30.007 Term Paper Team 6

Aaron Jiang, Wong Jae Hann, Nuryn Insyirah, Soumyadeep Mahata, Uh Yun Ning

Abstract
This project aims to reduce the effort required by caregivers to lift persons with disabilities (PwDs) up from the wheelchair and transfer them by automating the lifting process. According to NIOSH, lifting and moving patients is the single greatest risk factor for overexertion injuries in healthcare professionals, and 38% of caregivers experience severe back pain. To address this issue, we developed a modular prototype that can be used in most wheelchairs without complications and weighs less than 5 kg. The prototype uses an Arduino Mega and NMOS switches as the logic control, Time-of-Flight and IR sensors as the automation and feedback system, and inflatable TPU bags, solenoid valves, and pumps as the inflation mechanism. The prototype has 6-degrees of freedom for a smoother lifting experience and automates the lifting up and down process up to 15cm in height.

To validate our prototype, we conducted several experiments, including tensile and fatigue testing on the inflatable TPU bags to ensure they can support 700 N of weight and 5000 cycles of inflation and deflation. We also conducted user surveys to ensure comfortability and a heart rate monitoring test on the caregiver to measure the effectiveness of our prototype in reducing effort. Our results show that the prototype successfully automates the lifting process and reduces the effort required by caregivers, thereby reducing the risk of overexertion injuries. The prototype is also comfortable for the PWDs and caregivers, and the heart rate monitoring test indicates that it effectively reduces the effort required by the caregiver during the lifting process. Overall, our prototype has the potential to improve the quality of life for PWDs and caregivers, especially in Singapore's ageing society.

I. Introduction

As the elderly population continues to grow, so does the need for caregivers to assist with daily living activities. One of the most physically demanding tasks for caregivers is transferring patients to and from wheelchairs, which can cause back pain and other injuries. According to the National Institute for Occupational Safety and Health (2018), 38.3% of caregivers experience low back pain. Our research project aims to address this problem by developing a portable transfer assist device for wheelchairs that reduces the effort and chance of injury for caregivers when transferring patients. This leads to our problem statement as follows:

"How might we develop a portable transfer assist device for wheelchairs that reduces the effort and chance of injury for caregivers when transferring patients?"

The current pain points for our project are bulky and expensive transfer mechanisms, which can be impractical for daily use. Our project seeks to address these issues by developing a modular add-on lifting mechanism that is portable, sustainable and affordable. Our project is particularly relevant in Singapore, where the rapidly ageing population has increased the need for caregivers to take care of the elderly. It is important to consider the welfare of caregivers, including their physical health. By reducing the risk of injury and back pain, our project can improve the quality of life for both caregivers and patients.
Additionally, our innovative design, which incorporates modularity, sustainability, and affordability, can have a broader impact on the wheelchair market. Our design allows current wheelchair users to reuse their wheelchairs instead of buying another one with a transfer mechanism, thereby reducing waste and lowering costs.

II. Proposed Approach

A. System Requirements

To ensure our prototype was developed to suit our targeted users, use cases and unique features, we highlighted 7 key requirements of our prototype.

Functional Requirements	Design Parameters	Experiments Done	Measurable Outcome
Mechanism and seat are sturdy, robust, and reliable	- Supports up to the average weight of a Singaporean male, 70 kg without breaking. - At least 5000 cycles of inflation and deflation.	- Tensile Test - Fatigue Test	-Yield strength of material -Number of cycles before failure
Automatic lifting	Sensors that detect lifting	Tallying height reflected	-Inflation stops automatic

height calibration	height during device operation, having a range of 3cm-15cm to ensure uniform inflation of airbags and lifting of user	by the sensor with a meter rule	ally after set lifting height is reached -Lifting height is unform at all four corners
Comfortable for long sitting hours	More than 1-2 hours of sitting time	User testing and survey	Obtain user's opinion of the comfort levels when using the prototype
Seat offers multiple degrees of freedom	Independently controlled air bags with supporting sliding rails and guides	Visual inspection and measuring of angle an accelerometer	6 degrees of freedom. vertical lift (up/down), tilt left, tilt right, tilt front, tilt back
Lightweight and portable	Total mass of prototype is less than 5kg	Weighing of prototype using a weighing scale	-
Effort used by caretakers in wheelchair transfers is reduced.	Average heart rate of caregiver is lower when using the device.	-Heart rate monitoring test -Time taken to perform a lift	BPM over the course of lifting
Able to stop when device malfunctions	Emergency stop button	-	Able to break circuit manually and stop operation

Table 1: Functional Requirements of Working Prototype

B. Concept Selection

Ideas related to the theme of 'travel' were initially proposed and discussed on a Miro board. The ideas were then represented on a Morphological chart to identify and compare each product's functionality.

