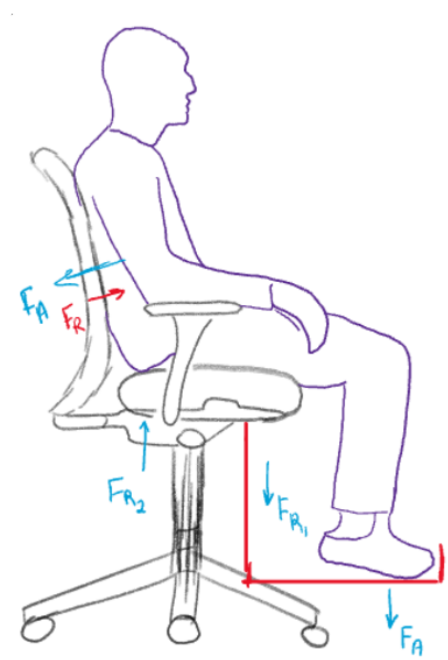


Figure 5: Design #1: The Lever Seat.

Our second original design, shown in Figure 6, was an assistive lift device that provides upwards force via a linear actuator to help patients with the STS motion. The idea behind this design was to adjust the force applied by the linear actuator to gradually wane the patient off of the device as they build up strength through repetitive use. Originally the device was designed to lift the patient by the arms using the supports on the side that would either sit in the patient's armpits or under their forearms. The idea behind this was that it would allow for a more natural lower body motion as the patient worked to stand up versus a system that applied force to the lower body. However, it was realized that the uniaxial movement of the arm supports would not easily allow for the patient to shift their body weight above their feet, a critical part of the STS movement. It was then determined that the force would be applied at the seat, as there were a number of ideas for ways in which the seat could swing upwards to guide the patient in the natural STS motion. The device is designed to be a stationary bedside lift that the patient would use to get out of bed. It would be placed on the wall adjacent to the bed, and the patient would scoot onto the chair, enabled by the ability to rotate the arm supports upwards to provide clearance.

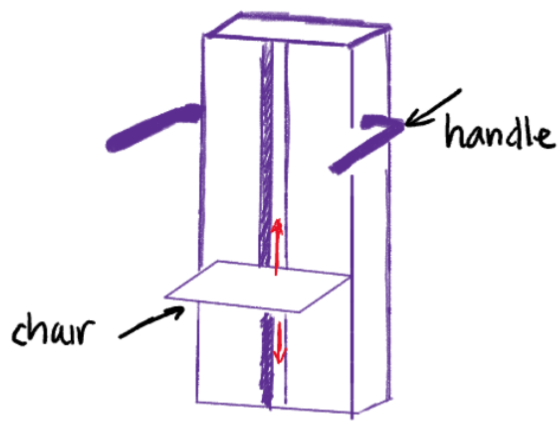


Figure 6: Design #2: Bed Attachment Lift.

After talking to physical therapists, we realized that our designs above were more of a passive device rather than an active device. We then tried to come up with more active designs. The fourth design was an improvement on an existing device, the NeuroGym Sit-to-Stand Trainer. The pulley system was designed to pull the patient up to guide through the process of going from the STS position. A weight-pulley-system would be used to adjust the difficulty level much like a weight exercising machine in a gym. The more work applied by the machine, the less work the patient has to put in. The first iteration of this design was that the patient had to hold onto a bar that was attached to the pulley system to be able to stand up. Over discussion, we found that this would require grip and arm strength that the patient might lack. Cuffs that would go around the wrists and attach to the bar were explored, however, we concluded that the wrists would be uncomfortable for the patient. Then the idea of a vest or belt around the waist being worn by the patient came up and seemed to be the most optimal choice. An adjustable vest would secure patients in the pulley machine and would allow free movement of their arms to further assist in standing. In the original NeuroGym Sit-to-Stand device, there is a belt that goes around the bottom of the patient, however, this might be too hard on the caregivers to lift the patient up to get it under the legs. With a vest, the patient can stay seated while being strapped in. This design is shown in Figure 7.

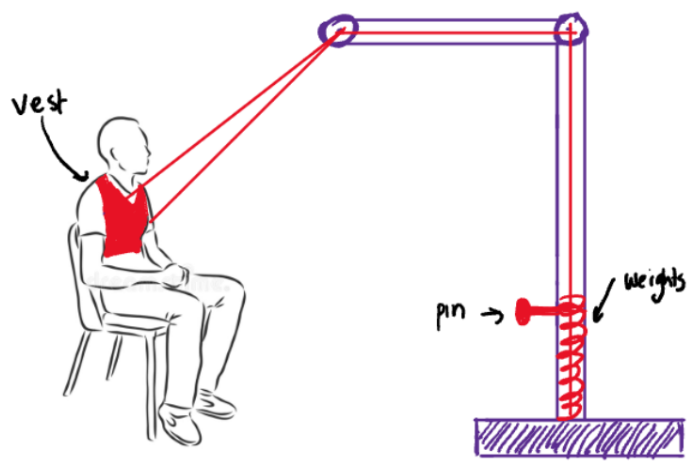


Figure 7: Design #4: The Vest Pulley System.

The fifth design was an improvement on the BioDex Squat-Assist Trainer, seen in Figure 8. This trainer would allow patients to train the necessary leg muscles engaging in the STS motion, by adjusting the resistance on the seat and to simultaneously measure the forces they are exerting vs. the aid they are receiving by the chair. These measurements would be obtained through force sensors which would allow the caregivers to quantify the patient's progress. The original squat assist offers mechanical aid, but lacks the sensor feature that would allow it to maximize the patient's improvement through careful force monitoring.

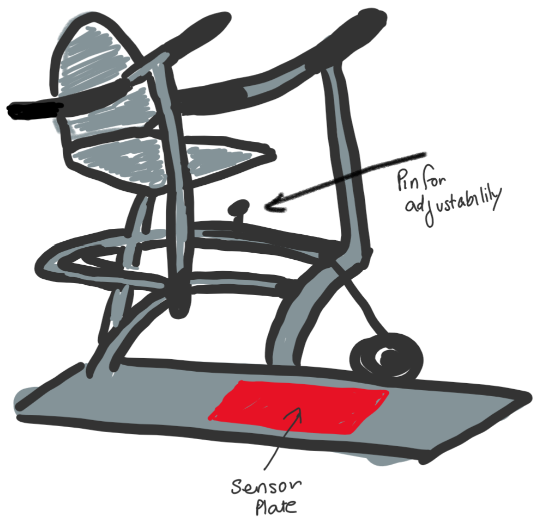


Figure 8: Design #5: Squat-Assist Trainer with Sensors.

The sixth design was an improvement on the Stand-Aid as the physical therapists at Fairlawn expressed how much they utilized this device. They expressed some cons that our group felt that we could improve upon with ease. Making the device wider will help accommodate larger patients, while still allowing thinner patients to use the same device. Adding in some supports, such as a resistance band around the waist, will help patients have a controlled sit. For the sharp corners, designing the device with less sharp corners or adding padding will help minimize this con. Our group also discussed possible grip adjustments to help change the difficulty level of the STS exercise as the physical therapists shared, pulling with the arms was easier than pushing. Since the Stand-Aid only had a pulling bar, adding the pushing aspect would enhance the device. Our group also was fascinated by the RJ Walker and decided to add a walker function to the Stand-Aid for patients that needed to practice the STS to walking motion. By removing the platform, the Stand-Aid would become a walker. Also, by adding force sensors, it would help quantify the patient's progress. This design can be seen in Figure 9, which we named the Intelligent Sit-to-Stand Aid (iSTS).

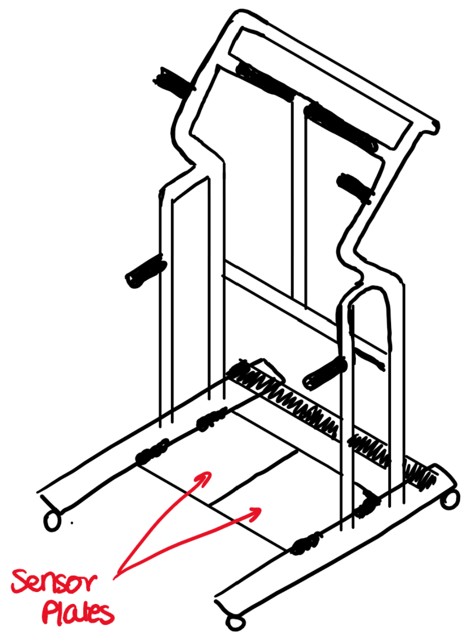


Figure 9: Design #6: Intelligent Sit-to-Stand (iSTS) Device.

