Smart Hoist: An Assistive Robot to Aid Carers

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***Abstract*—Assistive Robotics(AR) is a rapidly expanding field, implementing advanced intelligent machines capable of working collaboratively with a range of human users; as assistants, tools and as companions. These AR devices can provide assistance to stretched carers when transferring non-ambulatory patients safely.**

This paper presents the preliminary outcomes of the design, development and implementation of a patient lifting AR device, Smart Hoist. This device, an enhanced conventional patient lifter (standard hoist), is fitted with several sensors capable of interacting with the device operator and its environment, and a set of powered wheels. The assisted manoeuvring functionality of the Smart Hoist may help reduce prevailing lower back injuries among the carers while improving the safety of carers and patients.

Results collected from an evaluation of the preliminary version of the Smart Hoist conducted at the premises of IRT Woonona residential care facility confirms the system is easy to use and it reduces the effort of the operator, which may help in reducing lower back injuries.

I. Introduction

Global ageing, the rapid increase in the global population over the age of 65, in developed and developing countries is one of the greatest social and economical challenges for our society [1], [2]. In 2010, an estimated 524 million people (eight percent of the world's population) were aged 65 or older. By 2050, this number is expected to nearly triple to 1.5 billion, which represents 16% of the world's population. In Australia, where this research was conducted, there were 3.22 million people aged 65 years and over in June 2012, accounting for 14% of the total population [3].

As people age, their capability in performing daily living activities can lessen due to cognitive and physical impairments. Demographic trends in Australia indicate a continued decline in the relative availability of informal carers, coinciding with an increased demand for aged care services [4], [5]. Increases in the public costs of care [1], [2] for seniors is inevitable, given their greater longevity, reduced number of informal carers, and increased community expectations.

It is a well-known fact that there is a high injury rate experienced by carers and non-ambulatory elderly residents at residential aged care facilities when performing transfers (eg. bed to chair, chair to toilet and bath). It is imperative that residents and carers in aged care facilities have access to affordable new systems which would inevitably improve the quality of care. A report by the Academy of Technological Sciences and Engineering titled "Smart Technology for Healthy Longevity" [6], [7] canvassed various options based on the use of innovative technologies to address this challenge.

A new technology based on the principles of "Assistive Robotics"(AR) is now emerging. Assistive robots are able to work collaboratively with a range of human users; as assistants, as tools and as companions. These machines are able to perceive and understand human behaviour and needs, communicate with users in a human-centred manner, and respond safely and efficiently to directions. Although machines for assisting users in performing difficult tasks have been already adopted in many industry sectors, they are not yet prevalent within the aged care sector.

Advances in artificial intelligence and robotics gives rise to increasing opportunities to implement AR devices to assist senior citizens in their daily living activities and carers in safely performing their duties without being overly exhausted [8]. These technologies are becoming crucial given the aging population and the decrease in the number of working age caregivers [9]. In general, AR devices in an aged care setting fall into three broad categories; (a) devices for residents [10][11] (b) devices for formal carers [12] (c) devices for families of the residents [13].

This paper reports early research and engineering outcomes of an AR device designed to assist stretched carers at residential aged care facilities to reduce the physical strain on them. A typical carer's work shift involves several non-ambulatory resident transfers which are physically demanding for most of the carers. This device assist in performing such activities with ease which may have a positive impact on their capacity and quality of their work. A Joey™ Lifter ('Standard hoist') from AIS healthcare Pty. Ltd as seen in Fig 1 has been transformed into an AR device ('Smart Hoist', Fig. 2) with the primary aim of reducing the physical strain experienced by carers while transferring non-ambulatory residents in aged care facilities and reduce the likelihood of lower back injuries.

A key outcome of this work is that the Smart Hoist should operate in a manner similar to its conventional counterpart, just as brakes found in modern motor vehicles function similarly to those built generations ago, yet possess intelligent controllers in order to enhance safety. The intelligence imparted into the Smart Hoist will enable carers to perform different types of manoeuvres with ease. For the general user, the Smart Hoist can be considered as a standard hoist equipped with sensors capable of interacting with the operator and its environment (detecting its surroundings, for example the location of the bed,

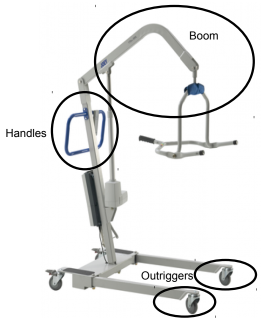


Fig. 1: Standard Joey™ Lifter from AIS healthcare Pty. Ltd.

bath or other residents), and a set of powered rear wheels. This enables the carer to direct the hoist as desired while the system automatically provides physical and navigational assistance through a computer-based decision-making system. This will greatly improve the safety and comfort for the resident, and the safety and confidence of the carers.