Function	Idea 1	Idea 2	Idea 3
Reducing friction for transit	Comfortable seating		Reduce baggage load
Assisting PWD	Wheelchair enhancements	Instruction Clarity	
Navigation / Commute Assist		Flag/ Direction mapping	Ridable/ reduce walking
Optimize clothing/ smart wear			
Reducing effort for transit employees	Power assisted vehicle mounting	Smart Nav Guides	
Portability/ Compact	Folding Mechanism		Modular System
Leverage tech/ robotics		AI Path Finding	Collision Detection
Sustainability	Material Selection	Solar Panels	Renewable Energy
Autonomy	Sensor/ Collision Detection	Independent decision making	Metrics/ usage reporting

Table 2a: Morphological chart of initial ideas (ideas 1,2 3)

Function	Idea 4	Idea 5	Idea 6
Reducing friction for transit	Efficient baggage loading	Transit weather conditions	
Assisting PWD			
Navigation/ Commute Assist			
Optimize clothing/ smart wear		Heated/ Cooled	Multi-purpose clothing
Reducing effort for transit employees	Baggage conveyor belt		
Portability / Compact		Compression	Detachable Components

Leverage tech/ robotics			
Sustainability	Reusable components	Environmentally friendly materials	Recycled materials
Autonomy	Automatic capacity detection	Intelligently auto adjust	Usage patterns reporting

(cont.) Table 2b: Morphological chart of initial ideas (ideas 4,5 6)

After which, each team member had to fill in independent Pugh charts via Google Forms to rate every product from 1-5 for each of the following selection criteria: (i) General interest, (ii) Feasibility to Prototype, (iii)Relevance to topic and (iv) Complexity. This narrowed down all the ideas to the Lifting Wheelchair Seat Assist which had the highest average score.

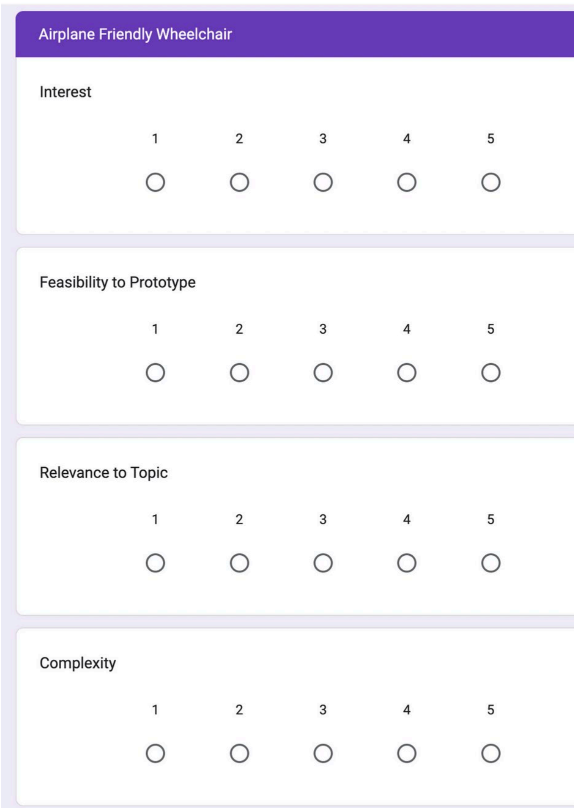
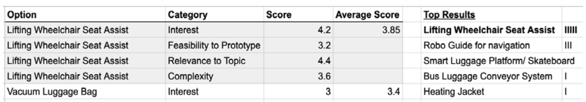


Figure 1: Example of the survey criteria and survey results

C. Concept Description

Based on our chosen concept, we identified an existing problem that requires the use of a lifting wheelchair seat assist. Transferring to and from the wheelchair is one of the most routine tasks for wheelchair users (PwDs). However, these transfers are often a struggle for many PwDs who have to rely on caregivers to lift them out and into their seat. (Risks of caregiver injury in patient transfer, n.d.) The repeated action of having to lift PwDs increases the risk of back pain and/or injury for caregivers. (Risks of caregiver injury in patient transfer, n.d.) As such, having an add-on mechanical device that can be fixed onto the wheelchair would enable caregivers to perform patient transfer safely and more efficiently.