3.3 Design Optimization

To ensure our group would be selecting the most optimal design, the team produced a design matrix that is based off of a Pugh Matrix which highlights the top benchmarks the group aims to hit in our design approach to correspond to a grade of -1, 0, or 1, with those numbers respectively representing worse than, the same as, or better than the baseline (Table 2). The baseline in this scenario is the original or something similar to the original device. The design criteria's scores are then multiplied by their weights and then added together to give a total score for each design. The team members spoke to each other in a conversation to determine both the weights and scores for the criteria and each design

Table 2: Our decision matrix.

Criteria	Weight	Lever Seat	Bed Attachment Lift	Pulley System	Squat-Aid w/ Sensors	iSTS
Comfort	8	1	1	1	1	1
Transportable	7	1	-1	1	-1	1
Stable/Safe	10	0	0	1	1	1
Cost	5	1	-1	0	-1	1
Exerise Leg Muscles	10	-1	-1	1	1	1
Accomodations	7	1	1	1	1	1
Ease of use	6	1	1	1	0	1
Aesthetics	3	0	0	0	0	0
Durability	9	1	1	1	1	1
Overall Score	**65**	**32**	**8**	**57**	**32**	**62**

The first approach the team had to the original client statement and objectives was a "Lever Seat" system design. When the patient applies force to the base, the seat would rise up beneath the patient's weight and support them into a standing position. While the device does help a patient achieve the transition from a sitting to a standing position, and checks off quite a few benchmarks, it fails to actively assist the patient and only offers the support. This system does not incorporate any active component that would encourage patients to rebuild strength in their lower bodies.

Looking through our Bed Attachment Lift, and the means with which we would achieve our goals in our design, we realized the pros to this design came from its originality and the fact that it would serve as an assistive device. However, it proved to have more challenges than benefits overall. After speaking to physicians working in the rehabilitation field, we learned that our original design concept does not fulfill our client statement because it would not allow patients to also exercise their muscles throughout the rehabilitation process. Instead, the device would be used passively and only aid the patients in getting into a standing position. In addition to these cons, the device plan was not fully thought out and would also require the incorporation of motors, something no one in our group was well-versed with.

The pulley system design was extremely unique, and utilized different mechanics compared to our previous ideas, it also fulfilled our client statement and was a rehabilitating device. However, similar to the lever seat system, it would not encourage any muscle training within the patient serving only as a passive rehabilitator.

Our fifth design idea was called the Squat Aid. This design not only fulfilled our client statement, and would allow patients to actively exercise their muscles while achieving a standing position, but it would also measure the progression of treatment with the addition of sensors. However, once again, the negatives of the design outweighed the benefits it posed. The device would be too difficult to reproduce within the time constraints we were limited to, and too expensive of a product to purchase entirely.

Our sixth design idea was to reconstruct an existing Stand Aid device and introduce unique modifications to the design to make it more original such as increasing the accommodations on the device with a variety of grip positions and the incorporation of sensors. This design would not only fulfill the client statement and passively aid patients to a standing position, but it would also actively encourage muscle stimulation and exercise as well, retraining patient muscles. The materials needed to build the physical prototype, unlike the previous designs, would also be easy to source and build as it would be fully mechanical. Lastly, the device is portable since it will have wheels that can be locked, and it will only require the help of one physician to operate the device. These last two pros fulfill checkboxes for many physicians working out in the rehabilitation field, as these were very common remarks made by the physicians we spoke directly to when we visited a local facility. On the other hand, this design posed many more complications than our other designs. For starters, since the design is based off of a pre-existing design out on the market, it is not an original design from our team and is only made to be unique based on the additions we make to it. The design idea also does not fit every patient size, and does not guide patients into a sitting position after standing. While both of these limitations are not crucial to satisfying our initial client statement, they are features which the physicians we spoke to pointed out when we interviewed them. Lastly, the corners of the design are too sharp and are uncomfortable for the patients to use for extended periods of time during rehabilitation.

Each design idea proved its own set of challenges and benefits, sometimes with the cons outweighing the potential long term benefits of the design to the patient, and the work that would have to go into the design. Ultimately, our group decided that the design that would not only achieve our group goals, satisfy the client statement and also benefit the patient was to improve upon the existing Stand Aid Device. And while this design posed many of its own individual challenges, the benefits identified in our decision matrix proved it would be worth it. More specifically, it scored in our main benchmark goals (benchmark grades of 9 or above) of being stable/safe, an active STS device and durable. Throughout the brainstorming process, we've outlined modifications that could be made within the device to enhance its structure so that it could fit more patients by simply elongating different parts of the device. Lastly, modifications in the structure and materials used throughout the design can be used to ensure patient comfort when the device is in use.

3.4 Stress Analysis Simulation

As a preliminary proof of concept, the team created a 3D model of the last design SolidWorks as seen in Figure 10 below.

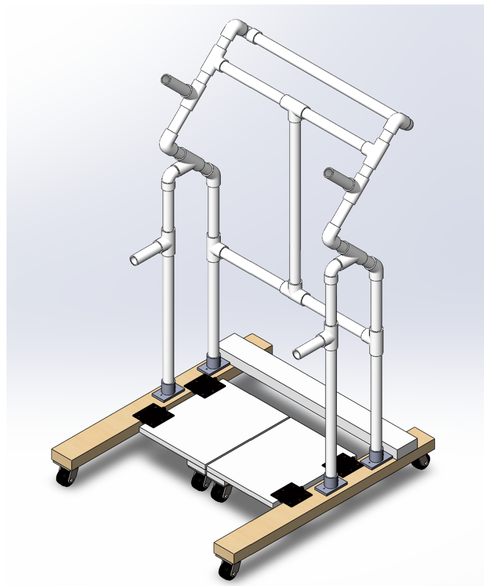


Figure 10: Computer Aided Design of Our Final Design, The Intelligent Sit-to-Stand (iSTS)

Furthermore, we carried out a static analysis to determine the stress and displacement of the device, when it experiences a maximum force of 200lbs. To execute the stress analysis simulation, the team started by simplifying the 3D modeled prototype. This was achieved by removing the 2 grip positions with low and medium levels of difficulty, as well as the wooden base which are not included in the simulation test as seen in Figure 11 below.

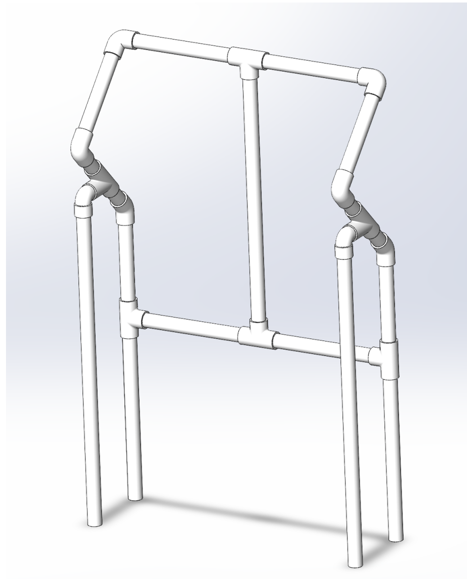


Figure 11: Computer Aided Design of The Simplified iSTS.

We conducted the statics analysis in SolidWorks by mimicking a 200lb patient using the first grip position, and setting the 4 legs as well as the diagonal arms as fixed geometry for the test constraint. We were able to conclude that a 200lbs uniformly distributed force on the first grip position will cause our prototype to be under around $1.908*10^6$ N/m^2 Von Mises stress, especially in the middle region of the device colored in red in Figure 15 (right picture). For both the stress analysis and displacement analysis, a low stress/displacement would be in the blue range and a high stress/displacement would be in the red range. Our results for the stress analysis mostly range in the blue range, which means that our prototype will not be under a lot of stress due to the materials lower displacement. These results were anticipated, due to our choice of the prototyping material being PVC, which renders our device to be weaker than it would be if it is manufactured with a more rigid material such as steel. As seen in Figure 15, while the device exerted low stress on the von Mises' scale roughly ranging from 58.58 N/m^2 to $7.634*10^6$ N/m^2, it exerted approximately as high as 3.189 mm when it came to displacement. Since we used a simplified version of the CAD prototype and only tested one grip position, more testing is needed once using more durable and stable materials.

