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IFAC PapersOnLine 52-25 (2019) 125–130

Cost Oriented robotic arm optimised to aid independence.

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Abstract: The aim of this research was to improve the quality of life of a wheelchair bound client living with muscular dystrophy by enabling her to perform tasks which most people take for granted, such as drinking independently. Due to the client's limited movement of her arms and neck, she was unable to lift a cup to her own mouth. To aid her in this endeavor, three different low-cost mechanical assistive concepts were created. These were presented to the client and the most suitable option was chosen to develop. Work then began on a functional prototype which was manufactured for under the 200 euro.

Keywords: Cost oriented robotics, assistive technology, ethics, mechanical engineering, automation, biomedical systems.

1. INTRODUCTION.

A service robot is a robot which operates semi or fully autonomously to perform services useful for the well-being of the humans and equipment, excluding manufacturing operations (Kopacek, 2015). As part of an undergraduate manufacturing engineering honours degree program, based in Waterford Institute of Technology Ireland, students are encouraged to use low cost automation and technology to improve the quality of life of individuals. Ethical considerations need to be part of the project specification. They can put boundaries on the scope of the project or add to the overall vision. Both the technical and moral elements need to be considered together for a holistic design. "Robotics unifies two cultures: Science and Humanities. The effort to design Roboethics should make the unity of these two cultures a primary assumption. This means that experts shall view Robotics as a whole." (Kopacek, 2018).

With recent advancements, and the increase of possibilities in area of assistive technology products, it can be considered to be a progressive and exciting field of engineering. According to a study conducted in 2012 by the Central Statistics Office of Ireland there has been a significant increase in the number of Irish citizens living with disabilities. The report concluded that approximately 600,000 people in Ireland are living with some form of disability and 244,000 people living with a condition that substantially limits basic physical activities; this shows an increase of almost 5% over a six-year period. (CSO, 2012) This community-based project involves the research, design and construction of a customised robotic arm for a wheelchair user with restricted movement due to the degenerative muscle tissue disease, muscular dystrophy. The user's needs and limited range of movement were taken into consideration to ensure that all demands are met. The final product should enable the user to perform basic tasks such as eating and drinking and the additional tasks of controlling an iPad.

2. RESEARCH AIM AND QUESTIONS.

The aim of this research project is to design and build a cost oriented robotic arm prototype, optimized to aid independent living. The research questions posed are the following:

Q1 Is it feasible to develop an assistive device at undergraduate engineering level?

Q2 How can the client's needs and requirements be established for the device?

Q3 Can a modern technology be used to produce a low-cost working prototype?

Q4 What are the ethical implications?

3. BACKGROUND TO THE PROJECT.

The term "assistive technology" (AT) applies to a wide range of products designed to improve the physical capabilities of a person living with disabilities. Modern day assistive technology products range from low-tech devices such as pointing aids, to high-tech devices such as prosthetics and communications systems. AT products compensate for a wide range of disabilities transforming the way in which

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10.1016/j.ifacol.2019.12.459

many people live their lives by making the impossible possible. Assistive technology can:

- Allow the user to live their life in accordance with the United Nations Convention on the Rights of Persons with Disabilities.
- Allow the user to carry out everyday tasks at home and in the community.
- Support and encourage the user to achieve their educational goals.
- Allow the user to achieve employment.
- Support the user in becoming digitally literate.

The recent advancements, made in both technology and materials, have allowed for a drastic increase in product abilities and quality. Figure 1 shows a timeline of notable advancements in assistive technology over a period of approximately the last century.