Option	Category	Score	Average Score		Top Results	
Lifting Wheelchair Seat Assist	Interest	4.2	3.85		**Lifting Wheelchair Seat Assist**	IIIII
Lifting Wheelchair Seat Assist	Feasibility to Prototype	3.2			Robo Guide for navigation	III
Lifting Wheelchair Seat Assist	Relevance to Topic	4.4			Smart Luggage Platform/ Skateboard	
Lifting Wheelchair Seat Assist	Complexity	3.6			Bus Luggage Conveyor System	I
Vacuum Luggage Bag	Interest	3	3.4		Heating Jacket	I

Using Fusion 360 CAD software, detailed designs of the lifting mechanism were created which encompasses the seat plates, inflatable mechanism, and connection mechanisms between the top and bottom plates to provide six degrees of freedom. These designs formulated the fundamental framework for the structure and enabled 3D visualization of the components layout on the seat and helped us identify potential design issues before assembling the physical prototype.

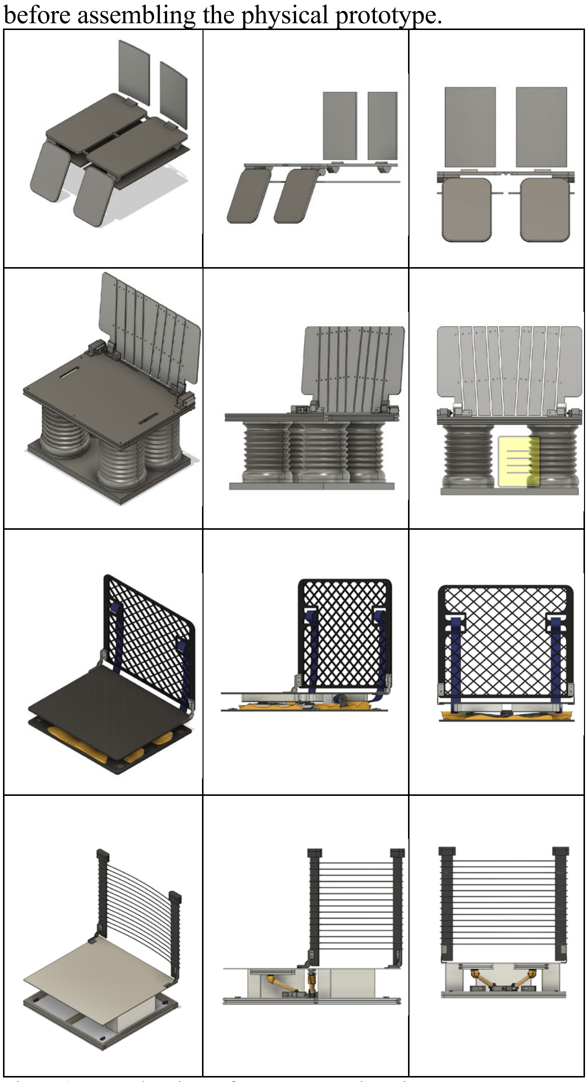


Figure 2: CAD drawings of our prototype iterations

From the CAD drawings, we were able to optimize the arrangement of the 2/2 solenoid valves. This allowed us to determine the ideal distance between each air bag and the 2 air pumps as the tube length would affect the inflation time.

The CAD drawings also enabled us to optimize the size and placement of the inflatable bags at the four corners of the seat as well, and with that we were able to start fabricating the air bags. By considering ease of manufacturing, pressure constraints and space constraints on the seat plate, we conducted a series of experiments with different shapes, including bellow, triangular bellow, trapezoidal and eventually settled on the cuboid shape. The benefits of using cuboid shape are that it provides greatest ease of manufacturing as well as optimization of space. The limitation of this shape however is the pressure build-up at the 4 corners of the bag. But given the construction of the bags was time consuming, ease of manufacturing was of higher priority than pressure or space considerations.