II. Smart Hoist System

Existing hoists used in aged care, although they have assisted lifting, consist of four unpowered caster-wheels, hence manoeuvring is manual and requires significant effort when loaded. As a result of this, a growing number of back injuries are reported amongst carers.

In order to understand the shortcomings associated with the manoeuvring of a standard hoist as experienced by the carers, the research team collaborated with the IRT Research Foundation, Wollongong, Australia. As a part of several co-design workshops, series of discussion forums were conducted involving the IRT facility management, residential carers and residents at IRT Woonona care facility to develop a set of design guidelines for the Smart Hoist.

Assisted manoeuvring proved to be the most important feature of the Smart Hoist. It was requested that the method of manoeuvring should remain the same as the current standard hoist as per social and ethical concerns. Additionally, following features were suggested by the forum participants and were agreed to be included in the Smart Hoist system.

- Weight measurement of the subject on the hoist.
- Ability to monitor the environment under furniture(esp. beds).
- Rear view mirror to monitor the environment behind the users whilst reversing.

A. Sensors

1) Handles: The handles of the hoist consists of four strain gauge installations, each in a full-bridge configuration. Each handle contains two bridges, the first pair measures torsion along the mounting axis of the handle as shown in Fig. 3a, the other pair measures the deflection of the handle up and down along the top fixed axis, which is effectively a sideways force on the handle (Fig. 3b). The location of these sensors were selected to obtain an optimal stain reading by performing a Finite Element Analysis (FEA) of the handle structure. In contrast to the standard hoist, the handle is disjointed in the middle to prevent strain transmission from one side to the other.

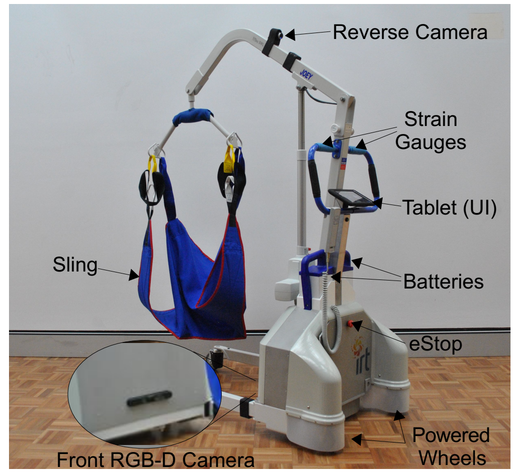
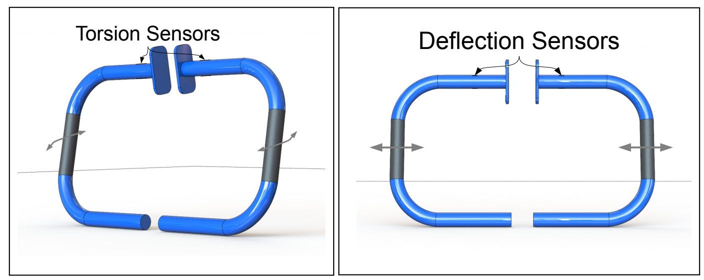


Fig. 2: UTS-IRT Smart Hoist [14].



(a) (b)

Fig. 3: (a) Torsion sensor pairs for detection of forward and backward forces. (b) Deflection sensor pairs for detection of sideways forces.

2) Cameras: There are two cameras attached to the system. A High Definition RGB camera at the top of the boom (Fig. 4b) to act as a rear view camera to aid when reversing the hoist, and a RGB-D sensor at the bottom of the hoist. This camera is useful when manoeuvring the hoist in confined spaces and avoiding objects which are commonly found under the beds of residents. Currently the RGB-D camera is also used in navigation assistance [14]. It is also planned to be used in future work related to autonomous navigation.