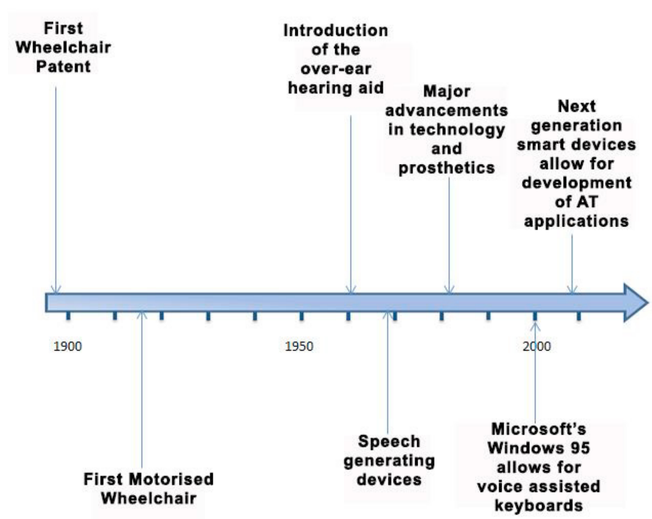

Figure 1. Advancements in assistive technology.

According to Kopacek and Hersh "until now robotics was a discipline based on: Mechanics, Physics, Mathematics, Automation and Control, Electronics, Computer Science, Cybernetics, Artificial Intelligence… Therefore, robots are frequently used as examples for Mechatronic Systems. For Roboethics nontechnical fields e.g. Philosophy, Ethics, Theology, Biology, Physiology, Neurosciences, Law… have to be added." (Hersh, 2015).

This project was split into two sections, the first involved identifying the needs of the client and collecting anthropomorphic data to ensure optimum results. Early design concepts were drawn up using SolidWorks, a three-dimensional (3D) design software. Prototypes were manufactured by means of 3D printing and tested to ensure functionality and safety. Several robot types were considered including jointed arm and cylindrical models but the S.C.A.R.A configuration was found to be the most suitable. It most accurately replicated the movement, abilities and aesthetics of a human arm whilst forming a compact unit when not in use.

The second section involved consulting with the client to present the prototypes and demonstration models. At this point the most suitable model was selected by the client and manufacture of the working prototype began. The movement of the robotic arm would be controlled with two joysticks as this was determined to be the optimum method of control by the client. DC motors supplied movement to the arm, servo motors were chosen in conjunction with an Arduino board for control to ensure high accuracy, repeatability and speed control. 3D printing and metalworking were utilised to produce the final product.

Finally, the robotic arm prototype was tested by the client and feedback analysed.

4. ETHICS AND ASSISTIVE TECHNOLOGY.

Hersh in 2015 said that "it has been suggested by Martin and Schinzinger (1996) that engineering should be treated as social experimentation. This has the advantage of making explicit the importance of informed consent. Informed consent also requires genuine understanding of the level of risk for benefits. In some cases, the general public has a very different attitude to risks from experts or regulatory bodies. Individuals are generally more willing to accept the risks from new technologies if they see obvious benefits." (Hersh, M., 2015)

In the case of this academic study from the start the client was consulted with, and, it was established that the results of this work would be a working prototype. The client and her Carer, (as the client was under 18 years of age at the time), were asked for consent so that certain information could be gathered. In addition, it was explained that there was no guarantee that the prototype would meet the needs of the client, as set out in the specification. The students could not predict if there would be unexpected consequences to using this assistive device and these could be either be positive or negative. The study followed the guidelines outlined by Hersh in 2015 "Responsible experimentation would require informed consent by all participants. The implications of the ethics of experimentation for assistive technology research include the following:

1. The importance of involving disabled people in the development of new assistive technology products, as part of the ethical responsibility for ensuring that the resulting devices do meet the needs of the group of disabled people they have been designed for and are likely to enhance their lifestyles.
2. Recognition that new assistive technologies can have unexpected and unforeseen consequences on the lives and social relationships of disabled people and their families and friends and personal assistants. There is an ethical responsibility to take these unexpected consequences into consideration.
3. The importance of not pressurising groups of disabled people to participate in questions or user studies on new

assistive devices." (Hersh, M., 2015). All the above was agreed before the study went ahead.

5. METHODOLOGY

A mixed methodology comprising of literature review, project brief, performance specification, objectives tree method, prototype design and manufacture was undertaken.

5.1 Literature review.

It was established that the client of this project has a form of muscular dystrophy, so the first step was to gain an understanding of her disability by gathering information which was given to the design team during an interview. Extensive information gathering was undertaken and it is summarized in the following sections.