The manufacturing process for inflatable bags made of TPU involves using a custom-made mould to ensure consistent dimensions. The bags are then welded using a steam iron, as other options such as a soldering iron or plastic heat sealer did not yield optimal results. The soldering iron's tip was too hot and the welding area was too small to maintain consistency, while the plastic heat sealer's heating surface area was too narrow. The bags also feature 3D printed threaded inserts that are inserted into circular cut-outs on the bags, allowing for standard m8 tube fittings to be screwed on. This process ensures that the manufacturing of the bags can be repeated, mass produced quickly and suitable for their intended use.

Aside from the hardware design, we also developed the circuitry system which consists of 2 separate sub-circuits in accordance with the placement of electronic components for the prototype. The first sub-circuit is for the 12V DC power supply and air pumps, while the other is for solenoid valves with MOSFETs to turn them on/off.

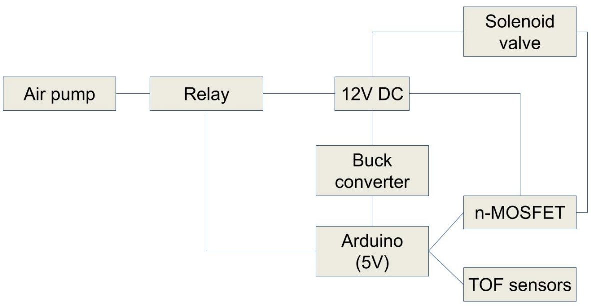


Figure 3: Simplified Schematic Diagram of the full circuit

III. Modelling

A. Component Selection

Assumptions:

Automation

a. Negligible ambient light for TOF sensors.

b. Uniform reflectivity from the top plate.

c. No interference from other IR sources.

Inflation mechanism:

a. Isotropic, adiabatic & homogenous gas distribution.

b. Zero leakage of fluids.

Material Selection:

a. Young's Modulus of Engineering materials is 1000 times lower than that of the ideal materials.

b. Our prototype doesn't exceed the fracture point.

Inflation mechanism:

a. Isotropic, adiabatic & homogenous gas distribution.

b. Zero leakage of fluids.

c. Air is modelled as an ideal gas.

d. We neglect the pressure build-up at the corners.

B. Performance Predictions

Table Head	**Performance table**		
	Parameters	***Predicted***	***Actual***
1	Volume of inflatable	2.1 L	2.1 L
2	Time to inflate 4 inflatables	~40 sec	~ 1.5 min
3	Pressure in each inflatable	~2.5 Bars	~ 2.5 Bars
4	Pressure required to lift the load	112264.39 Pa	~ 1.12 $*10^5$ Pa
5	Pressure at the side walls when fully inflated	112263.45 Pa	~ 1.12 $*10^5$ Pa
6	Inflation height	0.15 m	~ 0.13 cm
7	Battery life	51 mins	~ 43 mins
8	No. of running cycles in a single charge	35	27

Table 3: List of predicted and actual performance parameters

IV. Results

A. Prototypes

The prototype has 12V battery, sensors, logic control, air pump, solenoid valves, inflatable bags, and the seat plates (top and bottom). The inputs and outputs system as well as the logic control are shown in the Functional diagram in Fig. 2.

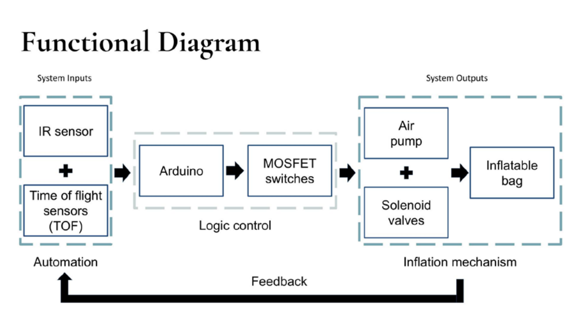


Figure 4: Block diagram of electronic components located in the prototype.

Sensors: The sensors implemented are: VL53L0X Time-of-Flight Sensors to measure the distance between the top and bottom plates of the seat; and the IR sensor to send commands to the Arduino to raise or lower the seat.

Logic control: The Arduino Mega microcontroller is the unit control of the prototype system, which has 54 Digital I/O pins (to provide enough pinouts for all the electrical components as well as 256kB of Flash memory (which is 8x more memory space than Arduino Uno). This is so that the Arduino Mega can handle our large code which uses ____kB of memory due to the Time-of-Flight sensors.
Air pump: 2 Xiaomi Mijia Portable Electric Air Compressor 1S Air Pump were used with a battery capacity of 200mAh and an air flow rate of 15L/min.

