COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

GRADO EN INGENIERÍA EN TECNOLOGIAS INDUSTRIALES

TRABAJO FIN DE GRADO

ONE HANDED BUTTON FASTENING

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Director: Bruce Flachsbart

Madrid

Junio de 2019

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FAST-ENER – a Mechanically Automated Buttoner

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Fdo.: Carolina Nieto Ibarzabal Date: 21/06/2019

I authorize the submission of this project

Fdo.: Prof. Bruce Flachsbart Date: 21/06/2019

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ABROCHADOR DE BOTONES CON UNA SOLA MANO

Autor: Nieto Ibarzabal, Carolina Coral.

Director: Flachsbart, Bruce.

Entidad Colaboradora: ICAI- Universidad Pontificia de Comillas.

RESUMEN DEL PROYECTO

Introducción

El proceso de elección del proyecto de fin de grado comenzó con el análisis de los problemas que afronta actualmente la sociedad y las posibles soluciones que se pueden proponer para zanjar dichos problemas. Principalmente, el estudio se centró en las acciones y limitaciones que sufren las personas con algún tipo de discapacidad. El objetivo principal de este proyecto es desarrollar un producto simple y sencillo, y a la vez esencial, que haga más fácil el día a día a personas con limitaciones.

Tras analizar numerosas complicaciones que sufren personas discapacitadas, ancianos o personas con falta de alguna extremidad, se decidió intentar dar una solución para aquellas acciones que es necesario utilizar ambas manos, ya que con una sola mano resultan complicadas. Para gente con limitaciones, tareas tan sencillas como abrocharse la camisa cada día es casi imposible, por lo tanto, se decidió desarrollar un producto que ayudase a la gente a abrocharse los botones de cualquier camisa o chaqueta. Actualmente el mercado solo cuenta con dispositivos manuales, pero no mecánicos.

Metodología

Los requisitos del proyecto son que el dispositivo debía ser nuevo y contar al menos con dos componentes mecánicos. Durante todo el proyecto se trabajó con un proceso iterativo, la primera etapa constaba de diseñar un prototipo basado en una idea inicial, posteriormente se fabricaba y finalmente se analizaban los puntos fuertes y débiles del prototipo. Una vez examinados los aspectos a mejorar, comenzaba de nuevo el proceso con el diseño de un nuevo prototipo, y sucesivamente hasta encontrar un diseño que cumpliese todos los objetivos del proyecto. Durante el desarrollo de los últimos prototipos, además se realizaron dos análisis, uno de optimización (DOE) y otro de ensamblaje (DFA) con el propósito de poder perfeccionar el proyecto.

Para el diseño de los prototipos inicialmente se diseñaban la mayoría de las piezas con el programa Creo Parametric 3D Modeling Software. Una vez ya diseñadas las piezas, estas

se imprimían en 3D en el estudio de la universidad de Illinois, concretamente se utilizaba la técnica de Modelado por Deposición Fundida.

Una vez elegida la idea, comenzó el proceso de "lluvia de ideas" sobre posibles productos y mecanismos que se podrían utilizar. El primer diseño se basaba en una máquina de mano con la cual, a través del accionamiento de un gatillo, se permitía el movimiento de dos o más partes en la punta de la máquina. Las principales funciones del diseño inicial eran ser capaces de coger el botón y manipularlo para poder pasarlo a través del agujero sin mucho esfuerzo por parte del consumidor.

La figura 1 muestran los primeros diseños en CAD de ganchos realizados.

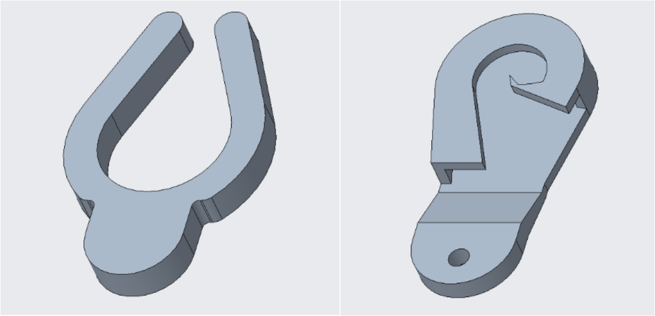


Figura 1 Diseños de ganchos en CAD

Aunque los primeros bocetos contaban con el uso de un gatillo, también se incluyeron diseños con ruedas como posible método de accionamiento en el cuerpo del mecanismo. Además, también se creó una plataforma con distintos tamaños de botones para probar la eficacia de cada uno de los prototipos.

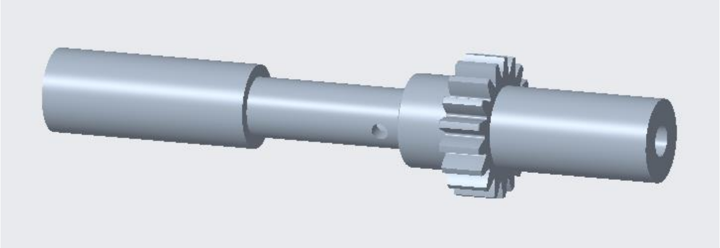


Figura 2 Diseño con rueda en CAD

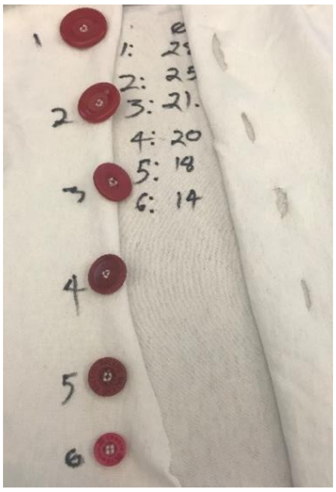


Figura 3 Plataforma de prueba

Tras el poco éxito conseguido con el primer prototipo, se decidió desarrollar una nueva idea, un mecanismo formado por 4 barras. Tras un intensivo estudio sobre los diferentes tipos de mecanismos de 4 barras, se eligió aquel que proporcionaba el movimiento mas satisfactorio para abrochar un botón. Este mecanismo proporcionaba un movimiento de barrido capaz de agarrar el botón y tirar para atrás. Se realizaron varias iteraciones dentro de este diseño. La primera iteración se basó en un diseño realizado con segmentos de madera, para comprobar si la escala y el movimiento elegido eran los correctos. La segunda iteración se trató de un diseño impreso 3D el cual era muy robusto y grueso.

Finalmente, en la tercera iteración se hicieron más finas las barras del prototipo, con la intención de que el diseño fuese lo mas compacto posible. Además, se añadió una rueda dentada como método de accionamiento a través de un gatillo. La figura 4 muestra la última iteración del sistema de 4 barras. Por otro lado, se diseño un gancho con 3 posibles posiciones diferentes. Asimismo, para acoplar el gancho al mecanismo se desarrolló un sistema de "*snap-fits*" para el fácil cambio de posición.

Figura 4 Última iteración prototipo de cuatro barras

Figura 5 Diseño del gancho en CAD

El mecanismo del diseño se basaba en un gatillo de accionaba una pista de engranajes, y a su vez esta accionaba el movimiento del mecanismo de las 4 barras, permitiendo al gancho rodear el botón y tirar de él para atrás y abrocharlo. Una vez finalizado el ultimo prototipo, se llevó acabo un “diseño de experimentos” (DOE). Se trata de un análisis realizado para optimizar una variable del diseño. En este caso se decidió optimizar el número de intentos exitosos entre diez intentos.

Para optimizar este parámetro es necesario decidir la pieza que se debe mejorar, y en este caso de decidió mejorar el gancho del sistema, ya que es una pieza esencial para conseguir rodear el botón y abrocharlo. Una vez determinada la pieza a mejorar, es preciso analizar que variables tienen relación, las tres medidas elegidas fueron: el tamaño del gancho, la posición del gancho en el sistema y la velocidad de accionamiento del mecanismo.

La conclusión del experimento fueron que era necesario aumentar el ángulo y el tamaño del gancho y maximizar la velocidad. Sin embargo, tras realizar todos los test, se llegó a la decisión que ninguna de las variables era significativa a la hora de optimizar el éxito del diseño. Se intentó seguir con el diseño a través de optimizar otras piezas del prototipo, pero el número de éxitos seguía sin ser suficiente. Por lo tanto, se decidió restructurar el diseño.

Resultados

Gracias a todos los prototipos realizados anteriormente, se fusionaron todos los puntos fuertes de cada uno de ellos para poder realizar un prototipo final. Este prototipo, se caracterizaba por ser mucho más simple y dócil. El funcionamiento del mecanismo se basaba en la introducción del modelo por el agujero, una vez que se ha rodeado el botón con el cable, se desliza el dedo con el control para atrás, para poder tirar del gancho. Y una vez que el botón este agarrado, simplemente se tira del botón a través del agujero. Aunque sea el diseño más sencillo, es a su vez el más efectivo.

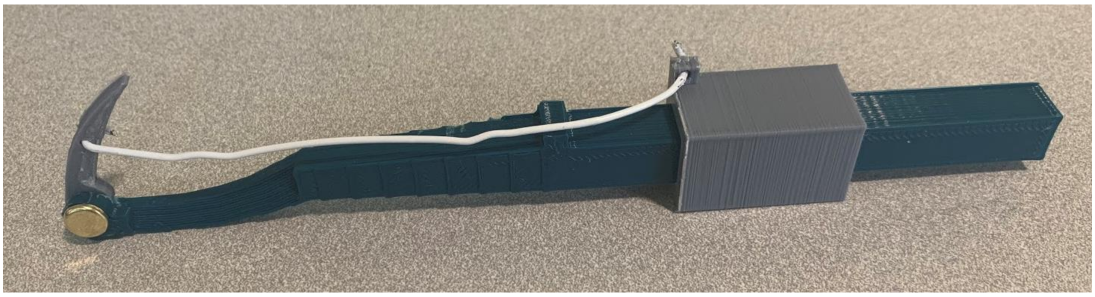


Figura 6 Prototipo final

Finalmente, una vez realizado el prototipo final se realizo el "Diseño de ensamblaje" (DFA), para minimizar el tiempo de montaje. Es importante optimizar el tiempo de montaje al máximo, ya que es decisivo para el coste total del proyecto. Los resultados del experimento fueron que el mínimo teórico de piezas es dos. Mediante la implementación de un *snap fit* en el punto pivote y la combinación del gancho y control deslizante en una sola pieza, se puede reducir el número de piezas al mínimo. Sin embargo, diseñar el gancho, la deslizadera y el cable en una sola pieza es muy impráctico. Además, el uso de *snap fits* provoca que el diseño sea mas frágil. Por lo tanto, se decidió continuar con el diseño de 5 piezas.

Conclusión

Durante este proyecto, se realizar cuatro revisiones completas, hasta llegar al diseño deseado. Se comenzó con un diseño basado en el uso de un gatillo como accionamiento. El siguiente diseño opto por ser un dispositivo activado mediante una rueda dentada. Tras analizar los puntos débiles, se desarrollaron tres iteraciones sobre un sistema de cuatro barras. Después de considerar las conclusiones del "diseño de experimentos", se optó por rediseñar el proyecto, hasta llegar al prototipo final, un diseño caracterizado por el empleo de una deslizadera. Con este último dispositivo se cumplieron la mayoría de los propósitos:

- Un diseño inédito en el mercado que contase con dos movimientos mecánicos.
- Un abrochador de botones fácil y sencillo de utilizar.
- Cómodo de utilizar con diferentes tamaños de botones.