3) Boom: Weight measurement and the Body-Mass Index(BMI) calculation is an added feature that is generally not present in the standard hoist. As shown in Fig. 4 strain gauges were placed at an optimal location that yeilded the highest strain, determined by performing a FEA of the boom structure.

The strain gauge readings at a given height of the boom can be approximated to have a linear relationship with the weight in the sling. The weight can be estimated at a maximum error of about two percent after proper calibration.

The velocity controller also uses the weight measurements in its logic.

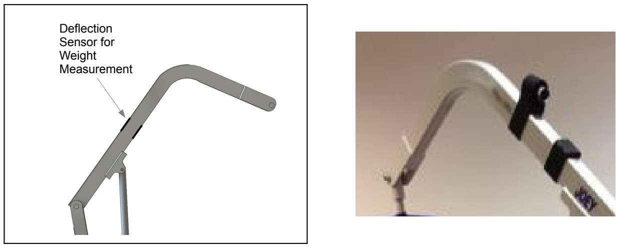


Fig. 4: Strain gauge location on the boom for weight measurement.

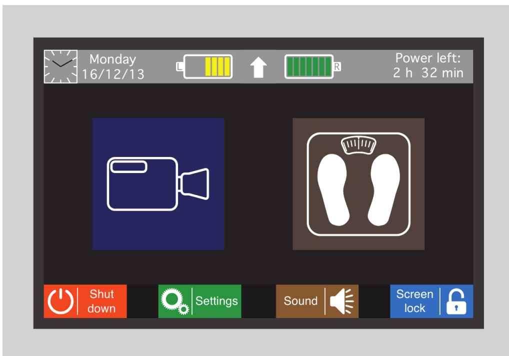


Fig. 6: User Interface of the Smart Hoist, the main screen.

B. Actuators

The standard system is factory fitted with two actuators, one controlling the lifting of the boom and the other one controlling the outriggers. These actuators were retrofitted with encoders to monitor their location which is required in weight measurement. In addition to these the rear wheels of the Smart Hoist were replaced with a pair of powered castors shown in Fig. 5. The wheel is 360° steerable and uses the Revolution 2™ assembly from 221 Robotic Systems [15].

C. The User Interface (UI)

For the purpose of interacting with the carers and displaying critical information of the system, such as battery level and other status/error messages, a UI has been included with the Smart Hoist.

As Android is readily interoperable with Robot Operating System (ROS), a Google® Nexus 7 - 2012 Tablet running Android version 4.3 has been used for the interface. The Tablet is tethered to the Hoist PC using USB to ensure a reliable connection to the host. The kiosk mode UI (Fig. 6) of the Smart Hoist is kept simple and intuitive, allowing users to interact with it easily. The design, development and implementation of the GUI also adhered to the corporative design approach.

D. Hoist PC

An Intense PC™[16] is included in the Smart Hoist as the main processing platform (Fig. 7). It is equipped with an Intel® Core™i7 processor running at 2.8Ghz with 4GB of RAM. The underlying operating system is Ubuntu 12.04LTE and ROS version Fuerte Turtle.

Fig. 7: Motor controller (left) and the Hoist PC (right) assembly.

E. Peripherals

1) Hoist Controller: A propitiatory embedded controller board was designed and built based on a Microchip PIC24 micro-controller, for low level hardware monitoring, power management, interfacing with other hardware (detecting e-Stop status) and data acquisition from the strain gauges. The Hoist Controller is interfaced to the Hoist PC via USB interface and it streams data frames at 10Hz to the Hoist PC.

2) Motor Controller: A Sasquatch controller from 221 Robotics Systems based on Atmel® AtMega 2560 Micro-controller is used for controlling the motors (Fig. 7). It receives information from the Hoist PC at 10Hz through an Ethernet interface. The velocity and steer angle of each individual motor are the input to the Motor Controller.

3) Batteries and Uninterrupted Power Supply(UPS): The Smart Hoist was designed to have two $LiFePO_4$ Batteries of $\approx 26V$, which weigh $\approx 4.5kg$ (Fig. 11). This chemistry was specifically chosen to increase the life span of the batteries. When both batteries are fully charged the Smart Hoist has a standby time of more than 12 hours and about 5 hours when it is in operation.

A super-capacitor UPS was included to supply power to the Hoist PC and other critical components for approximately three minutes in-between battery changes.