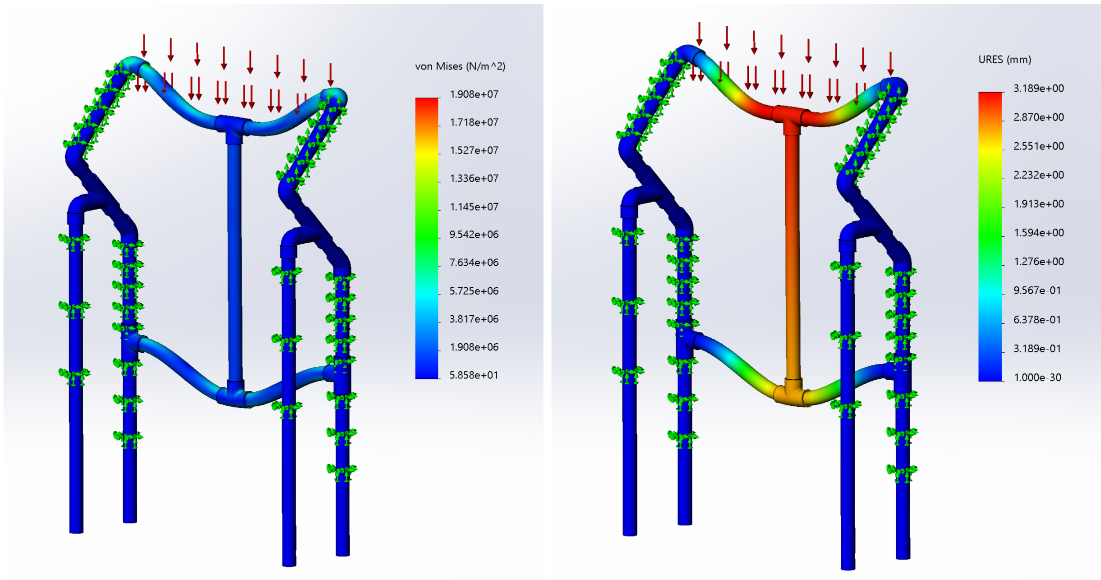


Figure 12: Stress analysis simulation (left) and displacement analysis simulation (right).

4.0 Design

After careful consideration, extensive research, stress analysis, and interviewing rehabilitation centers personnel, the team decided on creating the Intelligent Sit-to-Stand Aid (iSTS). This design innovation was the design of our choice, due to the positive feedback we have received from first hand users of STS devices on the market. It was made clear to us that there is no such product on the market that allows the patient and the caregiver to monitor their progress. For example, the therapists at Fairlawn encouraged us to go forward with this idea in hopes that this device will make its way to Fairlawn to be used by them and their patients. This design also scored the highest in the design matrix with a score of 62, hitting all the criteria, except aesthetics, which was deemed unimportant in the context of this project.

Our prototype can be seen in Figures 13-15. This device is an improvement on the currently marketed Stand-Aid device. The Stand-Aid device has only one grip position, cannot be converted into a walker, and does not have sensor technology. The iSTS device we designed has three different sets of handles to maximize the patient's comfortability and to allow for different levels of difficulty depending on the patient's abilities. It allows patients to use their upper body strength to push themselves up and stand on the device to be transported through the aid of a caregiver, transition to walking, or just to do STS exercises. Our design also incorporates a sensor at the base that captures the force applied when patients do the STS transition exercise. The signal is output to a computer monitor to allow monitoring the progress by the patients, physicians and physiotherapists. This fulfills objectives 5, 7, and 8. To offer safety and additional support, the device allows for additional attachments of different levels of resistance bands around the back of the device to help the patient rest and helps with concentric and eccentric motion. This fulfills objectives 5, 6, 7, 8, and 9. As the patient's mobility progresses over time, the device can be transformed into a walker by simply lifting the bottom platforms outward and locked into place. Furthermore, to allow for fast and efficient patient progress, the iSTS has force sensors that measure the force exerted by the patient over time and graphs the progress on a display. This feature will allow caregivers to carefully monitor the patient's improvement and to adjust the treatment plan accordingly. The sensors would be mounted onto separate removable platforms that would fit on to the base platforms, so the device can be used with or without the sensors. There will be two sensor platforms to measure the force of the left and right legs separately from each other to allow therapists and patients to compare the strength of the patient's legs. More details on the sensors and code are found in section 3.5.2 and Appendix B and examples of graphs can be seen in Section 6.3. This fulfills the stakeholder's wishes. The device uses strong lockable wheels to be able to be transported, stable while being used, durable, and maintain safety (objective 1, 2, 4, and 12). Objectives 9 (compact) and 10 (aesthetics) were not considered while designing the device as they ranked low in importance in the design objectives. Figure 14 shows how to use the iSTS.

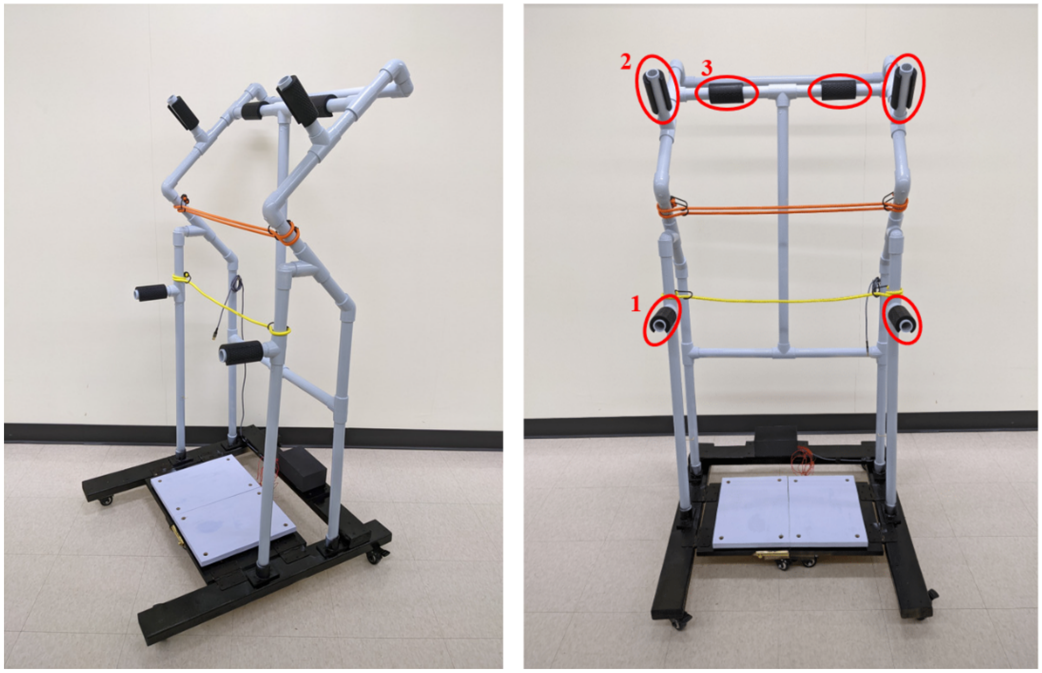


Figure 13: Isometric view of the iSTS (left) and the different grip positions (right). The lower grips are labeled (1), the middle grips are labeled (2), and the upper grips are labeled (3).

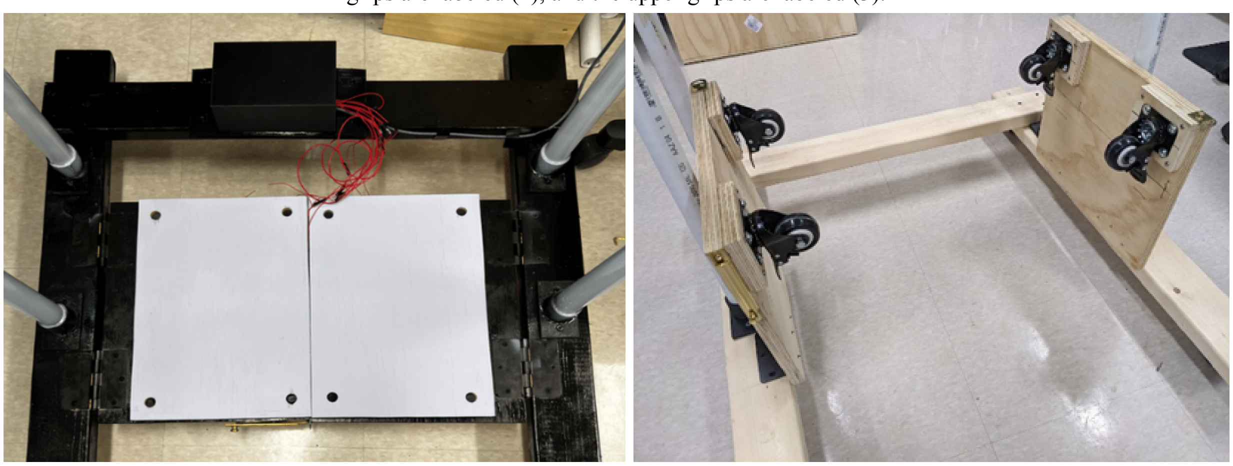


Figure 14: Closed platform with sensor plates (left) and open platform/walker mode (right).