ONE HANDED BUTTON FASTENING

Introduction

The process of choosing the final degree project began with the analysis of the problems currently facing society and the possible solutions that can be proposed to settle these problems. Mainly, the study focused on the actions and limitations suffered by people with some type of disability. The main objective of this project is to develop a simple and easy product, yet essential, that makes easier the day to day to people with limitations.

After analyzing numerous complications suffered by disabled people, elderly people or people with missing limbs, it was decided to try to give a solution for those actions that are necessary to use both hands, since with one hand they are complicated. For people with limitations, such simple tasks as fastening the shirt every day is almost impossible, therefore, it was decided to develop a product that would help people to button up the buttons of any shirt or jacket. Currently the market only has manual devices, but not mechanical ones.

Methodology

The requirements of the project are that the device should be new and have at least two mechanical components. Throughout the project we worked with an iterative process, the first stage consisted of designing a prototype based on an initial idea, later the prototype's strengths and weaknesses were manufactured and finally analyzed. Once the aspects to be improved were examined, the process began again with the design of a new prototype, and successively until finding a design that fulfilled all the objectives of the project. During the development of the last prototypes, two analyzes were also carried out, one for optimization (DOE) and another for assembly (DFA) with the purpose of being able to perfect the project.

For the design of the prototypes, most of the pieces were initially designed with the Creo Parametric 3D Modeling Software program. Once the pieces were designed, they were printed in 3D in the study of the University of Illinois, specifically using the technique of Fused Deposition Modeling (FDM).

Once the idea was chosen, the process of "brainstorming" about possible products and mechanisms that could be used began. The first design was based on a hand machine with which, through the actuation of a trigger, the movement of two or more parts at the tip of the machine was allowed. The main functions of the initial design were to be able to take the button and manipulate it to be able to pass it through the hole without much effort on the part of the consumer.

Figure 1 shows the first CAD designs of hooks made.

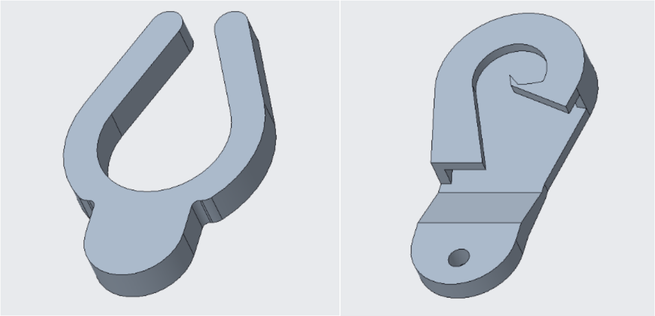


Figure- 1 Hooks CAD designs

Although the first sketches had the use of a trigger, designs with dials were also included as a possible method of activation in the body of the mechanism. In addition, a platform with different sizes of buttons was also created to test the effectiveness of each of the prototypes.

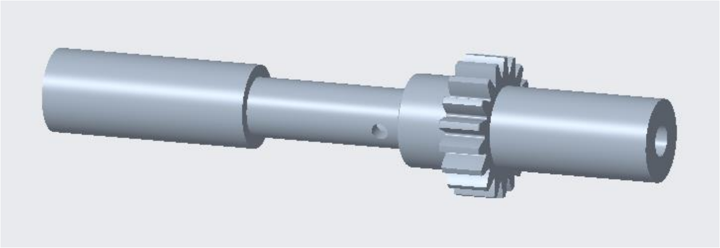


Figure- 2 Dials CAD design

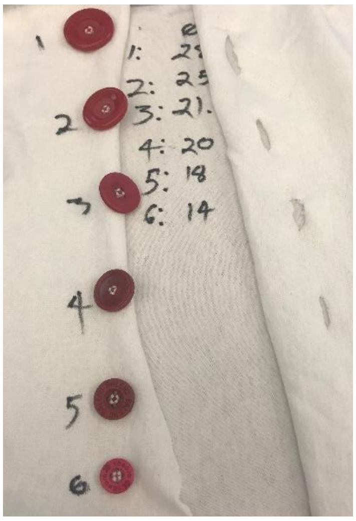


Figure- 3 Test platform

After the little success achieved with the first prototype, it was decided to develop a new idea, a mechanism formed by 4 bars. After an intensive study on the different types of 4-bar mechanisms, the one that provided the most satisfactory movement for button buttoning was chosen. This mechanism provided a sweeping movement capable of grabbing the button and pulling it back. Several iterations were made within this design. The first iteration was based on a design made with wooden segments, to check if the scale and movement chosen were correct. The second iteration was a 3D printed design which was very robust and thick.

Finally, in the third iteration, the bars of the prototype were made thinner, with the intention of making the design as compact as possible. In addition, a sprocket was added as a method of actuation through a trigger. Figure 4 shows the last iteration of the 4-bar system. On the other hand, a hook was designed with 3 possible different positions. Also, to attach the hook to the mechanism, a "snap-fits" system was developed for the easy change of position.

Figure- 4 Last four-bar system iteration

Figure- 5 Hook CAD design

The mechanism of the design was based on a trigger operated a gear track, and in turn this triggered the movement of the mechanism of the four bars, allowing the hook to surround the button and pull it back and fasten it. Once the last prototype was finished, a "design of experiments" (DOE) was carried out. It is an analysis made to optimize a design variable. In this case it was decided to optimize the number of successful attempts among ten attempts.

To optimize this parameter, it is necessary to decide the piece that must be improved, and in this case decided to improve the hook of the system, since it is an essential piece to get around the button and fasten it. Once the piece to be improved is determined, it is necessary to analyze which variables are related, the three measures chosen were: the size of the hook, the position of the hook in the system and the speed of actuation of the mechanism.

The conclusion of the experiment was that it was necessary to increase the angle and size of the hook and maximize the speed. However, after performing all the tests, it was decided that none of the variables was significant when optimizing the design's success. We tried to continue with the design through optimizing other pieces of the prototype, but the number of successes was still not enough. Therefore, it was decided to restructure the design.

Results

Thanks to all the prototypes made previously, all the strengths of each of them were merged to make a final prototype. This prototype was characterized by being much more simple and docile. The operation of the mechanism was based on the introduction of the model through the hole, once you have surrounded the button with the cable, slide your finger with the control back, to be able to pull the hook. And once the button is grasped, the button is simply pulled through the hole. Although it is the simplest design, it is also the most effective.

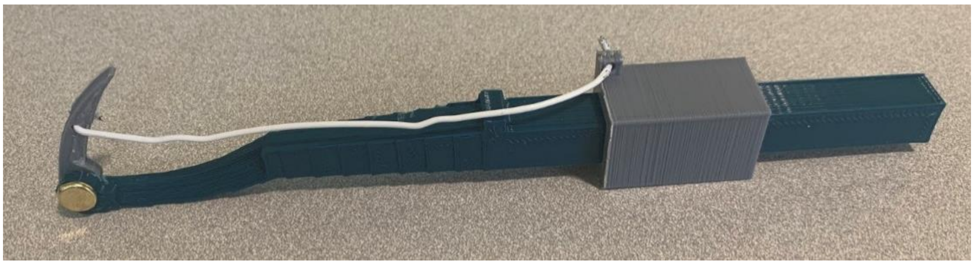


Figure- 6 Final prototype

Finally, once the final prototype was made, the "Assembly Design" (DFA) was carried out, to minimize assembly time. It is important to optimize the assembly time to the minimum, since it is decisive for the total cost of the project. The results of the experiment were that the theoretical minimum of pieces is two. By implementing a snap fit at the pivot point and combining the hook and slider in one piece, you can reduce the number of pieces to a minimum. However, designing the hook, slide and cable in one piece is very impractical. In addition, the use of snap fits causes the design to be more fragile. Therefore, it was decided to continue with the design of 5 pieces.

Conclusion

During this project, four complete reviews will be carried out, until the desired design is reached. It began with a design based on the use of a trigger as a drive. The following design opted to be a device activated by a gear wheel. After analyzing the weak points, three iterations were developed on a four-bar system. After considering the conclusions of the "design of experiments", it was decided to redesign the project, until reaching the final prototype, a design characterized using a slide.

With this last device most of the purposes were fulfilled:

- An unprecedented design in the market that had two mechanical movements.

- A simple and easy-to-use button buckle.

- Convenient to use with different sizes of buttons.

INDEX

Introduction

The process of choosing the main design project idea started analyzing the problems that society suffer daily and the possible solutions that can be developed to solve them. Mainly, the analysis was focused on actions and limitations that suffer people with any type of disability.

The iterative process started with an ideation stage, where after doing a research, a rough design was done. The next stage was the construction of a prototype that solves the current needs of the market. These stages would be repeated until the achievement of a final prototype that satisfied the objectives of the project. The requirements of the design were that the product must be new and must include at least two mechanical components. Furthermore, in each iteration an aspect must be improved. In the Figure 1, it can be seen the different stages followed during the design process.

My greatest assist in finding issues to solve were thinking about common actions done with two hands that would be difficult with only one. For the elderly, disabled or amputees, something as simple as buttoning a shirt is seemingly impossible. The main purpose of this project is to develop an easy and yet essential device to made something accessible to people who otherwise couldn’t. This device will enable people with reduced hand function to do up buttons independently, it will make dressing much simpler and can help promote independence.

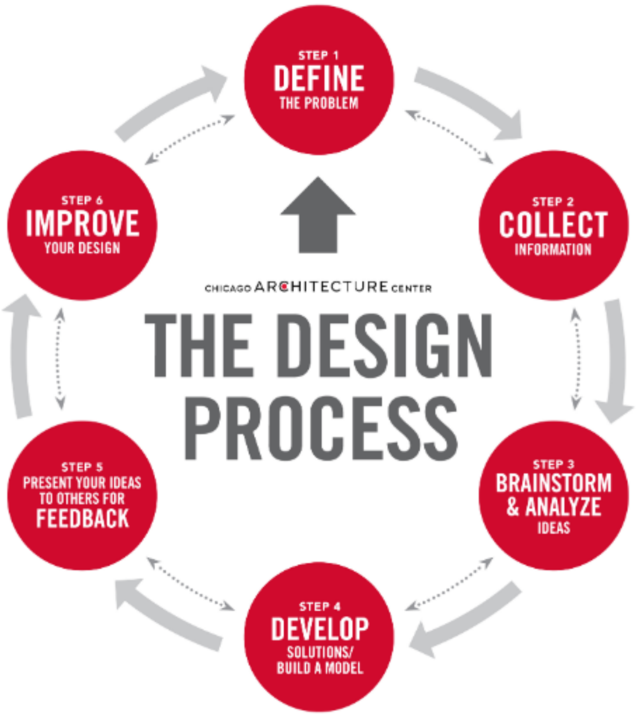


Figure 1 Design process steps [Source: https://www.discoverdesign.org/handbook]

Background Research

Existing products

Analyzing the product and searching for some similar products, I found that the market offers a couple of options but none of them are mechanical. The devices out there feature a metal loop or a hook enough to get through the shirt hole and surround the button. Then, pull the grip rubber handle with the button back through the buttonhole.