III. Design Challenges

A. User Intention Recognition

The main design consideration of the Smart Hoist was to ensure that the manual control of the Smart Hoist remains the same as that of the standard hoist. For any changes in the manoeuvring pattern, the methodology should be intuitive enough that the users can adapt to it with minimal effort.

1) Sensing: Main user input to the system is captured via the handles of the hoist. When the user tries to manoeuvre the Smart Hoist, forces are exerted on the handle in a similar manner to the standard hoist.

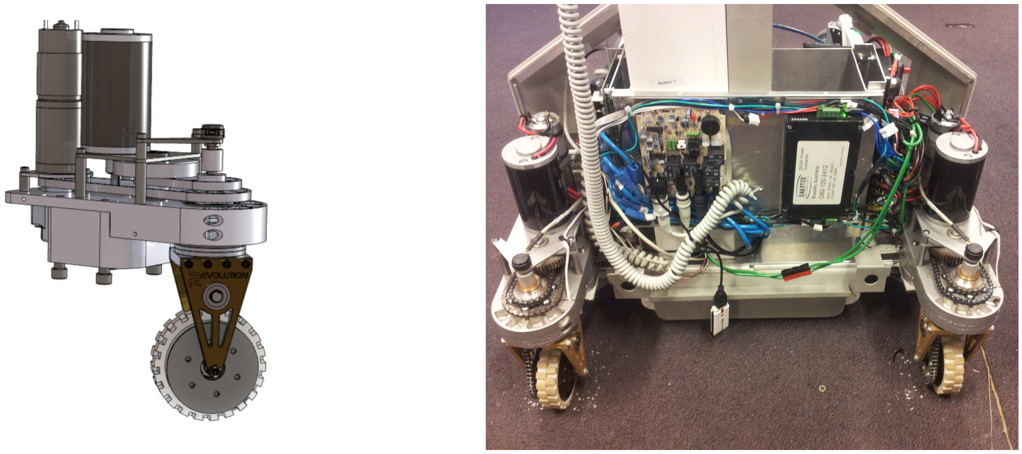


Fig. 5: Revolution 2™ omni-directional crab drive motors from 221 Robotic Systems, and how they're retrofitted to the Smart Hoist.

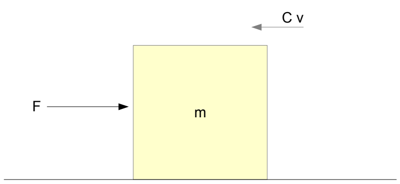


Fig. 8: Simplified force model

Although strain gauges are incorporated in this design, tactile sensor arrays can be an alternative solution in detecting user intention. The advantage of using tactile arrays over strain gauges is that the measurement is related to the pressure applied to the sensor and not the deflection of the member upon which it is attached, allowing further flexibility in its applications. In [17] it was shown that through the implementation of a multi-class support vector machine (SVM) it is possible to predict the user intention in two dimensions using a handlebar equipped with uniaxial tactile arrays. However, this approach requires further analysis before it can be reliably incorporated into the Smart Hoist.

A simple admittance control strategy has been adapted to convert strains into velocities. Fig. 8 represents a simplified force diagram. When a force of F is exerted on the handles of the hoist, a collective opposing force of Cv is applied when the system moves at velocity v. If it is assumed that the mass of the system m and the parameter C are fixed, the response of the system would be identical whether or not the system is loaded. As the momentum of the system is conserved (1) can be formed, giving the first order system (2), which can be discretized to (3) at instance k.

$$F - Cv = m\dot{v} \tag{1}$$

$$H = {}^{v}/_{F} = \frac{{}^{1}/_{C}}{({}^{m}/_{C})s + 1} \tag{2}$$

$$v_k = \frac{F_k + m.v_{k-1}}{m + C} \tag{3}$$

2) Motion Patterns: One of the major challenges in the system was to identify the motion patterns that are required for everyday use of the Smart Hoist. A standard hoist has four omni-directional caster wheels (Fig. 1) which gives the user the ability to manoeuvre it in any direction. Due to the limitations of the Smart Hoist system as described in Section III-B and for the ease of operation in this preliminary model it was decided to support only the major motion patterns which are categorised as follows,

- Forward & Backward motion
- Turn Left & Right during above motions (Variable turn angles)
- On the spot rotations, Clockwise & Counter Clockwise
- Side-to-Side motion, Left & Right
- Arc Forward & Backward during Side-to-Side motions (at variable arc radius)
- Diagonal motion (at varied angles)

3) Mapping User Intentions: The direction of the applied force on each handle is the main contributing factor in distinguishing the motion patterns. The four forces that are recognised using strain gauges are converted into linear velocities v_x, v_y in directions x, y, and an angular velocity, ω in the z axis. Table I presents how the motion patterns are recognised using these values.