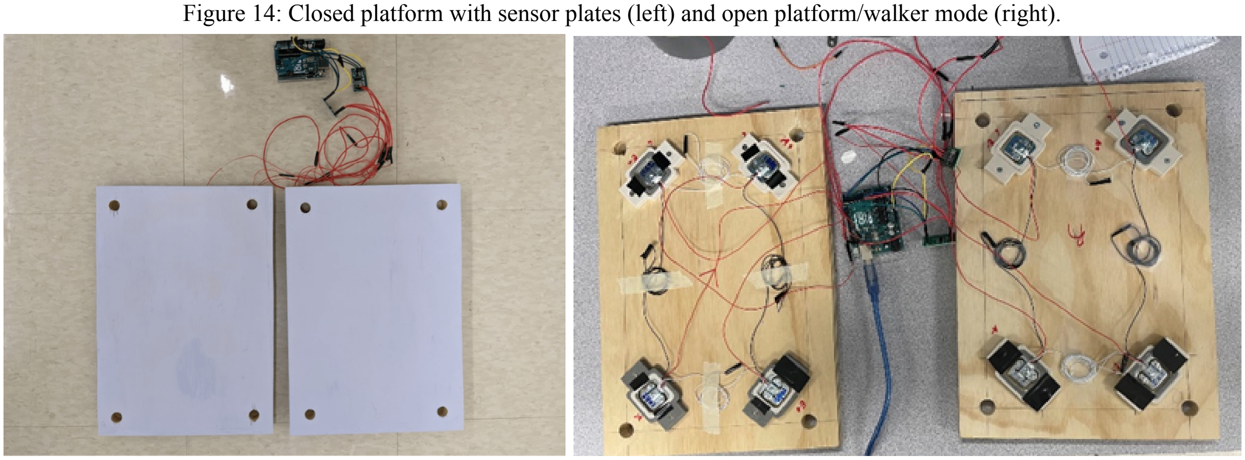


Figure 15: Front of removable sensor plates (left) and back of the removable sensor plates (right).

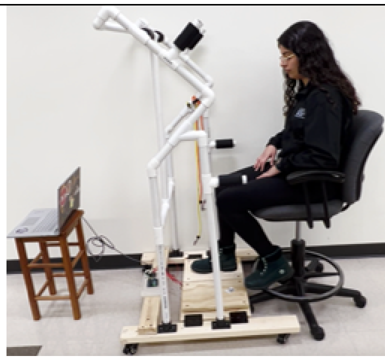
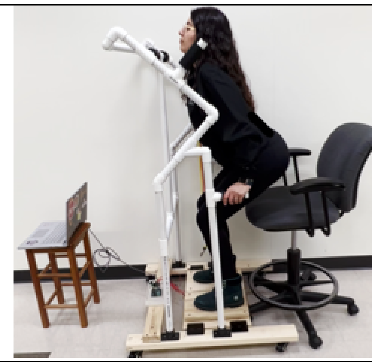
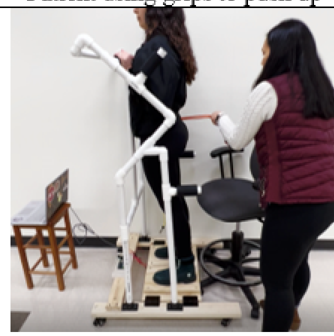
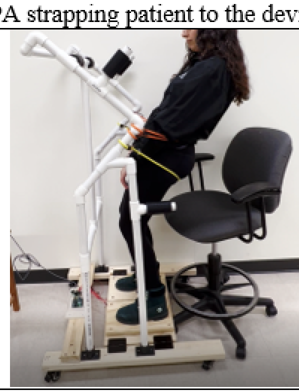
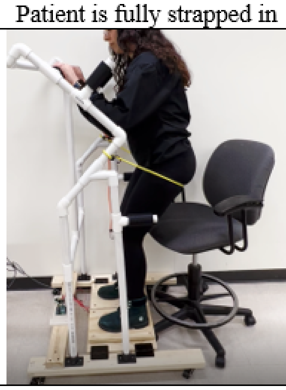
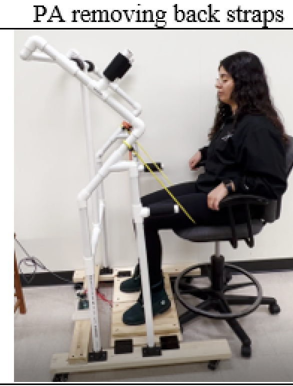
		
Patient Sitting (usually on bed)	Patient using grips to push up	Going into a standing position
		
Patient fully standing	PA strapping patient to the device	All 3 straps engaged
		
Patient is fully strapped in	Safety straps preventing falling	PA removing back straps
		
Thigh strap engaged for a controlled sit	Going into the seated position	Patient successfully sitting

Figure 16: iSTS device in use.

4.1 Prototyping Process

This section will follow along our prototyping process of selecting materials and the building phase.

4.1.1 Materials

To carry out our design of the iSTS, we had to think about what materials would be best to create the device's prototype. At first, wood was the only material that came to mind when creating our design as wood is a cheap but strong material. However, we quickly realized it would be difficult to create the body using wood. That was when we thought of using Polyvinyl Chloride (PVC) piping as the body and wood as the base. By using PVC pipes, we can take advantage of the many connectors available on the market and build our device like we are "playing with Legos." PVC pipes are made from a thermoplastic with high strength, rigidity, and hardness with an Ultimate Tensile Strength of 52 MPa. In bending, PVC can withstand 44 MPa for 1 hour in stress before breaking (short term creep rupture) and can withstand 28 MPa for an estimated 50 years in stress before breaking (long term creep rupture) (Vinidex, n.d.). For the base we used standard 2'x4' wood as the frame and 23/32" thick 2'x4' AC Radiata Pine Plywood as our base platform and sensor platform, a common material used for shelving and furniture.

The only problem that came up with using PVC as the body and wood as the base was finding a way to connect the two materials. We solved this issue by creating a custom piece using Computer-Aided Design and 3D printing the piece out of Nylon Carbon Fiber material, which is a "Carbon fiber reinforced nylon optimized for high strength to weight ratio, stiffness, and heat resistance making it ideal for structural applications and metal replacements" (MakerBot, n.d.). Epoxy was used to glue the PVC pipes to the PVC connectors and the 3D printed connector. By constructing the main body of the prototype out of PVC pipes/connectors, wood, and 3D printed parts we were able to keep the costs low.

For the HX711 sensors, which is a load cell amplifier that helps condition the signal from the load cell and makes it legible for other devices, we used Arduino Uno as our main motherboard to convert the outputs of the load cells into a measurement. It was programmed using an external Arduino library. This library reads the value of two load cells. The program was modified to serial print the load cell outputs to be incorporated into our Python code. This Python program reads the Arduino data and graphs the load cell outputs. To connect the Arduino Uno to the load cells, jumper wires were used and to connect the Arduino to a computer a USB-A to USB-B cable was used. To mount the sensors to a platform, our team designed, and 3D printed sensor mounts and covers out of PLA filament.

Other materials we sourced to create the final prototype included silicone grips to indicate where the patient can hold onto while using the device and making it more comfortable to hold onto than the PVC pipes. We also used lockable heavy duty caster wheels made out of polyurethane to allow transportation. Metal door hinges allow the bottom platform to be lifted out of the way for “walker-mode” and ¼” L screws to keep the bottom platform in place while in “walker-mode.” Resistance bands were purchased to ensure concentric and eccentric motion of the STS movement. Table 3 shows the costs of our prototype.

Table 3: Breakdown of our prototype costs.