These button fasteners have easy and large handles for elderlies and people with disabilities. Also, multiples sizes can be found, small ones for shirts buttons and larger for pants and jackets buttons.

Although these devices can be used with the left or right hand, struggle with the finishing motion of maneuvering the button through the hole. The average cost of these accessories is around $15.

Figure 2 Existing market products

Manufacturing techniques

During this project I have learnt and used some different techniques to quickly fabricate and assembly different parts of the final design. The most important techniques are 3D printing, machining and injection molding. The critical information about them is outlined below.

3D printing

3D printing is a process that automates the fabrication of a part from a three-dimensional CAD file. In 3D printing after the machine reads the CAD file, starts tracing down successive layers and building up the pattern. The benefits of this process are that is quickly and more cost-effective than other methods. Also, this additive construction enables the creation of almost any geometry. There are three main 3D printing techniques: Selective Laser Sintering (SLS), Stereolithography Apparatus (SLA) and Fused Deposition Modeling (FDM).

FDM is a technology where a temperature-controlled head extrudes thermoplastic layer by layer onto a build platform. The materials FDM uses are highly durable. The main benefits of FDM are that it is the most cost-effective rapid prototype method available. However, some concerns with FDM come with the fact that it is isotropic and is significantly weaker along the vertical print axis. Furthermore, the prints resolution is lower compared to other printing technologies.

On the other hand, SLA printing can print at a much higher resolution and can create clear prints, but the curing resin is very brittle and although it creates fewer support structures, the ones that it does create can sometimes be very tedious to remove, so it requires a lot more post-processing.

Finally, SLS printing eliminates the need for support structures by fusing powder together to form a strong print using a laser, but the heat can cause warping, and the surface of the part still requires post processing because of its rough surface. Since there is no support structure, it allows to create detailed small parts which will not be damaged in the post-processing. One weakness of this process is the significant number of hours needed to build, the warmup and cooling phase requires most of them.

Due to FDM is the most effective process, I designed a little gear with a diameter of 2.5 cm and 12 teeth. The final printed part is very precise and detailed however, there were some differences between the CAD model and the printed part, the most obvious difference was the surface texture. Some roughness is also present at the bottom edge of the gear, this is the support structure that remained after some post-processing.

Another minor issue with the FDM printers is that there is one surface on every part that will be weak in one direction. Because of the way the plastic is printed, the vertical axis of the part will always be weaker than both the other axises. This minor inconvenience is important to consider when creating parts. Because of the FDM machines however, the plastic that the parts are manufactured with are very light and durable. This allows for the collection of parts into a machine not to be heavy or overbearing. However, this could also be an issue because when the weight is too light, the part may be flimsy or brittle.

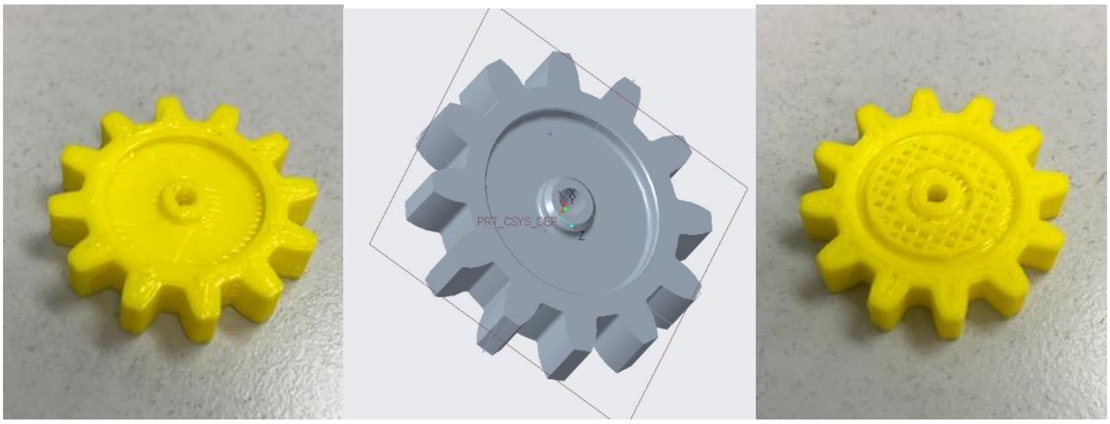


Figure 3 CAD model vs. Printed gear

Although the 3D printing has some weak points, this method is going to be useful for the final design project. It is true that other methods like the SLS allows faster and more accurate results, the high cost is not worth it.

Machining

Machining is a process which a piece of material is removed from any workpiece. In this procedure a 3D CAD model is used to machine the design from an aluminum block using a Tormach 3-axis CNC mill. In order to generate the tool paths, I used the program Creo and the program G-Code to generate the 3D CAD part. The Computer-Aided Manufacturing (CAM), based on a few parameters as clear distance, step over or tool, creates the G-Code.

During this process there are three sequences: roughing, re-roughing and finishing. Firstly, the general pattern is generated without much detail by removing considerable amounts of material. Then, during the re-roughing, the details of the piece start to be created. Finally, the last step is when the surface is been improved. Also, the tools used in the different sequences are a ¼” end mill and a 1/8” ball mill. Cut feed, step over and clear distance are some of the parameters that must be specified by Creo in each sequence.

In this case I designed a castle with the purpose of testing the benefits and disadvantages of the machining method. The castle has three points at the top, the outer two having smaller widths than the middle, as well as a rectangular window and door at precisely the same size in the base of the castle. This part was made with draft angles on the walls but no rounds on the corners. The draft angles are necessary for the block because when the part will be injected, it will be impossible to remove without the angles.

Figure 4 drill machine

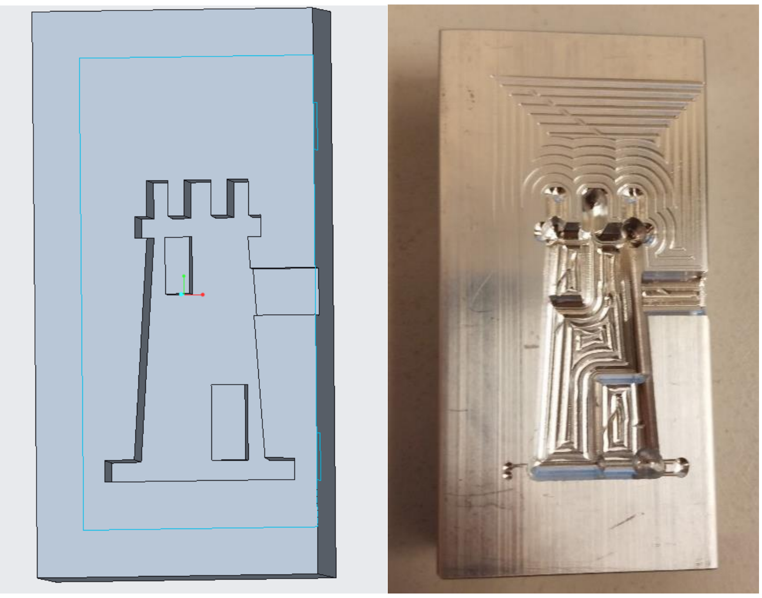


Figure 5 Creo designed Surface vs. machined block surface

As seen when comparing the Creo designed surface and the machined one, there are some very apparent differences in the design and machined block. The most glaring difference is that of the surface finish. With the end and ball mill, a perfectly smooth surface is difficult to attain without increasing the tolerance and thus increasing production time. These laps are caused by the mill moving a set distance away from each previous swipe. A smoother finish would require more precision and production time.

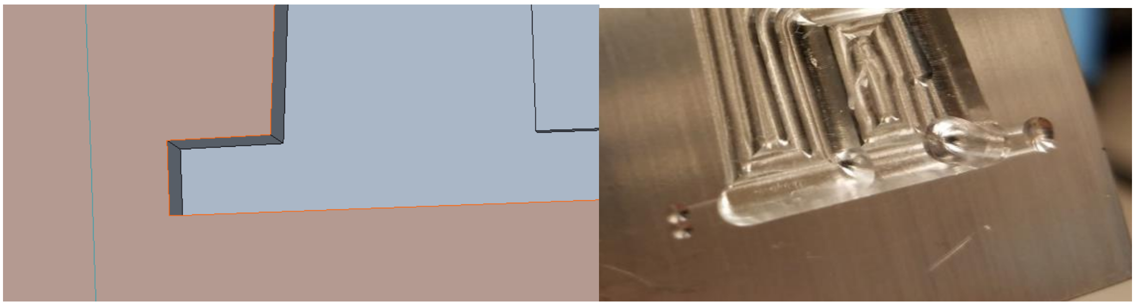


Figure 6 Creo designed base vs. Base of the machined block

Furthermore, in the model the base of the castle extends past its wall a distance. However, in the machined block, this dimension was smaller than that of the end used, so nothing could be done at this location. It is interesting that the mill left small indents around where the corners of the base would be, but avoided milling too far in. This problem is fixed easily by just scaling the dimensions of the block.

Also, the cutting speed and the cut feed were changed in order to decrease time. Cutting speed may be defined as the rate at the workpiece surface, irrespective of the machining operation used. However, the consequence of the change would be that the tool life of the mill would be reduced. Also, I could have increased the size of the cut feed, but this will reduce the accuracy of our design. Another factor that I could change is the step over, the lateral displacement at the beginning of each fun of the cutter. Similar to the cut feed, if we reduce the step over, we will reduce the accuracy of the design.

Overall, the block turned out, even with its flaws, to be still rather nice-looking. If redesigned, and if time were not a concern, the lap distance could be decreased and the dimensions could be better scaled to fill the block and allow the tool diameter to fit within the design and thus create a more accurate part that looked like the Creo design.

Injection molding

Injection molding is a process for producing parts by injecting molten materials into a mold. Two types of materials are mainly used. On one hand, thermosets allow to create permanent shape parts after the application of heat and pressure. On the other hand, thermoplastics are fragile at high temperatures, but once it cold down the material is harder than other. Furthermore, Mold flow analysis is employed in mold making industry because you can simulate the molding process and improve the design base on the results.

The Mold flow analysis will advise useful information as if the cavity is fulfilled or the required injection and clamping pressure. You can also know if exists any filling problem such as imbalances and bubbles. The first experiment done with injection molding was a study about how the modification of the temperature and pressure affects the length printed of a spiral.

Figure 7 Spiral mold

Many cases were simulated for different pressures and temperatures, the program gave many information as the total part weight and three different length fill confidence parameters. All the data is collected in Table 1.