TABLE I: Motion Classification

Motion Pattern	v_x	v_y	ω
Forward & Backward	$v_x \neq 0$	$v_y = 0$	$\omega = 0$
Turn Left & Right	$v_x \neq 0$	$v_y = 0$	$\omega \neq 0$
On the spot rotations	$v_x = 0$	$v_y = 0$	$\omega \neq 0$
Side-to-Side motion	$v_x = 0$	$v_y \neq 0$	$\omega = 0$
Arc during Side-to-Side	$v_x = 0$	$v_y \neq 0$	$\omega \neq 0$
Diagonal motion	$v_x \neq 0$	$v_y \neq 0$	$\omega = 0$

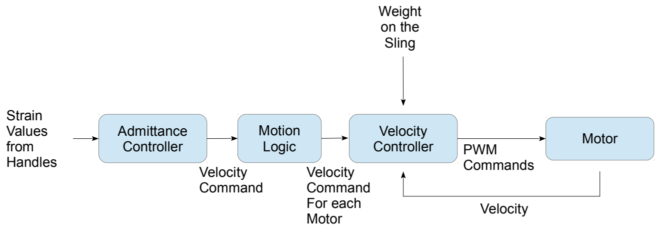


Fig. 9: Flow diagram of the Controller.

In the case of ideal readings the above equalities should hold. However, due to the presence of noise in the strain gauge readings, suitable thresholds are empirically determined by analysing the forces exerted to perform each motion pattern.

The Fig. 9 represents the flow diagram of the control subsystem. The final individual velocity for each motor is the output of the motion logic block. This output velocity is then fed into the velocity based motor controller which takes care of the low level velocity control.

B. Steering & Motor Control

Steering the Smart Hoist has proven to be a key design challenge, as the wheels of the standard hoist are able to steer full circle, and the casters were also omni-directional, the initial intention was to use kinematic steering to steer the hoist. Fig. 10 represents the wheel directions and velocities while performing such steering. Here the exerted force on the left and right handles, F_L and F_R is captured and converted to velocities v_x, v_y and ω. Motion logic then generates the individual wheel angles and velocities, v_L and v_R to suit that motion pattern.

Due to the limitations of the Revolution 2™, the speed of steering was not fast enough to cope up with sudden direction changes. This version of the Smart Hoist uses differential steering, which is achievable quickly by having different wheel velocities without the need of wheel steering. However, differential steering restricts the centre of rotation to the wheel axis, therefore the flexibility to rotate the hoist about any point is lost.

Side-to-Side Motion: Due to limitations such as the slow speed of steering, turning the wheels from forward direction to 90° can take up to 1 second at full steering speed. Wheels rotating while steering results in undesirable actions, such as circular motions. To mitigate this, a constraint was introduced into the motion of the wheels where the admittance control system is overridden until the wheel has reached the desired angle of 90°.

C. System Assembly and Enclosure Design

The enclosure forms part of the Smart Hoist that houses the majority of hardware components including the Hoist PC, the Hoist Controller, the Revolution 2™ motor assemblies, the Sasquatch motor controller, the Batteries and the UPS.

Since a standard hoist was used as the basis upon which to build the Smart Hoist, space was limited. This meant the