Solenoid valves: An inlet and outlet valve are required to control the flow of air into the inflatable bag from the air pump as well as out of the inflatable bag into the atmosphere. As such, each of the inflatable bag uses two 2/2 (2-way-2-position) solenoid valves.

Inflatable bags: The inflatable bags were fabricated using Thermoplastic Polyurethane sheets (TPU) material. Each of the bag was shaped into a cuboid structure to provide the bag with structural integrity and to ensure the bags fit according to the components' layout on the bottom plate.

Seat Plates: Polycarbonate (PC) was used for the rectangular seat plates measuring 43cm(L) x 45cm(W). The top, middle and bottom plates were cut to size using the waterjet machine. The dimensions are such to span the whole seat area of our wheelchair. Polycarbonate was our material of choice due to its affordability, rather high tensile strength compared to acrylic, availability and ease of fabrication. Transparent polycarbonate sheets are used to provide extra aesthetical value to the device, while allowing the user to see through the internal components of the device, hence extra care was taken to ensure the internal components were neatly arranged and organized.

B. Experiments

(i) Tensile Test

The tensile testing experiment was conducted to investigate the mechanical properties of different materials used in our prototype. Two different materials were tested which are TPU and PLA. From performing the Tensile Test, the following properties were determined, modulus of elasticity, yield stress, ultimate tensile strength, percentage elongation at fracture, percentage reduction in cross-sectional area at fracture and fracture stress. The measured values would help us determine whether the material is able to withstand a lot of stress applied on it.

Calculations and Analysis of Results

Specimen: Polylactic Acid (PLA)

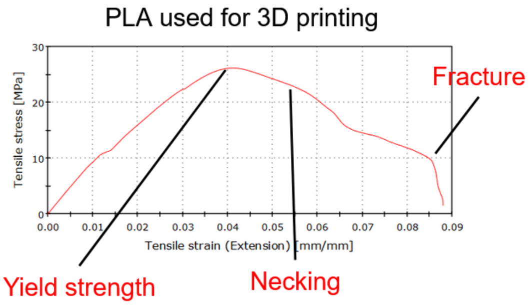


Figure 5: Graph of tensile stress vs. tensile strain of PLA

Yield strength is at 25 MPa. Strain at yield is around 0.02. Ultimate tensile strength (UTS) is estimated as slightly higher than yield strength, approximately 28 MPa. Strain at UTS is estimated to be 0.030. Fracture strain is 0. 085. Modulus of elasticity can be estimated as around 1250 MPa for PLA. PLA shows typical properties of a thermoplastic with clear yield point, UTS and fracture point.

Specimen: Thermoplastic Polyurethane (TPU)

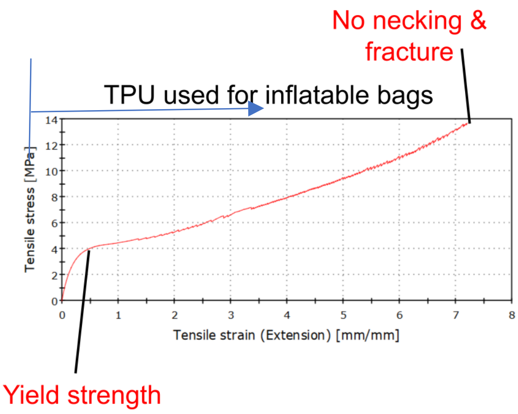


Figure 6: Graph of tensile stress vs. tensile strain of TPU

Yield strength is 4 MPa. Strain at yield is 0.4. Ultimate tensile strength (UTS) is not directly observed as there is no necking or fracture, which is due to TPU's high ductility. UTS cannot be estimated accurately. Fracture strain is not observed as TPU does not fracture within the tested strain limit. Modulus of elasticity can't be determined within the tested strain limit. TPU shows characteristic properties of an elastomer with high ductility, no necking and high failure strain. It yields at a low stress of 4 MPa and large strain of 0.4, indicating high elasticity.