Temperature (K)	**Pressure (MPa)**	**Total Part Weight (gr)**	**High (%)**	**Medium (%)**	**Low (%)**
436	31	5,9784	62,30	36,00	1,83
436	39	7,4579	63,20	36,90	0,92
436	47	8,1936	64,50	34,80	0,57
450	31	6,8253	60,70	37,20	1,73
450	39	7,9856	62,10	37,40	0,44
450	47	9,1034	50,50	48,80	0,51
463	31	7,7683	59,70	37,70	2,54
463	39	9,0172	52,30	38,5	0,38
463	47	10,2378	62,80	36,40	0,84

Table 1 Spiral MoldFlow predicted results

Using the density of the LPE (0,925 g/cm^3) and the cross-sectional area (20,4250 mm^2), the predicted results were calculated with the following equations.

$$Total\ Filled\ length = \frac{Total\ part\ weight}{Cross - sectional\ Area\ \times density\ of\ LDPE}$$

$$Length\ of\ High\ Confidence\ = Percent\ High\ \times Total\ Filled\ Length$$

$$Length\ of\ Medium\ Confidence = Percent\ Medium\ \times Total\ Filled\ Length$$

$$Length\ of\ Low\ Confidence\ = Percent\ Low\ \times Total\ Filled\ Length$$

Equation 1 Predicted results equations

Temperature (K)	**Pressure (MPa)**	**Total Part Length (mm)**	**Lengths High Confidence (mm)**	**Length Medium Confidence (mm)**	**Length Low Confidence (mm)**
436	31	316,43	197,136	113,915	5,790
436	39	394,741	249,476	145,659	3,631
436	47	433,682	279,725	150,921	2,472
450	31	361,258	219,382	134,388	6,249
450	39	422,627	262,451	158,062	1,859
450	47	481,837	243,328	235,136	2,457
463	31	411,171	245,468	155,011	10,443
463	39	477,274	249,614	183,75	1,813
463	47	541,879	340,300	197,244	4,551

Table 2 Spiral predicted length results

Bellow in Figure 8 is illustrated an example of the simulation realized with MoldFlow. In this case the parameters set are 47 MPa and 450K. The program predicted that the spiral would not be entirely fulfilled.

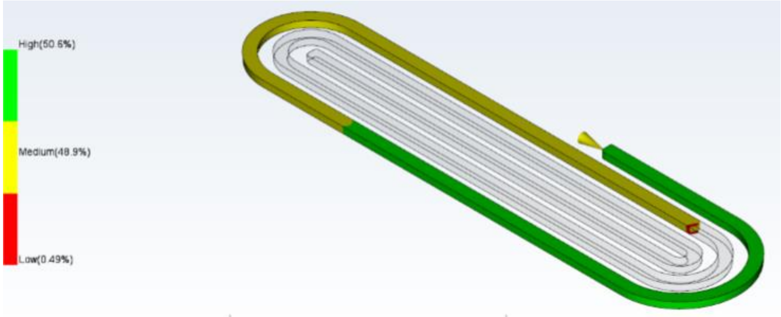


Figure 8 Spiral MoldFlow simulation

In the following charts are illustrated all the experimental information obtained with the modification of pressure and temperature:

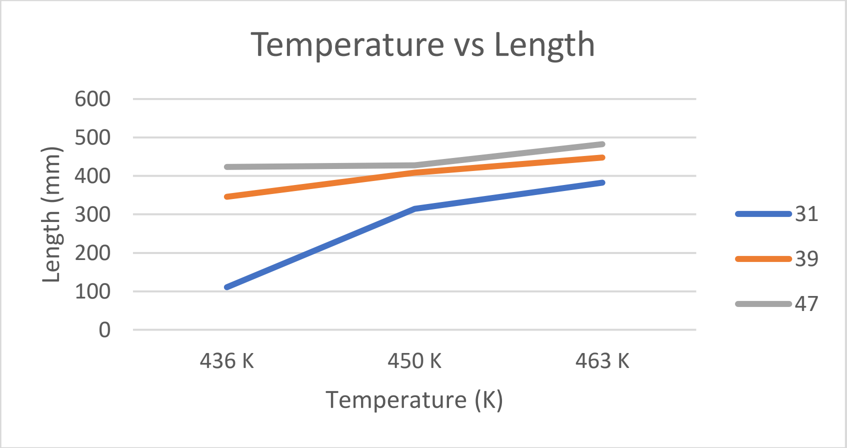


Figure 9 Plot of temperature and length

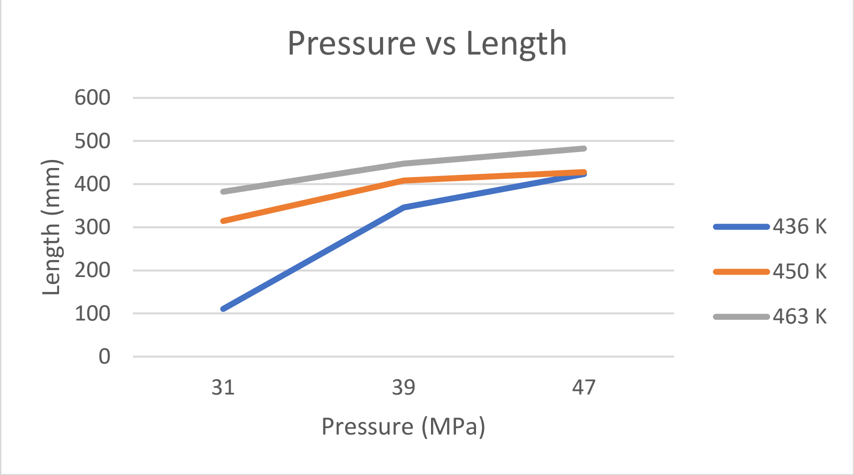


Figure 10 Plot of pressure and length

Looking first at Fig. 9, it can be seen that as the temperature increases, the length does slightly increase for all but one strange case. However, when comparing to the results seen in Fig. 10, holding temperature and increasing pressure causes a much more significant change in length.

Experimental length (mm)	**436K**	**450K**	**463K**
31 MPa	110,6	314,5	382,5
39 MPa	345,8	408,6	447,8
47 MPa	423,4	427,9	482,6

Table 3 Experimental Spiral Length

The next experiment was print one designed part, in this case was a castle, the same as the machining. Some of the dimensions designed were not machined into the block properly, leaving the mold deformed from the original design in a few ways, causing “problems”. Moldflow was not able to predict and possibly preventing some that it did, through the simulation not being entirely accurate.

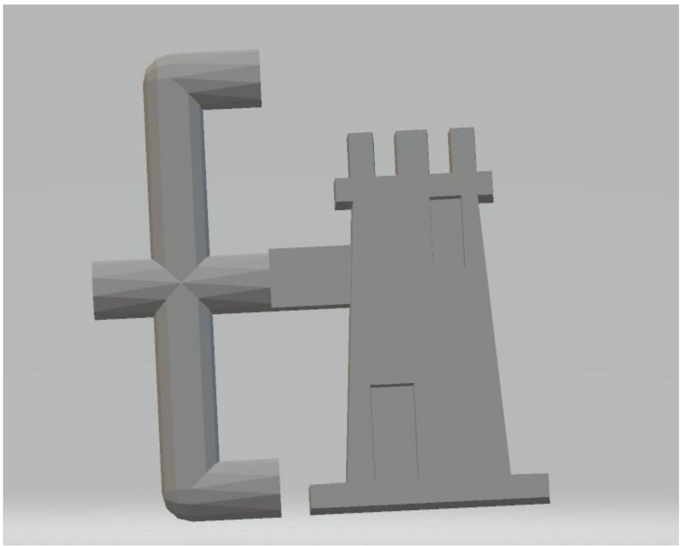


Figure 11 Part design

In the design, due to that the top extrusions were too shallow, it was impossible to flow through. Therefore, when we tried to replicate, the top of the castle was not completed. Nevertheless, Moldflow did not warn.

The only warning that Moldflow said was that the outer edges would be the last part filled, but it never suggested that it will not be completed. For the next time a potential fix would be to increase the depth of the posts.

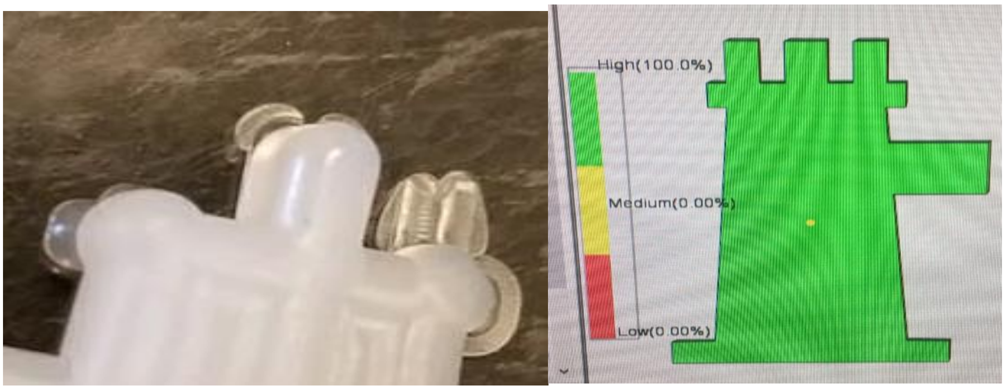


Figure 12 Unexpected Fill problems

Due to some small features and sharp corners of the design, it appeared some defects. The main defect in the part was the castle peaks at the top of the part. The castle was designed to have three peals at the top but ended up only finishing with only one of the three. Another small defect between the 3D model of the castle and the actual mold was that the door and the window of the castle were designed to be located more inward on the part instead of right on the edge.

One problem that was predicted by Moldflow was that of the injection pressure. Some of the corners were a low pressure, while the center was higher. This pressure difference may have caused a poor closing fill in the bottom corner of the part.

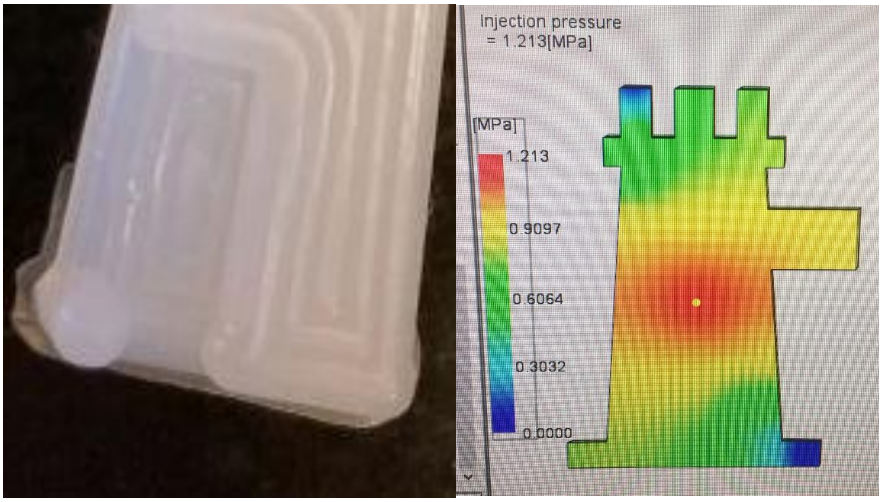


Figure 13 Moldflow predicted problem

These defects, although small, taught me that the parts should be designed with enough tolerance to prevent any kind of difference between the design and the printed part.

Objectives

Problem statement

The main purpose of my final design project was to help those people who have difficulties in common everyday actions. Within all the problems that exist currently in society, I focused on all the actions that require two hands to be done and with one hand will be difficult to do. After analyzing all these actions, I found that easy activities such as folding clothes, grabbing heavier items or buttoning a shirt suppose a big adversity for disable people.