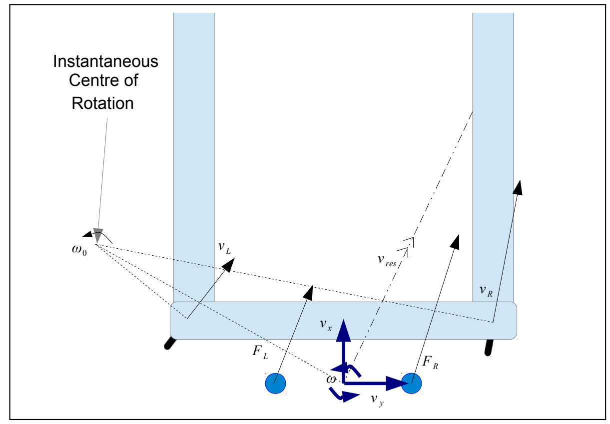
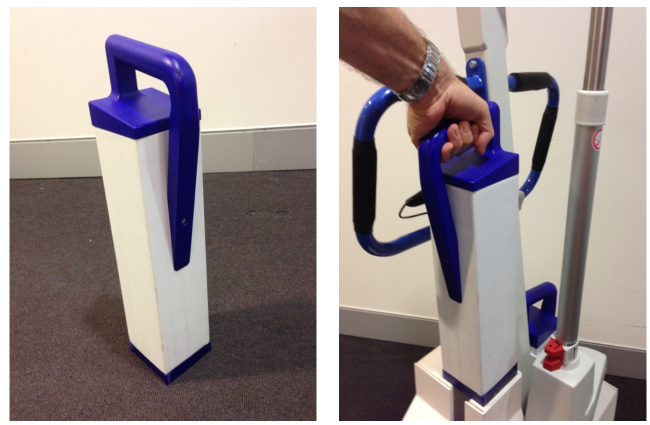


Fig. 10: Birds Eye view of the hoist, force on handles and velocity directions for steering.



(a) (b)

Fig. 11: Batteries used in the Smart Hoist.

enclosure housing the hardware components needed to be compact and provides its own structural integrity to support all hardware components. Having an Ingress Protection rating of X4 (IPX4) for the enclosure was an additional design consideration.

The majority of the design process was centred around the batteries. After estimating the power budget, it was deduced that 16 cells are required for a usage cycle of ≈ 5 hours per charge. As a result, the batteries were split into two packs (Fig. 11a) which were designed to be manageable in weight and easily inserted and removed from the Smart Hoist (Fig. 11b).

The design of the enclosure and placement of hardware components were planned and mapped in Solidworks™. A physical framework was then constructed using Aluminium. All remaining hardware components were mounted to this framework and wired. The external shell of the enclosure was then physically modelled in cardboard and Foamex™ for the initial iteration and the final version of the enclosure was manufactured in Polyamide using an additive manufacturing process called Selective Laser Sintering (SLS).

D. Occupational Health and Safety

1) Foot-guards: As the Smart Hoist uses powered motors it is extremely important to restrict accidental access to the powered wheels or caster wheels. Though covered foot wear is a mandatory requirement for carers at IRT, for extra safety foot guards were added to all wheels.

2) Maximum Run Speed: The maximum speed of the motors were limited at the Motor Controller firmware level to avoid the propagation of any undesirable velocities. Steps have also been taken to shutdown the motors in the event of critical failure scenarios (eg. motor controller loses communications with the Hoist PC) .

3) Braking: The Revolution 2™ motors were modified to have electro-mechanical brakes that would get engaged whenever there are no forces on the handles. This ensures the stability of the Smart Hoist and prevents the hoist from rolling while loading and unloading heavy subjects.

4) Emergency Stop (eStop): As with most industrial devices Smart hoist is equipped with an eStop Button that can be engaged in an emergency. This button immediately disconnects power to the actuator systems. The electro-mechanical brakes are automatically applied in this scenario and can be manually disengaged if necessary.

IV. Evaluation & Discussion

A. User Trials

After completing the development of the pilot device and obtaining the necessary research ethics approvals from IRT and UTS Human Ethics committees, two rounds of trials were conducted at IRT Woonona care facility (Fig. 12). A total of about 60 carers participated in these trials. After being inducted they were each asked to perform simple and complex manoeuvres, similar to those they perform in their everyday work with a standard hoist. Feedback was recorded on all aspects of the system, including system design, placement of camera and UI elements.

Feedback received from carers during the design stage and the user trials was extremely valuable in the development of the Smart Hoist. Most users were able to perform the complex manoeuvring tasks on their first attempt confirming that the device is easy and very intuitive to use [14].

However during these trials many carers were not comfortable with the one second delay that the wheels take to engage the side-to-side mode from the normal forward-backward mode caused by the slow steering speed on the Revolution 2™ motors that were used in the system.