Specimen: Polycarbonate (PC)

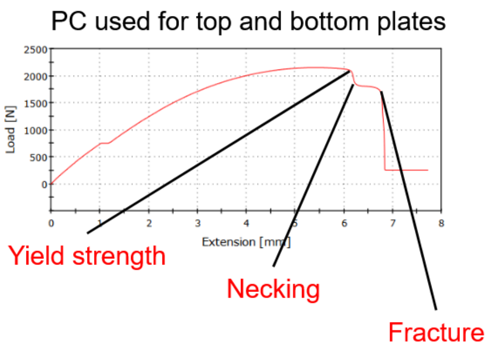


Figure 7: Graph of load vs. extension of PC

Yield strength is at 2100 N. Ultimate tensile strength (UTS) is estimated to be slightly higher than yield strength, at approximately 2200 N. Fracture strain = (6.75mm - 6.25mm) / 6.25mm = 0.08. Polycarbonate shows typical properties of a plastic with clear yield point, UTS and fracture point.

(ii) Heart Rate Monitoring

An experiment was conducted to monitor the physiological exertion involved in transferring a patient using both manual handling and a transfer aid (Lair). Two individuals, weighing 64kg and 50kg respectively, took on the roles of caregiver and patient.

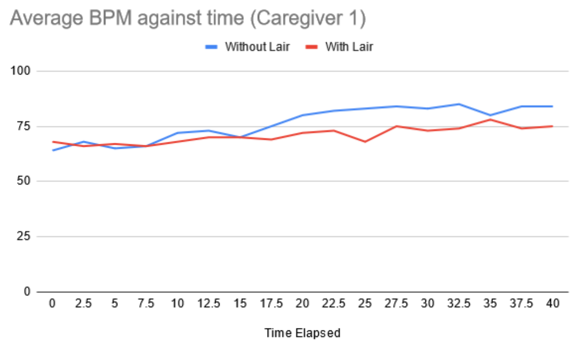
The heavier individual acted as Caregiver 1, attempting to manually transfer the lighter individual, who played the role of the Patient 1, from a regular chair to another place. Caregiver 1's heart rate (beats per minute or BPM) was measured throughout the duration of the transfer, 34 seconds on average, to determine the level of effort required. The BPM was monitored for up to 40 seconds to keep the experimental period consistent.

After a 10-minute rest, the transfer was repeated using Lair. Given that the mechanism Lair could not properly inflate beyond 5kg load, the air bags were fully inflated first before Patient 1 was to be seated. BPM was again monitored over 40 seconds. Each experiment was repeated 3 times with 10 minutes of rest in between to ensure the heart rate returned to unstressed conditions. An average BPM was calculated and plotted against time.

The experiment was then repeated with the participants swapping roles. It took 35 seconds on average, for individual 2 as Caregiver 2 to transfer individual 1 as Patient 2. Caregiver 2's BPM monitored over 40 seconds for both manual and Lair transfers, repeated 3 times with 10 minutes rest periods.

We infer that a higher BPM indicates greater cardiovascular strain and more strenuous conditions. Both caregiver's BPM was expected to decrease with Lair use. However, greater reductions in BPM for the lighter Caregiver 2 would be observed after using Lair.

Calculation and Analysis of Results



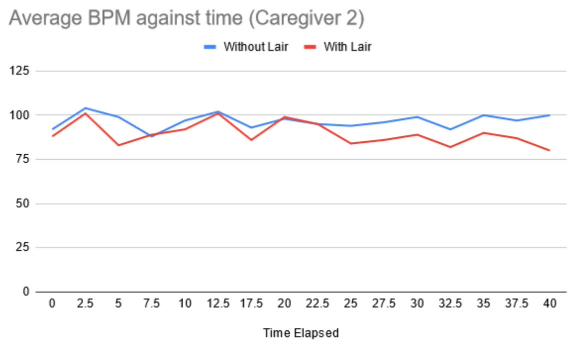


Fig 8 and 9: Comparison of the Caregiver's heart rate with and without Lair

The experimental results show a reduction in average heart rate (beats per minute or BPM) when using Lair for patient transfer compared to manual transfer, indicating lower exertion levels. For Caregiver 1, the average BPM reduced from 76 to 71 upon using Lair, representing a decrease of 6.6%. Similarly, Caregiver 2 saw their average BPM decrease from 97 to 90 when using Lair, amounting to a 7.2% reduction.

A lower BPM signifies that less cardiovascular effort was required for the user to transfer patients from point A to point B. Overall, the Lair system led to a lower physiological workload and reduced stress levels for the Caregivers during patient transfer, as indicated by the decreased heart rate. Lair was thus able to minimize the exertion and strain on healthcare workers.