My final design project is mainly focused on the following people:

- **People with disabilities**: Although there are many types of disabilities, the most common are physical disabilities such as paraplegia, tetraplegia, muscular dystrophy, etc. People that suffer any kind of disabilities are limited when they have to perform some daily activity.
- **Amputees**: the loss of limbs or body parts can cause a physical disability by limiting the usual function of a person.
- **Elderly**: as people get older, many diseases begin to appear with age as arthritis or arthrosis. One of the symptoms of arthritis is the inflammation of small hands and foot joints. This inflammation is joined with pain and muscle inflexibility. That is the reason why elderly people need some help when they have to do some daily activities such a buttoning their shirt
- **Kids**: for young people everyday is a learning day, and most of them need some help in the process of learning common actions.

Project goals

The main goal of this project is to make life easier to people that suffer limitations in simple daily actions. To solve these limitations, I want to achieve a device easy to use for people who do not have precise motor functions or do not have the ability to use two hands. This device will enable people with reduced hand function to do up buttons independently, it will make dressing much simpler and can help promote independence.

Also, I want to accomplish a quickly fasten without too much effort from the user, unlike the one on the market currently. Finally, a simple functionality is preferred to make movement in multiple directions in order to pull the button through the loop.

Design development

Ideation

My ideation is the first stage of the design process and consisted on thinking about the current problems occurred in society and tried to figure out a way to solve these problems. This stage started with a brainstorming. Brainstorming is a creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously. During this step I started thinking about actions where people needed the most help and these thoughts guide me in my ideation process. My main objective was finding issues to solve in common everyday actions done with two hands that would be difficult with only one. Some of the actions that I found difficult were buttoning a shirt, folding clothes and grabbing heavier items.

The design must be new and include at least two mechanical movements, also the prototype should include one aspect that would be optimized in each iteration. Some of the ideas that came up were:

- Grabber arm: This device was thought up to have grips capable of collapsing around smaller round objects. This device could also telescope to reach items in high or low places for people who could not reach.

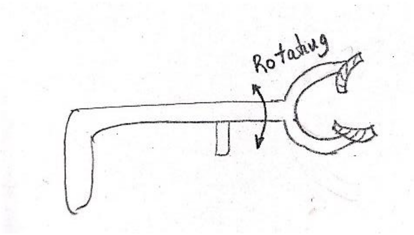


Figure 14 Grabber Arm

- Shirt folder: a string and pulley system that would be capable of folding a shirt quickly and easily.

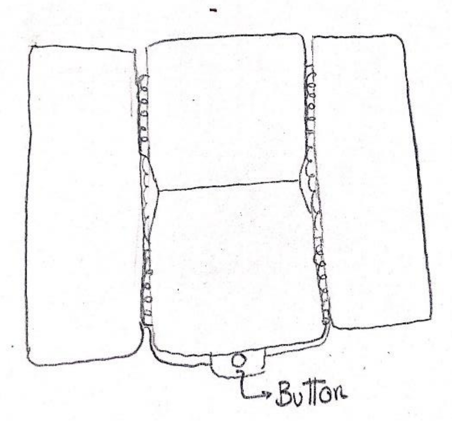


Figure 15 Shirt Folder

- Shirt buttoner: device capable of maneuvering a button through a shirt with only operation from one hand. The device would be gun-like, ideally requiring only a squeeze and wrist movement to use.

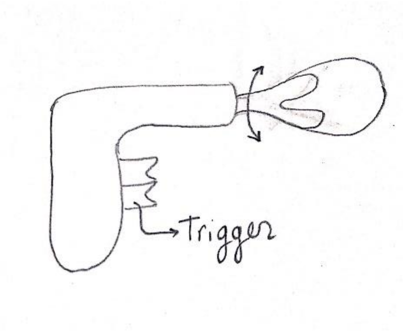


Figure 16 Shirt Buttoner

After a lot of thinking, I chose the shirt buttoner as the idea for my senior final project, due to it has a real world application and I can achieve a design compact and easy to use, and at the same time it will help people with disabilities as arthritis or amputees. The main difficulties of the project will be to design a device quickly working and able to pull together two pieces with one hand.

SWOT analysis

The SWOT analysis is a technique used to identify the Opportunities and Threats of the market and to understand your Strengths and Weaknesses. Once all this information is analyzed is easier to evaluate a product idea and develop a market plan and strategy to compete successfully in the market.

In the Table 4 is listed the SWOT analysis performed on the rough design of the shirt buttoner.

Strengths	**Weaknesses**
- Real world application - Compact, easy to use	- Product differentiation - Needs to work quickly
Opportunities	**Threats**
- Helps people with disabilities ie. Arthritis, amputees.	- Pull together two pieces with one hand - Buttoning action, pushing the button through the hole.

Table 4 SWOT analysis

Design tree analysis

The design tree is a decision technique that uses a tree model of decisions and their consequences. This technique allows to find solutions to potential problems that may occur. The design trees are used to achieve a decision analysis to help to identify a strategy to implement and reach a goal.

The diagram is composed of a central problem that is located in the core of the tree. The possible problem causes are described in the bottom of the tree. Finally, in the top of the tree it can be find the solutions that might be applied to reduce the problems that could appear.

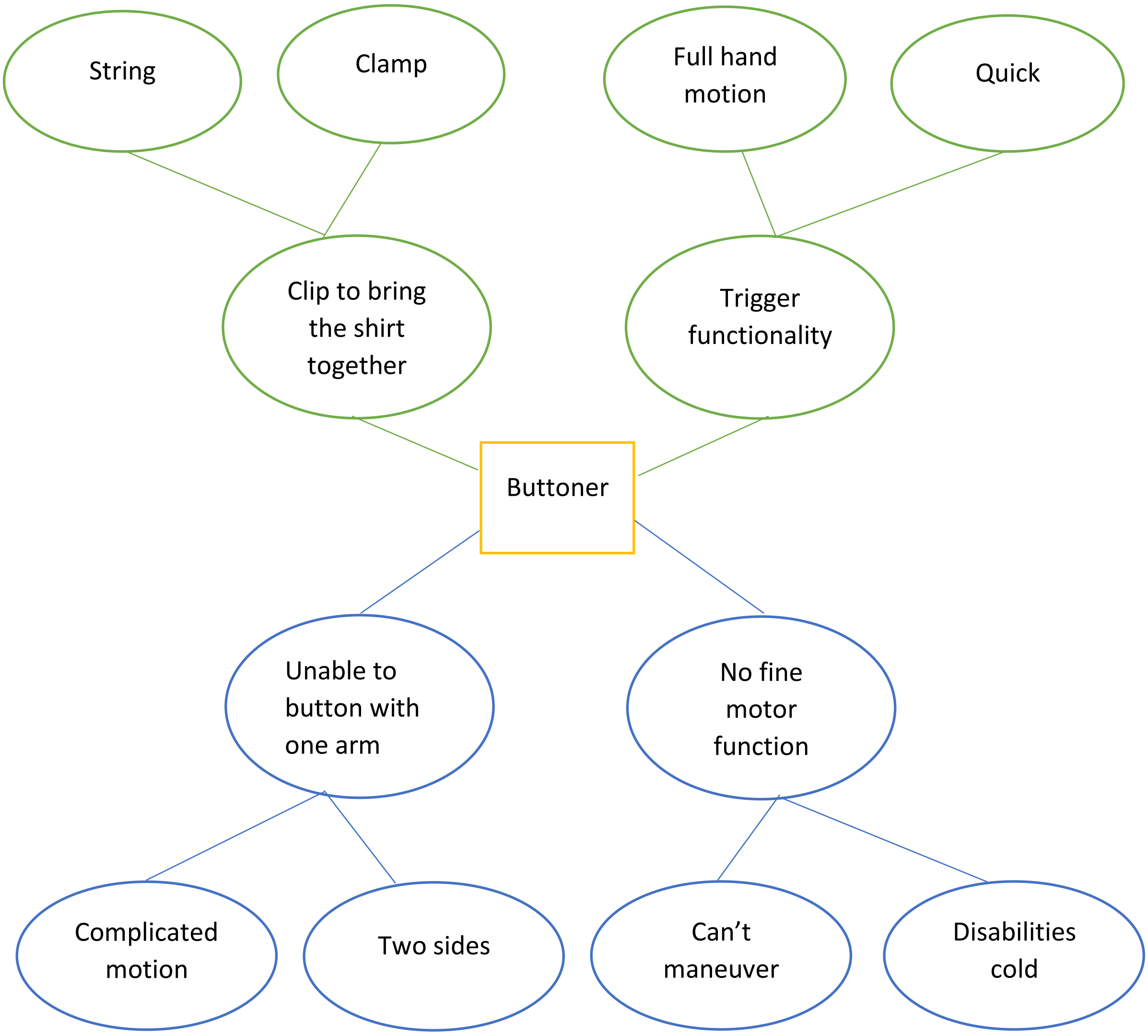


Figure 17 Design tree analysis

First designs

The initial design was intended to be a handheld machine using trigger functionality to maneuver two or more parts on the tip of the part. The two main functionalities of the initial design were to grab the button and manipulate the shirt and the button in order to move the button through without much effort from the user. I also thought of some ideas to use dials into the handle the device, these dials would act in similar ways to the triggers. Below are the first CAD designs of the initial design.