B. Experiment

An identical standard hoist frame was used in parallel with the Smart Hoist for comparison. The handles of the standard hoist were also populated with strain gauges to measure the forces exerted on the handles. A few simple tasks were performed using the same load of $\approx 75kg$ (i.e. same patient) on both hoists and the forces on the handles were recorded. Both hoists were manoeuvred on the same floor.

Tasks performed include;

(a) (b) (c)

Fig. 12: User trials conducted at IRT Woonoona, Australia. [14]

- Push the hoist.
- Pull the hoist.
- Rotate the hoist on the spot, Clockwise and Counter-Clockwise.

The comparisons presented in Fig. 13a and Fig. 13b show that the standard hoist requires a force of more than $40N$ per handle to perform push and pull operations, while the Smart Hoist only requires a force less than $30N$ on per handle to perform the same action. Similarly it can be seen that performing an in-place turn on the standard hoist requires a much higher force confirming comments received from the IRT carers. It can be seen that the Smart Hoist can perform this in-place rotation task with much less effort.

V. Conclusion

This paper describes an AR device that was developed by the University of Technology, Sydney, with the aim of reducing workplace injuries that could be sustained by the care workers in the aged and disabled care facilities when transferring non-ambulatory residents (eg. bed to chair, chair to toilet and bath). Every aspect of the Smart Hoist was developed following the co-design principles with the active involvement of the actual end user at every stage of the development. Though it is an extension of a standard hoist, apart from being motor driven, the Smart Hoist also has a number of attractive features.

Similar to a standard hoist, the Smart Hoist is operated by applying forces on its handles. This intuitive control system allows the users to seamlessly migrate to the Smart Hoist without an added learning curve that is associated with most AR devices.

Further evaluation for benefits of assistance using Electromyography (EMG) readings of the major muscles involved in manoeuvring the hoist is planned to be conducted in the forthcoming extended user trial. User feedback would also be rigorously analysed during this trial.

Future work for the Smart Hoist includes change of the wheel design (with high-speed steering, decreased friction with the floor while steering) and improvement of the control logic and navigation assistance which takes the information from the RGB-D sensor into account. The viability of the use of uniaxial tactile arrays in combination with the strain gauges to capture the user intention would also be considered in the future.

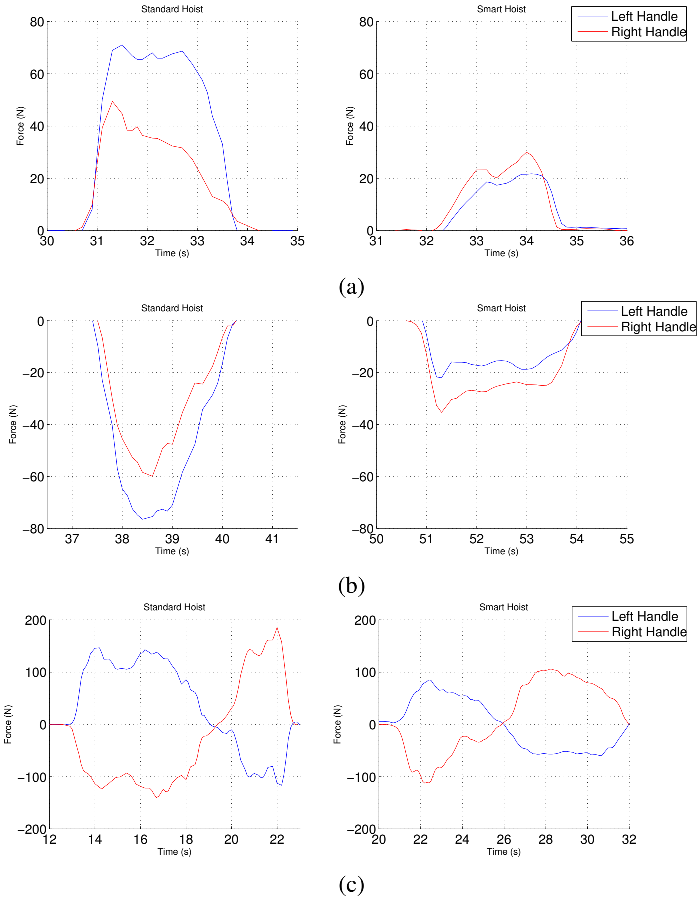


Fig. 13: Comparison of the forces required to do (a) Push, (b) Pull and (c) In-place Turn on the standard and Smart Hoists.

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