5.1.1 Muscular Dystrophy

According to Muscular Dystrophy Ireland more than 740 individuals are registered as living with muscular dystrophy but the real number is expected to be significantly higher with many cases going undiagnosed and unregistered. (MDI, 2016)

Muscular dystrophy is a group of diseases which cause progressive muscle tissue loss when the body ceases the production of the proteins necessary for new, healthy muscle. The difficulties and complications associated with muscular dystrophy include, but are not limited to:

Limited mobility and inability to walk due to failure in leg muscles. Difficulty breathing, eventually breathing assistance devices may be necessary. Scoliosis due to weakened back muscles. Reduction in efficiency of heart muscles resulting in possible heart failure. Difficulty swallowing resulting in nutritional issues.

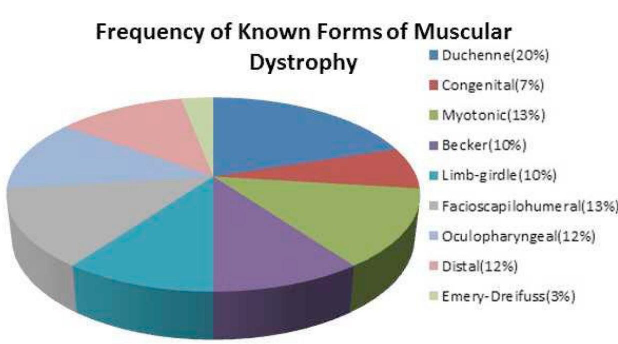

Figure 2. Types of Muscular Dystrophy. (MDI, 2016)

Although muscular dystrophy is considerably rare and not fully understood, there are nine confirmed forms of muscular dystrophy, these can be seen in Figure 2; Myotonic, Duchenne, Becker, Limb-girdle, Facioscapulohumeral, Congenital, Oculopharyngeal, Distal and Emery-Dreifuss.

5.1.2 Mobility chair used by the client

The Quantum Edge 2.0 shown in Figure 3, in conjunction with the iLevel seat, gives the user the capability to raise the seat to the user's required height and allows the user to carry out tasks and hold conversations at eye-level. This helps the user to feel more relaxed as they go about their daily lives in a more natural way. It uses two 12 volts' deep cycle batteries to produce maximum speeds of 6mph from a compact mid-wheel drive base which increases manoeuvrability in tight spaces. 20-centimetre caster wheels ensure smoother transitions over thresholds and obstacles. The iLevel seat allows the user to elevate the seat height by up to 25 centimetres and drive the chair at a slower, safer speed of 3mph as opposed to 6mph when the seat is in its default position. The iLevel uses an advanced system of electronic features to ensure that the user remains balanced and the chair remains stable

Figure 3. Quantum i-level (Quantum, 2017)

5.1.3 Motor selection for the robotic arm

There are many types of motors available as well as motor subgroups. With all this choice, it can be confusing when it comes to deciding which motor is best for a particular operation. Firstly, certain factors should be considered; Speed - what speed is required for the motor? Torque - how powerful does the motor need to be, what weight or inertia must it handle? Control - is positional or speed control an issue, does it need any feedback? Precision - are accuracy and repeatability needed? Weight - will the motor's own weight add to the power requirements? Dimensions - are there any size restrictions? Cost - how big is the budget? Holding - does the motor need holding torque?

The most commonly used motors in robotics are steppers and D.C. motors. There are different types of D.C. motors available including standard servos (speed control motors with encoder feedback) and R.C. servos (positional control motors with potentiometer feedback). Both these subsets can be made with brushless, coreless and standard motor types.

5.1.4 Arduino used to control the robotic arm

To communicate between the controls and motors on the arm a suitable controller had to be chosen. It was decided to use an Arduino Uno board. This board was developed as a novel way of teaching electronics and making them more affordable and accessible. The creators of Arduino Uno firmly believe in open-source software, as it makes it more accessible, and reduces research costs. Their goal was to make a microcontroller that would sell for $30 or less.