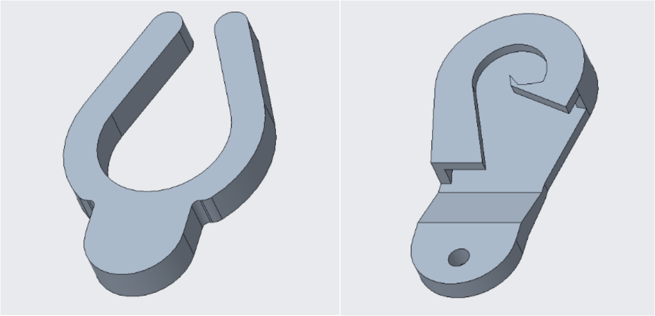


Figure 18 Hooks CAD designs

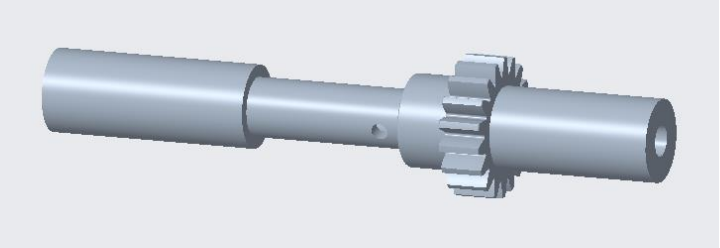


Figure 19 Dials CAD design

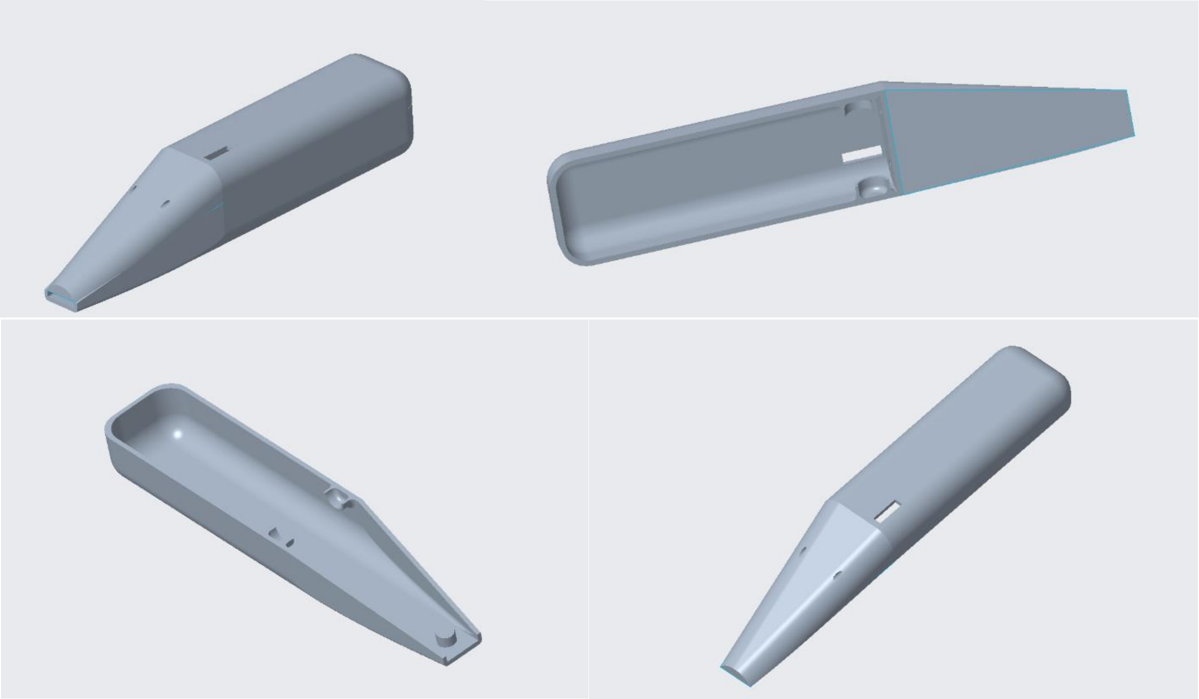


Figure 20 Dials body CAD design

Figure 21 First printed hooks designs

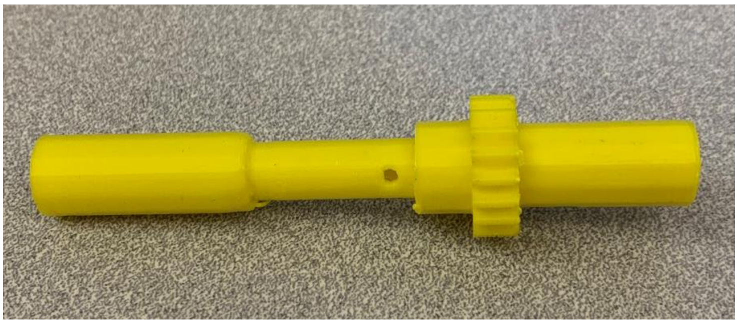


Figure 22 Printed dial design

In order to test the design, I create a platform with different button sizes to check the effectiveness of the different prototypes. The platform includes six different button sizes, the biggest has a diameter of 28 mm and the smallest a diameter of 14 mm.

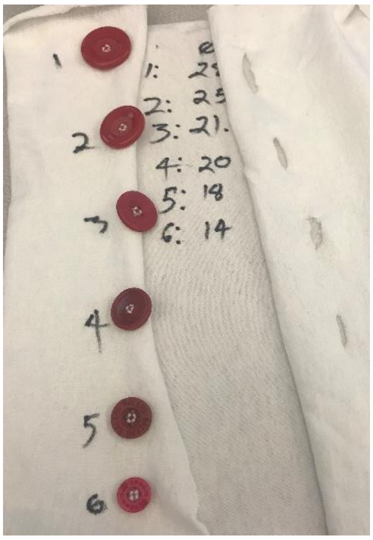


Figure 23 test platform

Prototype 1

Design description

From the primary idea of the trigger functionality, the first prototype ended in a four-bar system design due to how unwieldy the loop system was. The four-bar design was taken from research in a textbook in which I picked the path of the tip of the four-bar and then scaled the rest of the bars to create this motion. This mechanism enables a smooth, consistent sweeping motion in order to grab de button and pull it back. Down below scheme of the first prototype.

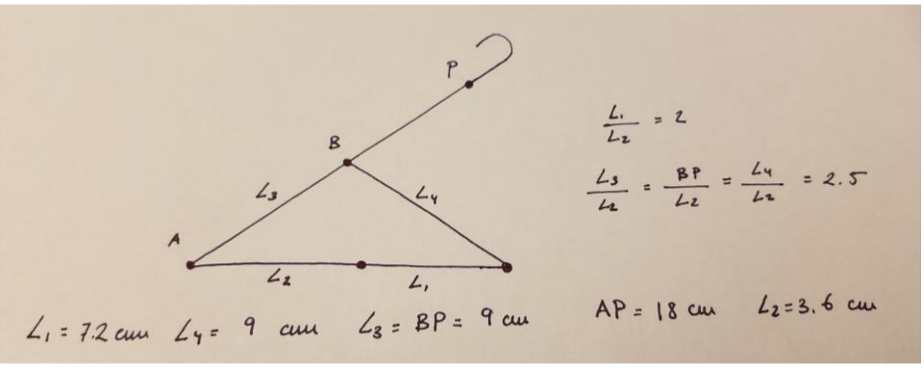


Figure 24 Four-bar system scheme

Within this prototype, the design was changed many times in order to achieve the most successful device. The first iteration was made of wood and was just created to check if the scale of the bar system was correct to achieve the path chosen. This design was flimsy and nearly ten segments were broken trying to drill holes for the pins, which were also shaky and kind of unreliable. It rubbed and squeaked but regardless it had the motion.

Figure 25 First iteration of the first prototype

The second iteration was 3D printed, the design was much smoother and easily to operate. The segments this time were designed too thick and overall it turned out to be a design bigger as first it was thought to be. The next step was to redesign the segments and try to make the prototype a little bit smaller so it will be easier to manage.

Figure 26 Second iteration of the first prototype

The third iteration was much thinner and also it included a gear in one of the bars. This gear will allow the movement of the bars due to the use of a gear track used as a trigger. This was the best iteration, but it was difficult to accomplish a smaller prototype. This iteration also included some different holes to attach the hook, so it can be studied which position is the most successful. As a result of the thickness of the segments, this iteration was not strong enough.

Figure 27 Third iteration of the first prototype

CAD design

First, I designed a physical hook which included snap-fits. Those snap-fits will allow an easy attachment to the four-bar system, I tried to find the easiest way to be able to change the position of the hook. The initial design of the snap-fits broke due to how small it was, so I design a platform with many different sizes of snap-fits to achieve a rigid yet small design.

Figure 28 First prototype hook CAD design

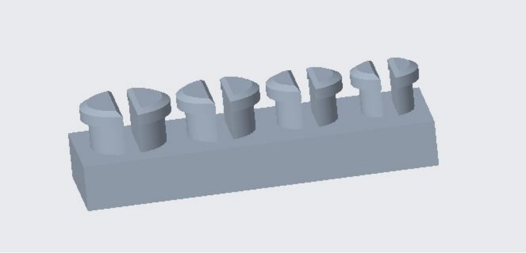


Figure 29 Snap-fits platform CAD design

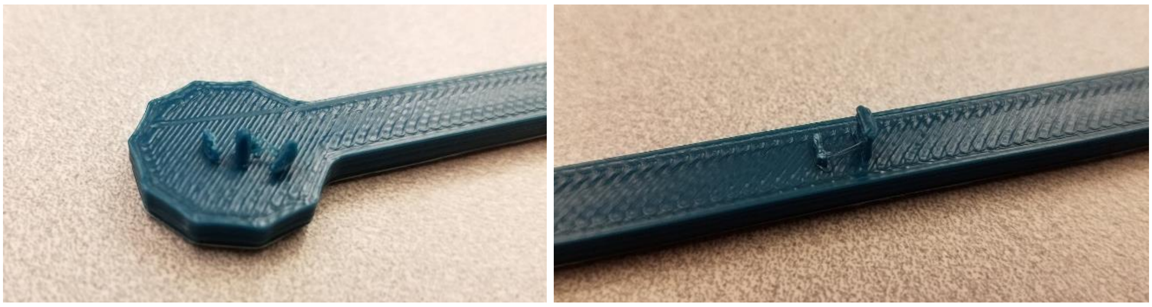


Figure 30 Failure of the first snap-fit design

Down below are some of the designs of the four-bar system, there are only three bars due to the design was thought to have two pivots stationaries, so segment one would not be necessary. However, the fourth bar was used in the prototype just as a space holder.

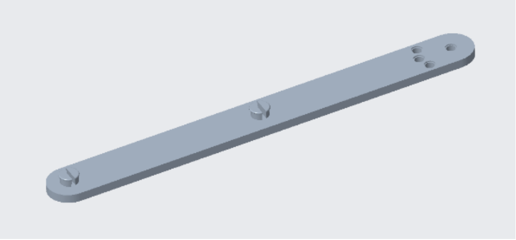


Figure 31 Segment three CAD design

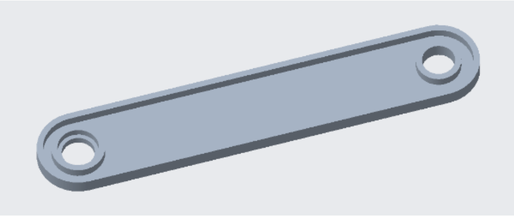


Figure 32 Segment four CAD design

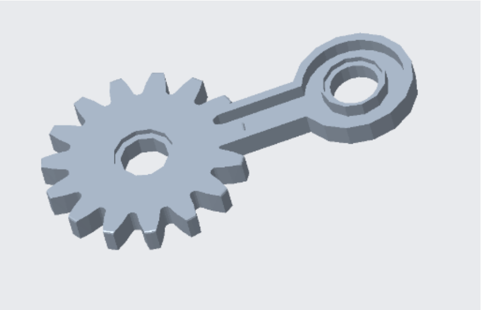


Figure 33 Segment two CAD design

Finally, is the design of the gear track used as a trigger to move the whole mechanism.

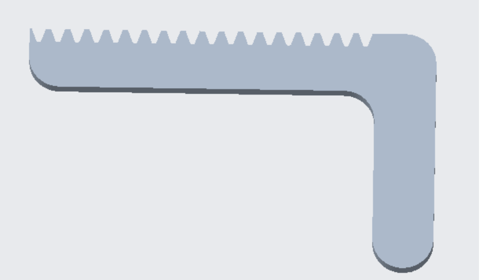


Figure 34 Gear track CAD design

Pros and cons

The benefits of this design are the easy mechanism to achieve a sweeping motion able to grab de button and pull it back, also to achieve the motion only a trigger will be necessary, so the user do not need to make too much effort. But unfortunately, there were more cons than pros. It was seemly impossible to scale down the prototype to achieve something manageable to manipulate. Also, other bad point of the design was it couldn’t get a full rotation, so the move was not enough to move the button through the hole. So many hours and effort were spent in this prototype, but it was a dead end, finally I decided to change the design.

Final prototype

Design description

The final prototype features a blend of all the prototypes in which I took what worked and discarded what didn't. A sweeping motion to grab the button was needed so I moved away from the 4 bar and toward the hook/switch idea. This method has also driven new geometries for the prototype in which I completely redesigned the body and the hook part. This final prototype works like so, first you stick the outstretched mechanism through the shirt button, then once you have approached the button, you slide your finger with the slider backwards pulling the hook closer between the button. Finally, once the button is firmly grasped, you simply pull the button through the hole. This prototype is the simplest one, but the most effective. The other designs that I tried all failed, so I opted for the most successful and simple design.