Material	Individual Price ($)	Quantity	Total Price ($)
PVC Pipes (1"x10')	8.12	3	24.36
2x4 Wood	free from WPI scrap pile	3	0
23/32" 2'x4' AC Radiata Pine Plywood	24.94	1	24.94
3D Printed Connector (Sudo Carbon Fiber)	2.5	4	10
1" PVC EL 45D	1.57	2	3.14
1" PVC Side Outlet 90D Connector	3.74	2	7.48
1" PVC Street EL 90D Connector	2.93	4	11.72
1" PVC TEE Connector	1.72	8	13.76
1" PVC Wye Connector	9.4	2	18.8
3D Printed Sensor Mounts/Covers (PLA)	0.3	16	4.8
Grips (pack of 2)	13.99	3	41.97
Wheels (pack of 4)	15.99	2	31.98
Door Hinge	3.82	4	15.28
1/4" L screws (variety packet)	8.89	1	8.89
Bungee Cords (variety pack)	free from WPI scrap pile	1	0
Epoxy	17.89	1	17.89
Arduino Uno REV 3	23.4	1	23.4
Load Cells	7	2	14
Jumper Wires	free from WPI	16	0
Arduino Compartment	7	1	7
C2G USB Cable	free from WPI scrap pile	1	0
		Total	**279.41**

4.1.2 Building the Prototype

At first, constructing the prototype seemed very simple and straightforward. We promptly learned that that was not the case. Building the wooden base proved it difficult to keep it stable, by how we first designed the base. It was stable enough for someone to stand on slowly, however, we wanted the base to be our foundation for the device. Our original design did not include the horizontal 2x4 going across the front of the base, but after adding it, it was a lot more stable. Another challenge was the base's platform. We need to add wheels to the bottom of the platform in order for the patient to stand on the device to be transported. However, if we positioned the wheels in the middle of each platform, the platform was not stable where the two platforms meet, but if we positioned wheels on the outer edge, the wheels may interfere with each other. We decided to prioritize safety instead of portability and placed the wheels on the outer edge of where the two platforms meet.

We also met stability challenges while building the PVC body. Our original design consisted of only two legs, instead of four. The shear forces were too great on the two legs and caused them to bend, adding two more legs distributed the forces across and allowed the device to be more stable. After adding the additional legs, there was one other point on the device that was not yet stabilized once force was applied. If a patient were to use the middle horizontal grips, the beam that the grips are on was not stabilized enough and caused it to bend. By adding a vertical beam connecting the two middle horizontal beams, it made it more stable. Building with PVC pipes allowed us to "cut and paste" pipes and connectors where desired.

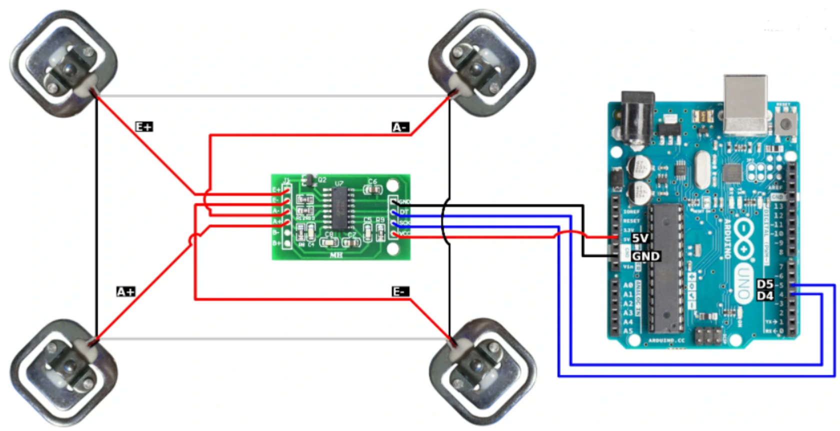


Figure 17: Schematic of the four load cells connected to the Arduino and the single load amplifier creating a Wheatstone Bridge (Luuk, 2020).

Force sensors were created using HX711 load cells. Four load cells were linked together to form a Wheatstone Bridge and connected to a single load cell amplifier. Following the schematic in Figure 17, the load cells were placed on the four corners of the wooden base and labeled E(+), A(-), A(+), and E(-). Each corresponding load cell had their white and black wires soldered together. The red output wires were connected to their respective place on the single load cell amplifier. From the amplifier, the outputs were connected to their respective digital pins on the Arduino. The circuit was then connected on the underside of a wooden platform with the load cells pointing downwards, so they will be compressed when someone stands on the platform. This process was repeated to create two identical force sensors that function like scales. The circuits were connected to an Arduino Uno where the data was compiled using a library provided by the load cell manufacturer. The serial data stream created by the library was pulled into a Python script where it could be mathematically and visually manipulated. The sensor code can be seen in Appendix B and examples of graphs from the code can be seen in Section 6.3.

Shown in Equation 1 is the calculation used in the Python script to find the patient’s leg strength. F is the force applied on the sensors, t being the time it takes for the patient to do a full

STS, and W being the weight of the patient. It is the impulse of the individual's standing force divided by the elapsed stand time squared (s^2) and the patient's weight (lbs). The integral is calculated using the trapezoidal sum under the recorded curve of the graph for each leg. Dividing by weight and time helps standardize the calculated value among patients. Making the time factor squared in the denominator generates lower scores for patients who take longer to reach a full stand

$$\frac{\int_0^t F\,dt}{t^2 W} \qquad (1)$$

4.2 Professional and Ethical Responsibilities

Below is a series of ethical and engineering design verification topics the team considered while designing this project.

4.2.1 Societal Influence

The iSTS device would not have a huge impact on society as a whole, but it would definitely improve the quality of life of many individuals that have suffered to complete the sit-to-stand movements. For example, individuals that have been bedridden, injured, or suffering from a stroke or muscle atrophy would benefit the most from such devices.

4.2.2 Ethical Concerns

Our product would not raise any ethical concerns, it will mainly serve to improve a patient's lifestyle and may also be used to aid athletes recovering from injuries.

4.2.3 Health and Safety Issues

The iSTS will improve the health and safety of patients by helping rehabilitate their sit-to-stand muscles so they will be able to perform a sit-to-stand on their own without external help. This will also help decrease the number of fall deaths as about 41% of elderly fall deaths is a result of poor transition from sitting to standing.

4.2.4 Manufacturability

The iSTS can be easily manufactured as it is made similarly to the already existing Stand-Aid. The device will be made from accessible materials such as steel and rubber. Similarly, the sensors and the program that allow for the device to measure patient progress are simple and do not require complicated or expensive equipment and hardware.

5.0 Methods

The following section will outline the experiments we will conduct on the prototype of the device. They were run to evaluate the 12 design objectives we considered while building the device.

5.1 Sensor Accuracy Test

Purpose: To test the accuracy of the sensors.

Methods:

1. The sensors were powered on by plugging the Arduino into a Laptop. The "Read 2x Load Cells" example library was uploaded to the board
2. Each sensor individually measured known weights of 5, 10, 20, 35, and 45lbs. Every weight was recorded 3 times by the sensors.
3. The recorded weights were averaged and converted from ounces to pounds.
4. A T-Test was used to statistically compare the recorded weights to the values of the known weights.

5.2 Standardized Strength-Scoring Test

Purpose: To measure the force difference between a natural STS movement versus using the prototype to stand.

Methods:

1. First the team utilized the device to demonstrate natural STS movements. The test subject first sat in a chair with the height of the seat being 20 inches off the ground.
2. The participant was then asked to achieve a standing position onto the sensor-base of the STS device without utilizing their hands for balance, and only distributing their body weight on their legs.

3. First, the sensors were turned on by plugging the Arduino into a Laptop. The Python program was run so the participant could input their body weight in pounds.
4. After setting up the force plates, one team member will put their feet on the plate and sit on a chair.
5. The members performed an STS movement with their arms in front of them. This is to prevent themselves from pushing up from up the chair. The test will be repeated a minimum of 10 times.
6. The force plate data was graphed, and a single factor ANOVA was used to find if there is a significant difference between individuals in the calculated strength values.
7. This test also showed what an average strength value was for a healthy individual.

5.3 Grip Assistance Test

Purpose: To measure how much assistance the 3 grips provide when an individual conducts a STS movement on the device.

Methods:

1. The sensors were powered on by attaching them to a Laptop. The Python program was run to graph the stand and calculate the strength values for both legs.
2. The participant first completed an unassisted STS 20 times to gather a baseline for their strength values.
3. The participant then completed a STS motion with the 3 grips on the device. The lower is labeled as (1), the center grip is (2) and the upper grip is (3) shown in Figure 11. Each stand was completed 20 times on each grip.