The decreased BPM, therefore, provides evidence that patient transfer can be performed more easily and comfortably using Lair as compared to manual handling alone. The experimental results clearly demonstrate the benefits of Lair in reducing physical demands and optimizing the well-being of nurses or nursing assistants engaged in patient transport.

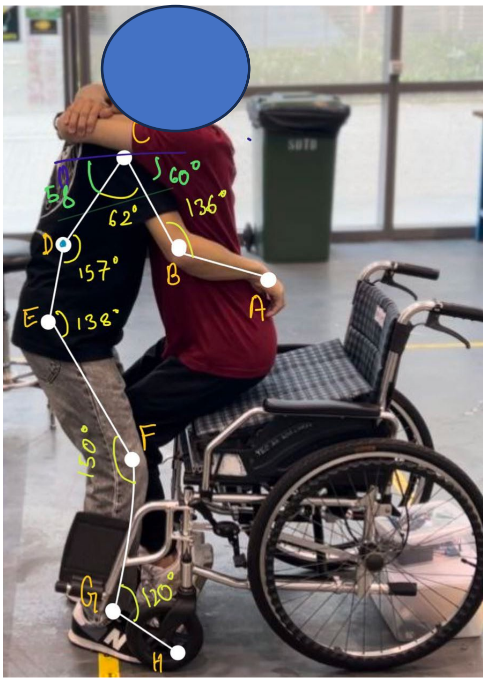
The results provided insights into the reduced exertion from using Lair, as indicated by decreased average BPM and heart rate plots. The larger BPM drops for Caregiver 2 who is transferring the heavier patient,

Patient 2 demonstrate the efficiency gains of Lair, optimizing caregiver workload and well-being.

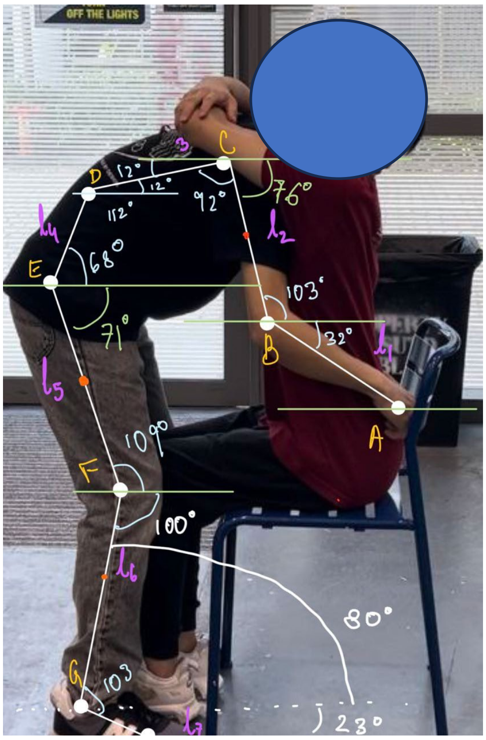
(iii) Time taken for inflation

The time taken was 1 minute and 30 seconds for all four bags to reach 15cm height without a load.

(iv) Torque analysis



With Lair



Without Lair

Figure 10 and 11: Free body diagram of torque analysis on patient transfer with and without Lair

Our patient weighs 529.74 N while the caretaker weighs 588.6 N. By calculating the torque at D with and without Lair, we find a reduction of 20 Nm when the caregiver uses our prototype Lair. This reduces overexertion from repeated patient transfers.

V. Discussion

Our first performance prediction was that the volume of the inflatable bag would be 2.1L. To test this prediction, we filled the inflatable bag with water and measured the volume of water poured out, which was found to be 2.1L. This confirms that the inflatable bag is properly sealed, as there are no leaks that would cause the volume to be different than predicted. This ensures that the inflatable bag will be able to properly lift the intended weight without any air leaks. Another performance prediction was that the inflatable bags should be able to lift at least 70kg, based on their ability to withstand an internal pressure of 1.12x10^5 Pa when a 70kg weight is loaded. However, our experimental results showed that the bags can only support a maximum weight of 5kg, well below the predicted capacity. This indicates that there may be leakage occurring when the bags are loaded beyond 5kg, preventing them from fully inflating and supporting the weight as predicted. This finding has significant implications for the accuracy/reliability of the experimental results, as the mechanism had to be fully inflated first before the user was seated and then lifted, instead of our intended use of the mechanism being able to inflate while the user was already seated. Secondly, this has also significant implications on the intended environment of our system it suggests that the current design of air bags may not be suitable for lifting heavier loads and may require further optimization in terms of fabrication methods to improve its weight bearing capacity. On top of that, the actual inflation time of 1min 30s exceeded the predicted inflation time of 40s, which suggests that there is also room for improvement in the use of an air pump with a higher flow rate to speed up the inflation process.