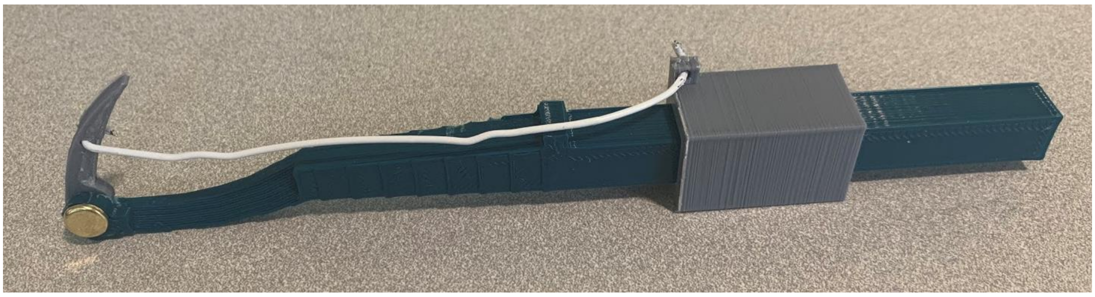


Figure 35 Final prototype

CAD design

After a lot of innovation and a lot of tweaks, these are final pieces of CAD for our product. After the testing of hook sizes and shapes in the DOE, I decided this design would be the most successful and efficient. The base part, being a long shaft followed by a curved half hook as the part of the clasp is what it has to be to grab the button. The base just serves the purpose of being long enough for the slider to move without opposition and to hook the button. The slider just allows the user to manipulate the wire that will be attached to the hook to change linear motion to rotational. The CAD is fairly simple in the fact that we had 3 parts that needed to function together. Only the hook needed a little bit of post processing to give a little sharp edge to the inside of it. Other than that, these parts fit together wonderfully with the help of the brass fastener and the wire piece.

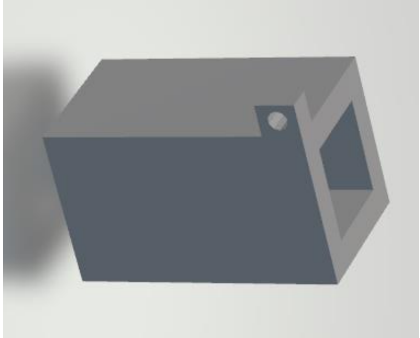


Figure 36 Slider CAD design

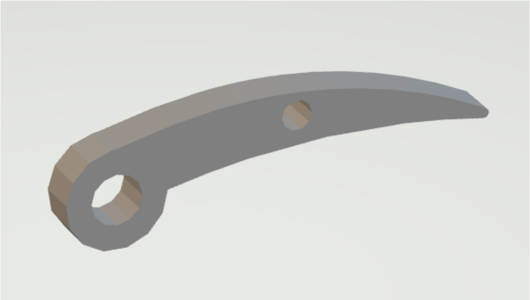


Figure 37 Hook CAD design

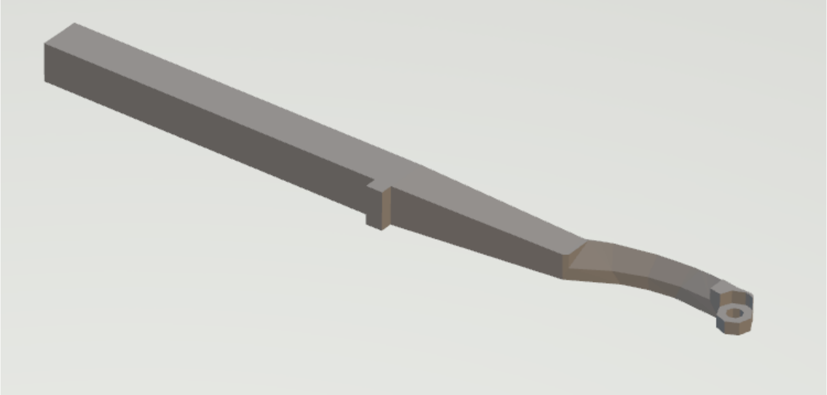


Figure 38 Base CAD design

Pros and cons

The main problem of the previous ideas and prototypes was the size of the design, finally with this last design I achieve a smaller and easier device to use. Due to its size and simple design, the user does not need to apply to much effort in order to button a shirt or a trouser.

On the other hand, one of its benefits is at the same time one of its weaknesses. Having developed a single and simple mechanism, it allowed greater efficiency with bigger sizes of buttons. As a result of the size of the hook when trying to button small sizes, buttons with a diameter less than two centimeters, the hook had little room to maneuver and it used to stay clipped around the hole.

Future Steps

The essential future step is to improve the effectiveness of the design. Not only is it intended to improve the number of successful attempts, but also to expand the number of different button sizes able to buckle. In order to achieve this, different sizes of hooks will be designed, to be chosen depending on the button. To make it easy to change the hook, the hitch system will be redesigned.

Instead of using pins to join the base and the hook, snaps-fits will be used. Thanks to the previous prototype, different types of snap-fits were tested. With snap-fits is intended to make the change of the hook easy and fast but at the same time ensure that the union is rigid.

On the other hand, the design of the wire joining the hook with the slider will be also improved. Because the wire is above the hook, on many occasions it was what caused the device to hook up with the hole and not allow the correct buckle.

Also, as is mentioned bellow the DOE experiment was done with the four-bar system prototype, then other future step is to realize the experiment with the current prototype design, trying to improve as much as possible the device.

DOE experimentation and optimization

Introduction

The purpose of the DOE experimentation is to plan a product parameter optimization approach and carry out one design experiment with analysis demonstrating of the product improvement. The first step of the experimentation is to brainstorm which aspect of the product should be improved and why. After that, the next step is to decide which variables have a causal relationship with this aspect and how can they be changed. Finally, is important to decide how these changes will be measured, because if there is not any procedure to measure with precision the changes, the design cannot be improved. Due to the long time and effort invested in the four-bar system prototype and the believes that this design was the most fruitful, the DOE experiment was tested with that design.

In the design for the experiment, I have decided to optimize the hook of the prototype. The hook, being one of the most important pieces of the prototype, seemed like a good burst to optimize because it would cause the most change for the better in the success of the product. I chose to manipulate the hook in ways that would increase the success of grabbing the button, keeping the button under control, and being able to manipulate the button through the buttonhole. I did this by varying the size/scale, the design, the angle as compared to the rest of the prototype, and the speed in which we approach the button. Using these variables, I attempted to find the right combination for favorable, consistent outcomes.

For the first variable, I chose to vary the size of the hook. As it was impractical to print out two completely different hooks, we used relative size by running the experiment with the button. I had two sizes of buttons and two sizes of hooks. I tested the two scales to see if a larger hook would be more beneficial in grabbing and maintaining control of a similar button size. Next, I measured how a design change would affect the outcomes. The two designs of hooks were as follows: one hook had a straight horizontal hook (Figure 39) and the second hook had the point aiming down at about a 45-degree angle (Figure 40). The third experiment that I tested was the angle that the hook was positioned at on the rest of the prototype. The hooks were positioned 30 degrees apart from each other.

I tested this to see if the degree change had any effect on the motion needed to grab the button successfully. The final test that I did was the speed in which the hook would be moved. The second speed was about double the first. I tested this to make sure that if the speed was faster or slower, it would not affect the success of the hook.

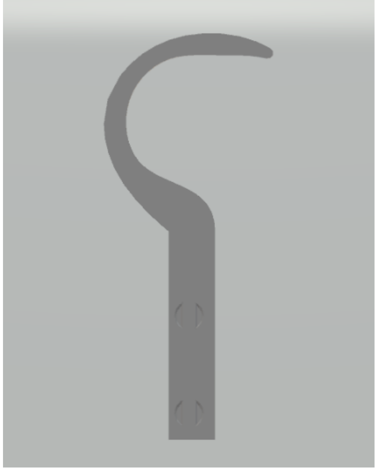


Figure 39 First hook design

Figure 40 Second hook design

Running the DOE

For practicality, the experiments were run in a method that required the least amount of part-swapping possible, changing only the speed first, then relative size, then hook angle, then hook style. Other than convenience, the order did not affect the results. Some problems did occur during the DOE, namely snagging on the shirt. This was the main cause of failure, and happened at least once per ten trials, the other failure being the button not catching onto the hook, which occurred less commonly. One way to improve this method would be to improve the test platform with heavier fabric with more consistent cut patterns for holes. All measurements in trials were taken once unless a part became loose during testing, which only occurred twice.

Analysis

The following figures show the complete DOE Design Matrix for the four-bar system design.

	Hook Shape	Angle	Size	Speed	Result 1	Result 2			
Test	X1	X2	X3	X4	Y1	Y2	Y average	Std. Dev.	Variance
1	1	1	1	1	5	4	4,5	0,707	0,5
2	1	1	1	-1	6	5	5,5	0,707	0,5
3	1	1	-1	1	4	8	6	2,828	8
4	1	1	-1	-1	6	4	5	1,414	2
5	1	-1	1	1	3	3	3	0	0
6	1	-1	1	-1	5	7	6	1,414	2
7	1	-1	-1	1	3	6	4,5	2,121	4,5
8	1	-1	-1	-1	4	7	5,5	2,121	4,5
9	-1	1	1	1	4	6	5	1,414	2
10	-1	1	1	-1	5	7	6	1,414	2
11	-1	1	-1	1	5	3	4	1,414	2
12	-1	1	-1	-1	3	5	4	1,414	2
13	-1	-1	1	1	5	5	5	0	0
14	-1	-1	1	-1	6	5	5,5	0,707	0,5
15	-1	-1	-1	1	7	7	7	0	0
16	-1	-1	-1	-1	8	7	7,5	0,707	0,5

Table 5 Design matrix

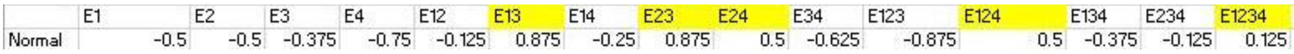
The system standard deviation and average system variance were calculated, Table 6 displays de results.

System Standard deviation	1,938
Average System variance	1,149
2-Sigma threshold	2,298

Table 6 Deviation and variance results

The main effects (E1, E2, E3, E4) and the interaction effects (E12, E13, E14, E23, E24, E34, E123, E124, E234, E1234) are calculated to analyze the average effect of each variable. The sign of the effect gives the information about if the variable increases or decreases the output. Down bellow in Table 7 is collected the results of the main and interaction effects.

The 2-sigma system standard deviation is the value that determines whether an effect is significant or not. In this case, if any effect calculated is greater than 2,298, it shows that is decisive por the process. As it seen down below in Table 7, any of the effects calculated seem significant.



	E1	E2	E3	E4	E12	E13	E14	E23	E24	E34	E123	E124	E134	E234	E1234
Normal	-0.5	-0.5	-0.375	-0.75	-0.125	0.875	-0.25	0.875	0.5	-0.625	-0.875	0.5	-0.375	-0.125	0.125

Table 7 Main and iteraction effects

To contrast the result, also the graphic method was used. Table 8 displays the effects sorted form lowest to highest. Also, the table shows the standard deviation of the cumulative probability.