4. The strength values calculated from the Python Program were recorded on a spreadsheet while images of the graph were saved to a folder.
5. A T-Test was used to compare the strength values from the unassisted stand to the stands using the 3 grips.

6.0 Results

This section serves to detail the outcomes of the project. The result of each design objective from Section 3.2.1 will be determined, as well as the ways in which these objectives were evaluated. Additionally, test results from Section 3.6 and the feedback the team received from the Fairlawn Rehabilitation Hospital will be discussed.

6.1 Evaluation of Design Objectives

After testing, the team went through our design objectives and evaluated if those objectives were satisfied, partially satisfied, or not satisfied/abandoned by our prototype. Table 4 displays the design objective outcomes.

Table 4: Design objective outcomes.

Objective	Requirement	Outcome
1. Easily transportable by hospital staff	Can move across many surface types with relative ease and fit through hospital doors	Satisfied
2. Device remains stable throughout use	Device does not move unintentionally when subjected to reasonable force vectors	Partially satisfied
3. Affordable	Hospitals should be able to purchase it; If the device is cheaper, then treatment can be more affordable to patients	Satisfied
4. Durable	Device has a use life of 10 years	Satisfied
5. Is able to exercise the leg muscles used in STS	Strengthens leg muscles; Utilize resistance to build tension in muscles and exercise them	Satisfied
6. Comfort	-Device should be wearable for extended (?) periods of time -Comfortable while in use	Partially Satisfied
7. Satisfies diverse clients	Device should take into account different weights, heights, and shape of patients	Satisfied
8. Is able to assist the user in regaining a standing position in a natural way	-Helps user stand from a seated position in a natural way	Satisfied
9. Compact	Can be easily stored	Not Satisfied/Abandoned
10. Aesthetically pleasing	Device is appealing to the user/eye	Not Satisfied/Abandoned
11. Easy to use and maintain	Helps technician/patient easily use/fix the device	Satisfied
12. Safe	Low risk to users and staff	Partially Satisfied

6.1.1 Easily Transportable

The device is on wheels and requires little force to roll around. The wheels swivel 360 degrees, allowing the user to route the device in any direction they desire.

6.1.2 Stability

The device is designed to remain balanced and stable during use. There are not any reasonable loading scenarios that would cause the device to tilt or deform. However, the basic materials used to create the prototype are susceptible to undesirable flexion. This flexion would not exist in the final device, as realistic materials and manufacturing processes would be used.

6.1.3 Affordable

The device is made of common and affordable materials. There are not any specialty components or electronic components beyond wiring and a microprocessor. Furthermore, the affordability of the device is demonstrated by the use of similar devices in the relevant industries.

6.1.4 Durable

The device prototype has endured over 100 STS repetitions using each grip configuration without any sign of failure. A final, manufactured device would likely have an unlimited use-life because all materials used would be able to endure stresses well over any stress the device would ever experience.

6.1.5 Exercises the Leg Muscles

The device is modeled after the Stand Aid, a device used in rehabilitation hospitals to provide support for patients as they stand up while still requiring them to use their own strength to complete the STS motion. Because the device is an active device, and does not apply force to the patient, it would be considered a good device for conditioning leg muscles.

6.1.6 Comfort

The prototype was not optimized for comfort, as other priorities were higher. However, the device is modeled after the Stand Aid, which is generally comfortable.

6.1.7 Satisfies Diverse Client Base

The prototype was created 50% wider than the original Stand Aid in order to accommodate larger users. Additionally, the added grip positions create different levels of assistance that users can select based on their current strength.

6.1.8 STS Motion is Natural

The STS motion being natural during device use was a key design requirement, as the team wanted to ensure the user's muscles would be trained for everyday STS activities. The device does not restrict or influence the user's leg motion in any way, allowing for a natural STS motion.

6.1.9 Compact

This objective was abandoned due to other objectives being higher priority.

6.1.10 Aesthetically Pleasing

This objective was not considered during the prototype phase. However, a final, manufactured device could easily be designed for aesthetics.

6.1.11 Ease of Use

The iSTS device only requires one clinician to assist the user with entering and exiting the device. The software essentially runs itself, sensing when a patient has started an STS and when they are finished. There are not any complicated features that the user has to interface with.

6.1.12 Safety

The prototype is mostly safe, but it shouldn't be used without the supervision of a clinician. The team also recommends adding a seat that secures the patient like the one on the Stand Aid to limit possibilities of falls. A human factors study would need to be done to further evaluate safety.

6.2 Test Reports

The team conducted tests on sensor accuracy, the standardization of the leg strength formula, and the significance of each grip position.

6.2.1 Sensor Accuracy Test

Through several trials using known weights, it was found that the right sensor is 89%-92% accurate and the left sensor is 80%-85% accurate. Three trials were conducted on each sensor for a known weight, and this process was repeated for four other known weights, making the sample size 15 trials on each sensor. The accuracy values were found by averaging the measured weight values from the sensors and dividing by the respective known weight values, with 100% meaning the measurements were the same as the known values. We found that both sensors were reading lower than they should be. This is likely due to the sensors being very cheap and of low quality or from the auto-calibration of the sensors, executed by the Arduino program. Adding an intercept could potentially increase sensor accuracy, however it would first have to be understood whether the sensor readings are consistently low or simply low on average. This would require more testing.

6.2.2 Grip Assistance Test

The team was able to detect a statistically significant difference (alpha = 0.05) in strength scores when a patient uses the lower set of grips versus when standing without any grips. This result adds validity to the concept of strength scoring using the leg strength equation. The team would expect the strength score to be higher in the use case where no grips were used during the STS, which is what was observed. The test failed to return significant differences for the other grip positions, but this is likely due to poor sensor response time, which has a high influence on the strength equation. A higher-quality sensor would eliminate sensor lag.

6.2.3 Standardized Strength-Scoring Test

The purpose of this test was to see if the strength values returned from the strength equation are fit for being compared across users of different weights. The strength equation has user weight in the denominator, attempting to standardize the values. This test was conducted to see if there was no statistically significant difference in output strength values when five different users used the same grip configuration on the device. A one-way ANOVA test was used to check for differences between the samples, and it was concluded that there were no significant differences (alpha=0.05), providing some evidence that the strength equation is standardized.

6.3 Sensor Graphs

One of the key features of our device is the ability of the sensor data to be outputted into a visual graph for the physician and the patient to view. With these graphs, you are able to compare each leg strength with the Standardized Strength-Score generated from Equation 1. These graphs also help visualize the progress of the patient's full STS movement to identify if the patient was struggling or if they have done a full STS as the program only stops once the patient's full weight is reached. This feature is also helpful with weight shift exercises as the physician will be able to know if the patient's full weight is actually on one leg. The graphs are especially helpful long-term when comparing the patient's progress over months of rehabilitation. With short-term use, the physician will not be able to get enough data to fully analyze the patient's progress, but they will be able to see even small progress through the graphs and Strength-Score.

To help interpret the graphs, the following tips are listed below:

- Person with Strong Legs
    - S-Curve (almost linear before full weight is achieved)
    - Higher Strength-Score
    - One curve may be steeper than the other (if one of the patient's legs is weaker than the other, they will apply more of their body weight to the stronger leg, which will produce a steeper curve)
    - One strength score may have higher than the other (similar to the steepness of the curves, if one leg of a patient is stronger than the other, that particular leg will produce a larger strength score)
- Person with Weak Legs
    - Graph has many curves/bumps (represents that the patient is struggling to get up during eccentric motion)
    - Lower Strength-Score
    - One curve may be steeper than the other (if one of the patient's legs is weaker than the other, they will apply more of their body weight to the stronger leg, which will produce a steeper curve)
    - One strength score may have higher than the other (similar to the steepness of the curves, if one leg of a patient is stronger than the other, that particular leg will produce a larger strength score)

An example of an unassisted STS of someone with strong legs and an assisted STS of someone with weak legs can be seen in Figure 18. In the unassisted graph, the patient has an S-Curve for both the right and left leg and before the full weight is reached the graph almost follows a linear trend. The patient relies mostly on their right leg as the Strength-Score for the right leg is higher and the red line representing the right leg is positioned much higher on the graph. In the assisted graph, the patient had a harder time getting up as the patient tried to get up, but failed and sat back down; This is represented by the initial plateau in the graph after the first incline by the curves. The patient was able to stand up on the second try, however you can see some struggle in the bumps on the curve. This patient also had a lower Strength-Score and relied more on their right leg.