VI. Conclusions

In conclusion, our project aimed to address the issue of overexertion injuries in caregivers of persons with disabilities (PWDs) by automating the lifting process. The results of our experiments demonstrate that our modular prototype, which automates the lifting up and down process up to 15cm in height, can reduce the effort required by caregivers and the risk of overexertion injuries.

We designed the prototype to be adaptable to most wheelchairs without complications and to be lightweight, making it accessible to a wider range of users. The use of Time-of-Flight sensors and a 6-degree of freedom system architecture enhances the performance of the prototype, ensuring a smoother lifting experience.

Our experiments included tensile testing on the inflatable TPU bags, which showed that they are durable and reliable, and user surveys and heart rate monitoring tests that confirmed the comfortability of the product and the effectiveness of the lifting automation in reducing caregiver effort.

Our project has the potential to significantly improve the quality of life for PWDs and caregivers in Singapore's aging society. By reducing the risk of overexertion injuries, caregivers can provide better care to their patients without compromising their own health. Our prototype offers a practical and cost-effective solution to the problem of lifting and transferring PWDs.

In the future, further refinement and testing of the prototype will be necessary to ensure its effectiveness in real-world scenarios. However, our experiments provide a strong foundation for the potential success of the product, making it a promising solution to an important issue.

VII. Appendix

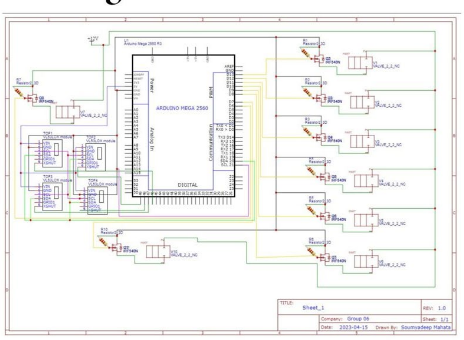
Schedule

Week 1 - 3	• Brainstorming • Idea selection
Week 5 & 6	• CAD • Mechanism selection
Week 7	• Purchase components • Contact sellers • Material selection • Start manufacturing bags
Week 8 & 9	• Refining prototype model • Finalizing concept • Decide functional requirements • Assembled first inflation mechanism • Inflation experiments
Week 10 & 11	• Finalised bag manufacturing methods • Assembly of prototype • Coded logic for Arduino • Sensors testing • Circuitry testing • 3D integration brainstorming
Week 12	• Finalised component placement • Assembly of prototype • Experiments
Week 13	• Final debugging & testing • Review preparation • Poster & term paper

Budget

Inflating mechanism	• Pump • Iron	• Valves & tube fittings • Inflatable bag materials	SGD 603.07
Backrest	• Hinges	• Stepper Motors	SGD 91.81
Electronics	• IR module • MOSFETs	• Relays • Buck Converter	SGD 190.59
Electricity and Power	• Batteries • Cables	• Connectors	SGD 89.88
Housing & casing	• Containers	• Insulation	SGD 11.25
Props	• Wheelchair	• Cushion	SGD 70.78
Miscellaneous	• Glue, tape, Magnetic Sheet, etc.		SGD 22.85
		Total Spent:	SGD 1080.23

Schematic Diagram



VIII. References

[1] *TELEKELO, K. E. B. A. L. E. B. I. L. E. O. T. E. N. G.* (2016, February 8). College Of Engineering and Technology CETG 211 Experiment Lab Report 1 TENSILE TEST. Retrieved April 21, 2023, from https://www.researchgate.net/publication/300065454_Tensile_Test

[2] https://myuplyft.com/blog/risks-of-caregiver-injury-in-patient-transfer

[3] *Average height for men and women worldwide*. Worlddata.info. (n.d.). Retrieved April 22, 2023, from https://www.worlddata.info/average-bodyheight.php

[4] *Risks of caregiver injury in patient transfer. UpLyft®*. (2023, January 24). Retrieved April 21, 2023, from