5.1.5 Additive Manufacturing of the robotic arm

The cost of 3D printing has reduced dramatically in recent years making it a more viable prototyping method. These budget printers may not have the accuracy and repeatability of the more expensive ones but are perfectly suitable for producing small prototypes. During the course of this research a low-cost model using the Reprap Prusa 3D printers was manufactured. This is a fused deposition type printer where a series of thin layers of plastic are melted and layered.

5.1.6 ISO 14971:2007 International Standard Regulations (ISO 14971:2007, 2007)

The ISO 14971:2000 is concerned with processes for risk management to the patient, operator, other persons, the equipment and surrounding environment. It relates to the use of custom-made assistive technology products and the risk assessment cycle is depicted in Figure 4.

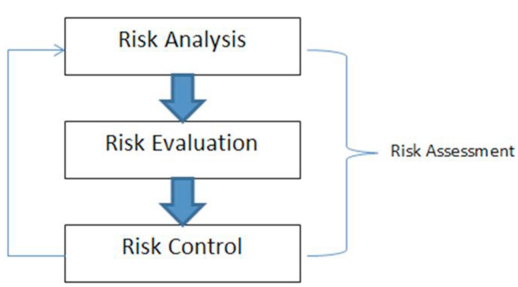

Figure 4. Risk assessment cycle.

In this standard the following topics are covered:

Harm: What is the risk to the safety of the user and how is it evaluated? To evaluate the risk of harm to the user a specific process is used where the potential risks are analysed using active risk assessment cycle to ensure optimum control on a real time basis.

Hazards: This involves identifying the source of harm, intended use and misuse, known and foreseeable hazards and a systematic risk assessment process.

Risk Control- Engineering. This involves eliminating risks either by design or redesign. Protective measures to prevent the user from harm are covered in this section, such as alarms, warnings, labels etc.

Life Cycle: This section covers the complete life of the assistive technology product from design and conception to its decommission and proper disposal.

Manufacturer: The guidelines for the individual responsible for the design, manufacture, packaging and labelling of the device.

Postproduction: This section aims to ensure that all risk evaluations are appropriately implanted, overall residual risk is acceptable, postproduction processes are in place and necessary information is documented.

5.2 Primary research

The primary research consisted of taking the project brief from the client, transforming the brief into a performance specification by using the performance specification method. The objective tree (OT) method, diagram Figure 5, was used. It specifies the main performance requirements of the product. It explains how these attributes are achieved and why they are needed in the design.

Following consultation with the client Table 1 was established and used in the OT.

Table 1. List of design objectives

The arm will be safe
There will be no sharp edges
There will be an emergency stop
All belts and gears will be covered
The secondary arm will deliver a drink
The drink will not weigh more than 500g
The arm should hold a minimum of 1kg
The arm will be securely attached
The arm will be bolted to the chassis of the chair
The arm will be independently powered
There will be a rechargeable power supply
The arm will be easily controlled
It will be controlled via joystick
The arm will hold a tablet
The arm will have a secure holder for a tablet so it cannot fall during normal use of the chair
The arm will be safe
Primary arm will lift 2kg

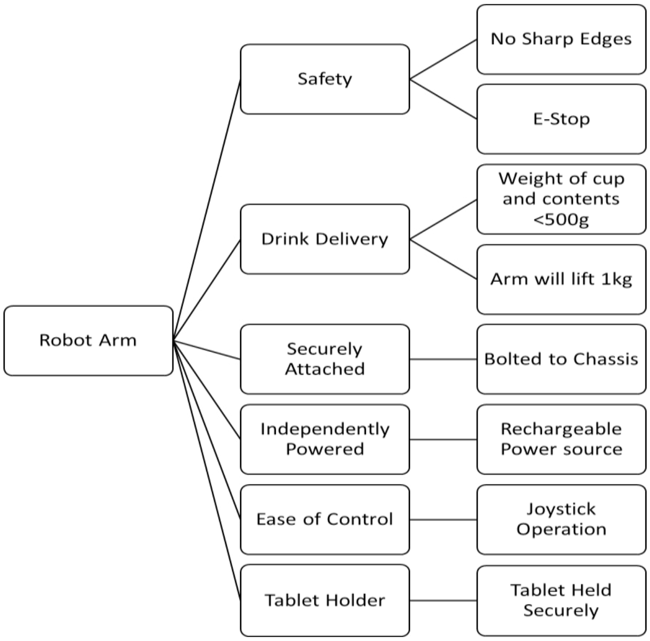

Figure 5. The objectives tree for the robotic arm.