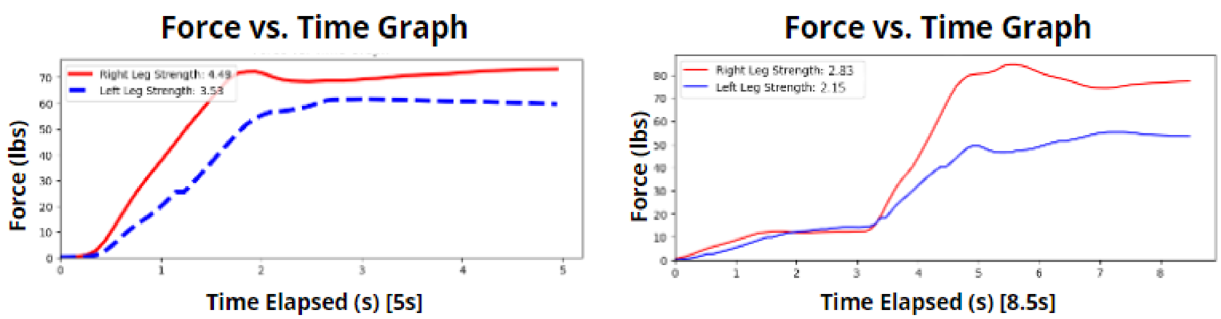


Figure 18: Unassisted STS of a person with strong legs (left) and assisted STS using the third set of grips of someone with weak legs (right).

6.4 Clinical Feedback

The team received positive feedback from the care providers at the Fairlawn Rehabilitation Hospital in Worcester, MA.

The conclusions were:

- The visual display of force data is a new tool that can aid both care providers in understanding their patients' condition as well as help patients comprehend what their body is doing.
- The force sensing and strength scoring technology can be used outside the scope of the Stand Aid and introduced to other devices and activities at the rehabilitation hospital.

7.0 Analysis and Discussion

Our MQP team set out to build a device that would assist elderly patients in their sit-to-stand transition movement, while also actively engaging their lower leg muscles in the process so that they also rebuild the strength of their leg muscles. Over the course of the project, the team incorporated loading sensors onto the device as it filled another gap identified while conducting our background research. These sensors offer both physicians and patients a unique mode of tracking and quantifying progress throughout rehabilitation. Our device may be used in hospitals and rehabilitation centers to help exercise the STS muscles while simultaneously monitoring the patient's progress.

The physical iSTS prototype features three different sets of grips. Different grips provide different rigor for the exercise regimen. As the patient progresses through their treatment, building more strength in their legs and requiring less assistance to get up, physicians can guide them to the next set of grips. The higher the position of the grips, the harder the exercise for the patient and more force is required on their part to achieve a standing position. Once they've overcome the last set of grips and can get up with no trouble, the patient can utilize the device as a walker to get from one place to another. Testing of these grips in the Grip Assistance Test as described in 5.3 proved that when a patient utilizes the lowest set of grips to achieve a standing position over no assistance at all, they express a significantly lower strength score. This is because the patient relied more on the device for support, assistance standing and maintaining balance throughout the movement, therefore they exerted less force and presented a lower strength score. These quantified results from the sensor readings and grip testing proved our hypothesis that patients would score a higher strength score with unassisted transitions.

Our sensors are able to detect the differences of grips after conducting statistical analysis between the unassisted stands with the various grip positions. From the Standardized Strength-Scoring tests in 5.2, the team discovered that each member had very similar strength scores. This aligns with our observational hypotheses as each team member is healthy and able to achieve a standing position without any assistance. The curves of each of our graphs also exemplified this conclusion, since each graph had few to no fluctuations which meant a smooth transition into standing. Each graph achieved a steady plateau before team members had all their weight on the sensor platforms.

The ability to detect the force output from the legs independently allows clinicians to understand patient performance that may not be visible to the naked eye. For example, if a patient with a weak left leg is overcompensating with their right leg, the sensor's readings will indicate the discrepancy. This type of overcompensation can lead to limping and other significant health problems down the line. By plotting the force data, the user is able to visually interpret important patterns in the graph. If a user is struggling. They will notice the plotted force line wobbling much like their muscles are. Additionally, their strength score, from the strength formula, will tell them how much work their legs are doing and how much they are relying on the device grips to push or pull themselves up. The data display allows the physician or the physiotherapist to adjust the rigor of exercise to help patients improve the strength in the weaker leg. This is the most important feature that this device provides; a feature that is absent in the devices currently available in the marketplace.

8.0 Conclusion

The team started with the objective of developing a medical assistive device that aimed to aid patients in achieving a standing position from a sitting one and simultaneously exercising their muscles. After many design ideas and iterations, as well as interviewing first hand users in the rehabilitation field, the team decided to take a new approach to solving this engineering problem. This approach would offer an innovative solution that has not been previously introduced to the market; The Intelligent Sit-to-Stand Aid (iSTS). The iSTS is a four in one device, acting as a transportation method, an exercise machine, a walker and most importantly a means to evaluate and track patient progress. This device can be used by the patients and their caregivers in various healing stages.

When the patient begins their treatment, they would be able to use the device as a transportation method by standing on the platform and being pushed around by a caregiver. To increase the difficulty of the exercise and to further challenge the STS muscle group, the patient can use different handles on the device to set the rigor of the exercise. As the patient starts improving and being able to perform the full STS motion alone, they have the option to remove the platform and use the machine as a walker. Finally, while the machine is being used to exercise the muscles, the patient or the caregiver have the opportunity to place an additional platform with sensors that would be able to track the forces applied by the patient from each leg and produce meaningful graphs indicating patient progress.

While the functional prototype was made out of inexpensive materials, the team was able to produce meaningful results that earned the liking of various future potential users and doctors. These results consist of data points and graphs indicative of the forces being applied by the patient, allowing the user to monitor their progress. Due to the novelty of our design, the team filed an intellectual property disclosure to patent our sensor innovation.

9.0 Recommendations

The Intelligent Sit-to-Stand Aid (iSTS) is a versatile device that can be used to maximize a patient's rehabilitation process. While the device is considered a success at its current design state, the team sees value in further improving our device. While the intellectual property disclosure remains effective for the iSTS, the team hopes to implement some or all of the following improvements:

1. Adding a small interactive monitor to the device that can produce real data for better performance.
2. Replacing the wiring from the Arduino system with a Bluetooth option, making the device more compact.
3. Using a more advanced set of sensors which could increase the accuracy of the data collected.
4. Making the device's height and width adjustable to allow for a diverse group of patients to use it comfortably and so that the device can fit through standard doorways.
5. Making the device waterproof so it could endure different conditions.
6. Adding the back pads from the original Stand-Aid design, instead of the bungee cords so that patients are supported while being transported.
7. Making the grip positions adjustable so that different patients can use them comfortably.
8. Increasing the weight limit to 300-400lbs to allow more patients to use it.
9. Improving the sensor code to be more versatile with different user modes and easy to use.
10. Developing an app for an improved user interface.

All of the devices on the market lack the ability to easily track patient progress, and our innovative solution would be able to potentially fill this gap on the market, and for this reason the team thinks that licensing this device to a company will help us achieve our goal to bridge the gap.

References

Baumgartner, R. N., Waters, D. L., Gallagher, D., Morley, J. E., & Garry, P. J. (1999). Predictors of skeletal muscle mass in elderly men and women. Mechanisms of Ageing and Development, 107(2), 123–136. https://doi.org/10.1016/s0047-6374(98)00130-4

Centers for Disease Control and Prevention. (February 10, 2017). Important facts about falls. Centers for Disease Control and Prevention, https://www.cdc.gov/homeandrecreationalsafety/falls/adultfalls.html.

Family Caregiver Alliance. (2016). Caregiver Statistics: Demographics, https://www.caregiver.org/resource/caregiver-statistics-demographics/.

Graham-Field Store. (2011). *Lumex Stand Assist Patient Transport Unit, LF1600*. Amazon. Retrieved April 21, 2022, from https://www.amazon.com/gp/css/order-history

Iwanicki, A. (February 5, 2015). How I Felt After 70 Days of Lying in Bed for Science. Vice. https://www.vice.com/en/article/jma83d/nasa-patient-8179-200

Jamie Cormier, Danielle Rizzuto & Taylor Shaver. (November 12, 2021). Semi-Structured Interview with Fairlawn Rehabilitation Hospital (C. Chung, S. Chelak & B. Pham, Interviewers) [Fairlawn Rehabilitation Hospital].