The third and final step was to design robotic arm concept prototypes. Various designs are shown in Figures 6, 7 and 8.

5.3 Different concepts

Following the establishment of the performance specification a number of different concepts were designed. They are depicted in the following sketches:

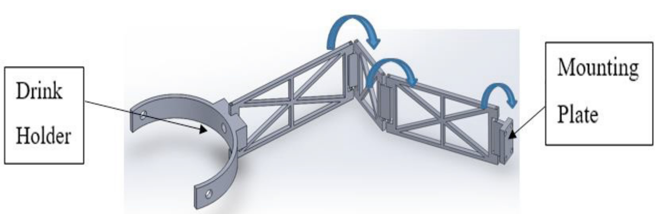

Figure 6. Rear mounted arm.

The arm shown in Figure 6 would be mounted to the rear of the chair behind the user's head. The arm would fold neatly behind the back of the chair when not in use. It would swing out around the shoulder, then back towards the mouth, when required.

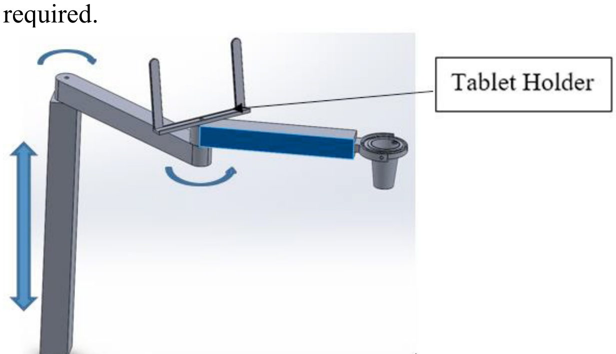

Figure 7. Side mounted arm.

The arm depicted in Figure 7 would be mounted to either side of the chair and fold tightly to the side of the chair when not in use, so as not to hinder movement through doorways. When in use the upright of the arm would move upwards telescopically while the arm swings out in front of the user. This would hold a tablet at eye level for the user to view. The secondary arm would move independently to move a drink to the users mouth when required.

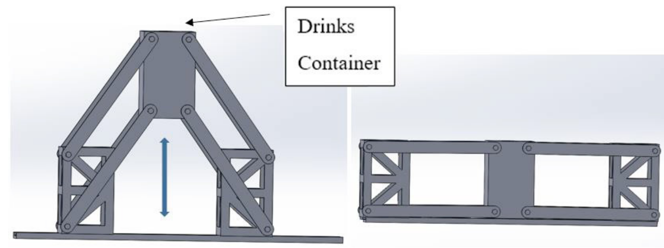

Figure 8. Sissors mechanism.

Figure 8 shows the third concept. This scissors mechanism would be embedded into a table which would be attached to the armrests of the chair. The mechanism would be raised from inside the table and the drink container would be presented to the user. The table would be easy to attach and remove for convenience.

5.4 Design Analysis

Having chosen the side mounted arm concept with the client's approval (Figure 7) considerable effort was put into the design analysis. The following list was the focus of this analysis; *the raising mechanism, the arm pipe sizing, the lead screw calculation and the servo selection.* A bill of materials was established for the components that were either custom designed or sourced on-line.

5.5 Detailed design drawing

Detailed drawing for each of the bespoke 3D printed parts was drawn using SolidWorks. A gyroscopic end effector to hold the drinking cup was also designed so that no spillage would occur due to the arm not being level. Details of this part can be seen in Figure 9.