Janssen, W.G.M., Bussmann, H.B.J., Stam, H.J. (Sep. 1, 2002). Determinants of the Sit-to-Stand Movement: A Review, *Physical Therapy*, 82 (9), 866–879, https://doi.org/10.1093/ptj/82.9.866.

Joerns Healthcare. (2022). *Amazon.com: Hoyer Journey SIT to stand lift - hoyer ...* Retrieved April 21, 2022, from https://www.amazon.com/Hoyer-Journey-Sit-Stand-Lift/dp/B007GBDANU

Luuk, I. (April 17, 2020). 50kg Load Cells with HX711 and Arduino. 4x, 2x, 1x Diagrams. https://circuitjournal.com/50kg-load-cells-with-HX711

MakerBot. (n.d.). *MakerBot Nylon Carbon Fiber Material for METHOD*. MakerBot. Retrieved April 12, 2022, from https://www.makerbot.com/3d-printers/materials/method-nylon-carbon-fiber/

Millington, P.J., Myklebust, B.M., Shambles, G.M. (July 1, 1992). Biomechanical Analysis of the Sit-to-Stand Motion in Elderly Persons, Arch Phys Med Rehabil, 75 (7), 609-617, https://doi.org/10.5555/uri:pii:000399939290124F.

Rittweger, J., Frost, H., Schiessl, H., Ohshima, H., Alkner, B., Tesch, P., &Amp; Felsenberg, D. (2005). Muscle Atrophy and Bone Loss After 90 Days' Bed Rest and the Effects of Flywheel Resistive Exercise and Pamidronate: Results from the Ltbr Study, *Bone*, 36(6), 1019–1029, https://doi.org/10.1016/j.bone.2004.11.014

Roebroeck M.E., Doorenbosch C.A., Harlaar J., et al. (1994). Biomechanics and Muscular Activity During Sit-to-stand Transfer, *Clin Biomech*, 9, 235–244.

Schenkman M.L., Berger R.A., Riley P.O., et al. (1990). Whole-body Movements During Rising to Standing from Sitting, *Phys Ther*, 70, 638–651.

Vander Linden, D.W., Brunt, D., McCulloch, M.U. (1994). Variant and Invariant Characteristics of the Sit-to-stand Task in Healthy Elderly Adults, *Arch Phys Med Rehabil*, 75, 653–660.

Vansun. (2022). *Amazon.com: Vansun Patient Lift Sling, back curve widening design- make ...* Amazon. Retrieved April 21, 2022, from https://www.amazon.com/Vansun-Patient-Transfer-Widening-Design/dp/B08MFB1MW6

Vinidex. (n.d.). *PVC Properties*. Vinidex Pty Ltd. Retrieved April 12, 2022, from https://www.vinidex.com.au/technical-resources/material-properties/pvc-properties/

Wheeler J., Woodward C., Ucovich R.L., Perry J., Walker J.M. (Jan, 1985). Rising from a Chair: Influence of Age and Chair Design, *Physical Therapy*, 65(1), 22-26, https://doi:10.1093/ptj/65.1.22. PMID: 3966081.

Appendices

A: Sample Interview Questions

1. What type of injuries/circumstances require patients to need an assistive sit-to-stand device that helps strengthen the muscles?
2. Are the patients who need STS devices mostly the elderly, injured athletes, or bedridden patients?
3. Is the sit-to-stand devices' use limited to patients undergoing physical therapy?
    a. Do healthy individuals have a use for STS devices?
4. What types of machines/equipment or technologies do you have in your facilities to aid in physical therapy for restrengthening leg muscles, if any?
    a. What are features that you appreciate having in these devices? What features do patients seem to like?
    b. How would you recommend improving the current devices?
    c. What exercises/aiding technologies have been most effective in overall patient recovery? STS exercise?
5. How much training is necessary for staff members to understand how to use the current devices?
6. Are patients able to use these devices on their own, if not how many people are usually required to assist the patient?
7. For hospital use, does the insurance company, the patient, or the hospital pay for the device?
8. Are there any institutions, resources or people you think we should reach out to who would provide greater insight on these types of devices?
9. Can we measure and take pictures of a hospital bed?
    a. Are we able to come back to take more measurements or test our prototype?
    b. Is it ok if we reach back out to you if we have more questions? If so, what is the best way to reach you?

B: Sensor Code

Shown below is the Python code used in our device. It takes the force inputs from the HX711 Arduino library and converts it into an array. This allows it to plot the sensor inputs into a Force Vs. Time graph. The program also prompts the user to input their weight in pounds to calculate their strength during a stand.

```
import serial
import time
import json
import numpy as np
import matplotlib.pyplot as plt
from numpy import trapz


arduino = serial.Serial(port='COM4', baudrate=57600, timeout=.1)

# weight = 0
draw_graph = True
read_interval = .02 # 50 times a second

start_time_of_stand = time.time()
full_length_of_stand = time.time()
time_started = False

def read_arduino():
    # arduino.write(bytes(x, 'utf-8'))
    # time.sleep(read_interval)
    data = arduino.readline()
    return data.decode("utf-8")

def ask_weight():
    return input("Enter Weight: ")




load_1 = []
# load_1_time = []
load_2 = []
```

```python
while True:
    value = read_arduino()
    if 'Tare load cell 2 complete' in value:
        print("Starup complete")
        break

weight = float(ask_weight())

print("Place feet on device.")

while draw_graph:

    value = read_arduino()
    # print(value)
    # if 'Tare load cell 2 complete' in value:
    #     print("Starup complete. Step on scale.")

    if value != '' and value[0] == '{':
        json_value = json.loads(value)
        if json_value['load_cell_1'] > 1 or json_value['load_cell_2'] > 1:
            if not time_started:
                start_time_of_stand = time.time()
                time_started = True
            load_1.append(json_value['load_cell_1'] / 16)
            load_2.append(json_value['load_cell_2'] / 16)
        if ((json_value['load_cell_1'] / 16) + (json_value['load_cell_2']
/ 16)) >= weight-15:
            # start new while loop
            timeout = 3
            timeout_start = time.time()
            while time.time() < timeout_start + timeout:
                # print(json_value['load_cell_1'])
                value = read_arduino()
                if value != '' and value[0] == '{':
                    json_value = json.loads(value)
                    load_1.append(json_value['load_cell_1'] / 16)
                    # load_1_time.append(time.time())
                    load_2.append(json_value['load_cell_2'] / 16)
            full_length_of_stand = time.time() - start_time_of_stand
            break
```

```
print(full_length_of_stand)
start_time = time.time()
load_1_time = []
time_elapsed = 0
elapsed_time_interval = full_length_of_stand / len(load_1)

for i in load_1:
    load_1_time.append(time_elapsed)
    time_elapsed += elapsed_time_interval



plt.rcParams["figure.figsize"] = [7.50, 3.50]
plt.rcParams["figure.autolayout"] = True

y1 = np.array(load_1)
y2 = np.array(load_2)
x = np.array(load_1_time)

plt.title("Force vs. Time Graph")
plt.xlabel("STS Time (s) " + "[Elapsed Time:
"+str(round(full_length_of_stand-3,1)) + "s]")
plt.ylabel("Force (lbs)")

load_1_area = trapz(y1, dx=5)
load_2_area = trapz(y2, dx=5)

label1 = "Right Leg Strength: " +
str(format(load_1_area/(full_length_of_stand**2 * weight), ".2f"))
label2 = "Left Leg Strength: " +
str(format(load_2_area/(full_length_of_stand**2 * weight), ".2f"))
#label3= "Elapsed Time: "+str(format(full_length_of_stand,".2f"))
#Shows graph with new power formula

plt.plot(x, y1, color="red", label=label1, linewidth=3)
plt.plot(x, y2, color="blue", label=label2, linestyle="dashed",
linewidth=4)
#plt.plot(lable=label3)
#plt.plot(x, y1, color="white", label=label3, linewidth= 1)
```

```
plt.legend(loc="upper left")
plt.ylim(bottom=0)
plt.xlim(left=0)

# Compute the area using the composite trapezoidal rule.

print("Right Leg Strength: " + str(load_1_area/((full_length_of_stand)**2
* weight)))
print("Left Leg Strength: " + str(load_2_area/((full_length_of_stand)**2 *
weight)))
#print("Elapsed Time: "+str(format(full_length_of_stand,".2f")))

plt.show()
```