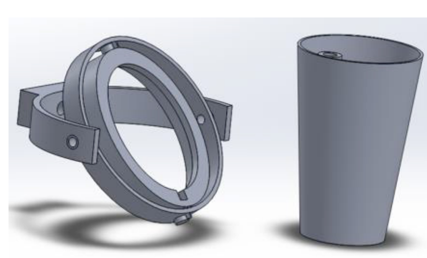

Figure 9. Gyroscopic End Effector.

5.6 Building of the arm

The investigation into materials allowed for optimal material selection for each component. This resulted in a final product which could withstand the daily stresses that it would be exposed to. CES Edupack proved to be an invaluable resource throughout this particular process. Following the pipe sizing calculations, the finite element analysis software ANSYS was used to ensure that the arm could physically withstand the forces it would experience when carrying a load. A factor of safety of two was employed.

When all the individual parts were printed, painted or received from suppliers, work began on assembly. The rising system was first to be made, followed by the arm. Once it was put together work could begin on wiring and programming. The arm was controlled by two PCB mounted 2-axis joysticks which were tested and approved by the client. The first joystick controlled the overall height of the robotic arm by supplying movement to the leadscrew motor and the rotational movement of the first servo motor. This allowed the entire arm length to move towards the user. The second joystick controlled the second motor. This allowed the arm to accurately and safely approach the user. The arm was controlled with an Arduino Uno. The Uno was chosen as it is the smallest Arduino with enough input/output pins.

6.0 DISCUSSION

Designing the robotic arm in 3D then using 3D printing to manufacture the parts made it much easier to refine and optimise. By actually ‘handling’ the printed parts it was easy to see how small changes could improve the parts, both functionally and aesthetically. It also greatly facilitated sizing the servo motors and refining the overall size of the arm. In 3D printing the material is added layer by layer. There are certain design rules that must be respected for this process to produce optimal features, such as tight internal corners or hollow parts. These features cannot be produced by mainstream machining but are possible using 3D printing. Thin parts can be produced in the direction of the grain in 3D parts but not across the grain, as they are weak and subject to failure. Thick parts are not an issue for 3D printing as they can be filled with different densities of infill if they are not subject to large stresses.

The servos used for the arm were only hobby servos and getting data sheets for them proved impossible. The length of life of these motors was questionable and there was no guarantee with them. For initial testing purposes, they did fulfil what was required of them. Both servos moved the arm with no signs of strain or random behavior. The leadscrew motor also works as expected but was a little slow. In hindsight it would have be better to find a slightly faster motor. The arm is expected to be connected to the 12V supply on the chair when fitted. If this is not possible in the future, and the 8.4V supply used for testing becomes the permanent supply, then a different leadscrew motor would be definitely required.

The Arduino was the ideal microcontroller for this project. Its ease of use and abundance of dedicated online tutorials and forums made it easy to learn. The Dupont input/output connections make wiring easy to connect, and also this facilitated changes. The serial monitor is a very useful tool for debugging the software as it can be used to print inputs to the screen which can be used to find poor connections or faulty components. The variety of add-ons, also known as shields, such as the D.C. motor shield used for the robot give it great functionality and modularity.

7.0 CONCLUSION

To begin this project, it was essential to gain an understanding of muscular dystrophy. This was achieved through online research and research into the client’s abilities which found the user to have most mobility in her right arm. This meant that any controls to be designed should be mounted on the right-hand side of her motorized wheelchair. The complexity of the project and vast number of skills employed throughout the course of the project meant that many issues arose including; 3D printer calibration issues, software issues and programming issues. However, each issue was eventually solved through trial and error along with perseverance and guidance from supervisors. Time keeping became an issue in the later stages of the project; this was mainly due to late shipments of parts which led to a standstill in progress. Through improvisation with alternative parts and in particular, alternative servo motors, all schedules were eventually met.

A working prototype for under 200 euro was achieved with a novel design. The client did get to use the prototype successfully, but reliability soon became an issue. Further development with more robust motors was recommended. A video clip on ‘Engineering Technology WIT’ Facebook page shows the final product fully functional with its client demonstrating it.

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