Rank	Main Effect value	Probability	Standard Deviation	Effect
1	-0,875	0,0313	-1,863	E123
2	-0,75	0,0938	-1,318	E4
3	-0,625	0,1563	-1,01	E34
4	-0,5	0,2188	-0,775	E1
5	-0,5	0,2813	-0,579	E2
6	-0,375	0,3438	-0,402	E3
7	-0,375	0,4063	-0,237	E134
8	-0,25	0,4688	-0,078	E14
9	-0,125	0,5313	0,0784	E12
10	-0,125	0,5938	0,2372	E234
11	0,125	0,6563	0,5791	E1234
12	0,5	0,7188	0,7764	E24
13	0,5	0,7813	1.101	E124
14	0,875	0,9063	1.318	E13
15	0,875	0,9688	1,863	E23

Table 8 Sorted main effects

Figure 41 displays the cumulative probability of main effects. The y-axis corresponds to the value of the main effect and the x-axis to the standard deviation.

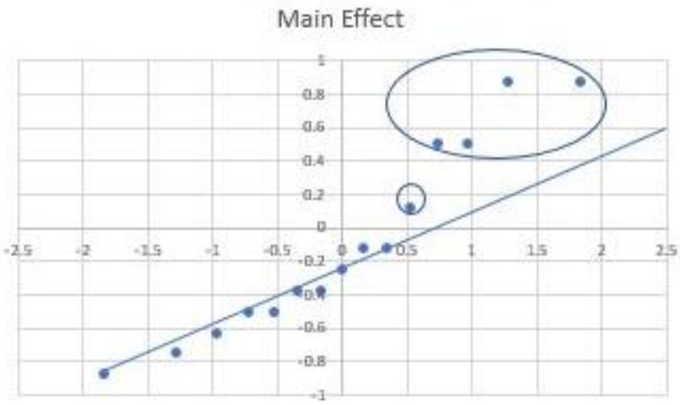


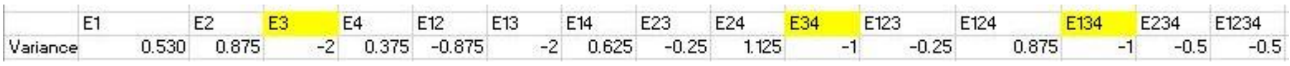
Figure 41 Cumulative probability of the main effects

As it can be seen, five effects are significant. The deterministic effects were used in the characteristic equation to predict the output value.

$$\mathbf{Y} = y_{\text{ave}} + \frac{E13}{2}(x_1)(x_3) + \frac{E23}{2}(x_2)(x_3) + \frac{E24}{2}(x_2)(x_4) + \frac{E124}{2}(x_1)(x_2)(x_4) + E1234(x_1)(x_2)(x_3)(x_4) =$$

$$= 6{,}6875 + 0{,}437x_1x_2 + 0{,}437x_2x_3 + 0{,}25x_2x_4 + 0{,}25x_1x_2x_4 + 0{,}0625\, x_1x_2x_3x_4$$

Finally, the noise effects were calculated to be able to perform one last method, which is characterized by minimizing the variability. As in the main effects, neither of the noise effects are significant in this case. The residual effects were also sorted and plotted to check if one of them is significant for the process.



	E1	E2	E3	E4	E12	E13	E14	E23	E24	E34	E123	E124	E134	E234	E1234
Variance	0.530	0.875	-2	0.375	-0.875	-2	0.625	-0.25	1.125	-1	-0.25	0.875	-1	-0.5	-0.5

Table 9 Noise effects

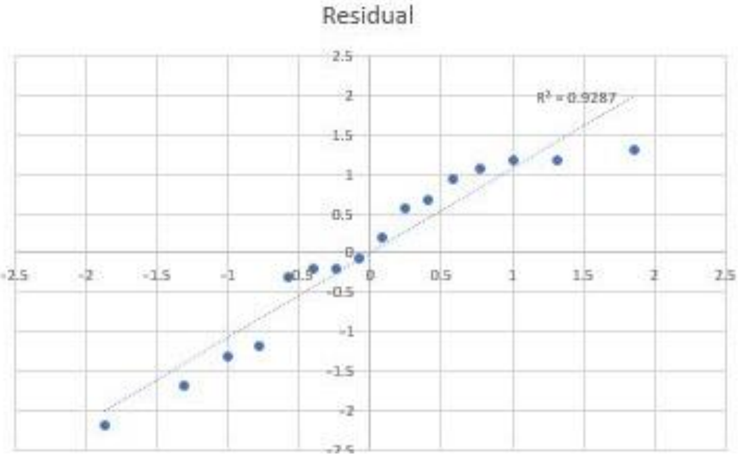


Figure 42 Cumulative probability of residuals

To minimize variance, each variable should be set to high. This produces an overall success count of 6.69 out of ten trials theoretically. These results could be improved by improving the test platform and through running more trials per test. However, this DOE method is extremely time consuming, requiring a total of 320 total trials, swapping parts between to produce the results shown.

Conclusion

The conclusions were to make the hook the wider design, make the angle of the hook wider, make the hook larger, and to maximize the speed, which is actually extremely unexpected. The methods in testing these variables worked well with what my main purpose that was trying to make a product that creates on target, consistent outcomes. I think in this case, I used the most efficient approach possible in the way the data was collected in order to make the prototype as efficient as possible. But, after running all the test by counting successes out of ten, I found that any single variable was significant, even in the variance there was not any data useful.

With this knowledge, I tried to move forward in improving other parts of the prototype, with these prior results in mind. Even though I tried to make some new designs of experiments that I could use to improve the design and how I could make the device simple and easy to use for the user. But the four-bar system had only an optimized success of almost seven grabs over ten, which just was not enough, so the best solution was to restructure the design.

DFA

Introduction

During the course, it has been learnt how to realize a DFA analysis and how to analyze the results. First of all, the design of assembly analysis was performed with a little fan in order to learn and practice. The process starts with the disassemble of the fan and then, the next step is to measure all the components before reassembling them. Once the fan is dissembled, the next step is to calculate and record the α and β values of each component, and with the tabulation approximations find the handling and insertion time. Also, any extra time must be added for any size or handling difficulty, snaps or insertion difficulties, and finally calculate the total operational time.

After the total operational time is calculated, it must be compared with the current time it takes to reassemble the fan. Through this analysis, it can be found if each component of the design is included in the theoretical minimum number of parts or not, and then minimize the parts and create an easy and functional assembly process for the product.

Results and Discussion

First, there is the base piece of our product (Figure 44). This piece is absolutely necessary to the success of the product and has been innovated and optimized throughout the timeline of the project. Since it is the main piece of our prototype it will have 360 degree alpha and beta symmetry because it has to be placed in a certain spot for all the other pieces to fit properly. This part does not have any handling, alignment, inserting or securing difficulties.

Next, there is the hook piece of the product (Figure 45). This piece is also necessary because it has an important function in the clasping around a button function and it moves on its own from all the other pieces. This pieces alpha and beta symmetries are also 360 degrees just because the hook only fits the base in one way. This part does have an alignment to a medium hole on the base piece.

The slider piece (Figure 46) is also a necessary piece of the prototype because it is the contact point for the user and moves the wire to move the hook. This piece also has 360 degree alpha and beta symmetry because of the latch point on the paper clip. The slider has an alignment to a large hole on the base piece.

A brass fastener (Figure 47) is what holds the base piece to the hook. This part is not necessary seeing how it could be replaced with a snap fit. However, because of the accuracy and tolerancing of the undergraduate 3D printers, the snap fits were not able to be created at this small of a scale. Therefore, I moved forward with the brass fastener to hold the pieces together. The fastener has 360-degree alpha symmetry and 0 degree beta symmetry. The fastener has an alignment to a medium hole through the base piece and the hook. It also has two hold difficulties in which the part needs to be held down while the prongs of the fastener need to be peeled down.

The final part is a piece of wire (Figure 48) used to manipulate the hook from the movement of the slider. In this design, the wire is not necessary because it connects the movements of the slider to the hook but can be consolidated into one solid piece. However, with a possible redesign, I could see how the wire may not be needed to achieve the same motion. The wire has 2 alignments to 2 small holes in the slider and the hook which also both need to be manipulated through the holes by bending the wire. The wire has alpha symmetry of 360 degrees and beta symmetry of 180 degrees.

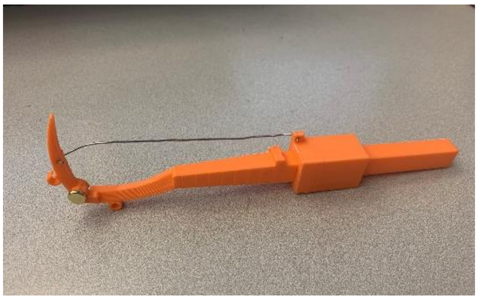


Figure 43 Assembled design

Figure 44 Base piece

Figure 45 Hook piece

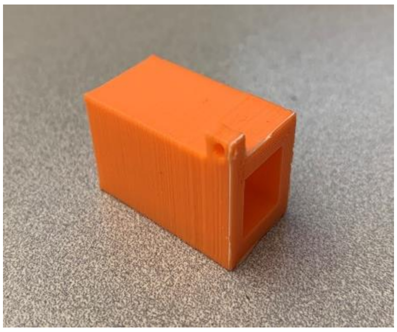


Figure 46 Slider piece

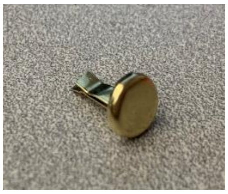


Figure 47 Brass fastener

Figure 48 Wire

Conclusion

The way that the product is designed was at all times conscious of how easy the whole experience of using this product would be, no matter if it was in use, assembly, or repair. During the design for assembly lab, I learned how important it was to minimize parts and maximize efficiency. It has been noticed that the assembly of the product would be paramount in the cost of an actual product and how much the market value would be.

The theoretical minimum of parts is 2. By implementing a snap fit at the pivot point and combining the hook, slider, and wire into one piece, it can get the number of parts down to a minimum. However, designing the hook, slider, and wire into one piece is rather impractical at this stage and would likely take weeks of brainstorming and tweaking. Similarly, using a snap fit to combine the joints, and thus removing the need for a pin, is too small and fragile with the printers that it can be used and therefore cannot be constructed on such a small scale. That is why it has been chosen to go with 5 pieces instead of the minimum.

Two things have been thought that could improve with the assembly time, that would be to remove the brass fastener and to find a way to make the wire piece more efficient. It could be replaced the brass fastener by using a snap fit so that the part could still rotate but would be using less parts. It could also be made the wire more efficient by replacing it entirely by another part or by making it easier to assemble to the hook and slider. These improvements would make significant improvements to the assembly time without compromising functionality. Through these ideas, the product would not only become much easier to assemble, but also easy to take apart and repair. In the end, the progress that have been made into the betterment and innovation of the product is outstanding and has led to a product with unlimited potential and exceptional functionality.

Resources

The Creo parametric 3D Modeling Software CAD program was used in order to design the different pieces of the project. Once de design was done it was 3D printed in the innovation studio of the University of Illinois. The material used in 3D printing was the Fused Deposition Modeling due to is the most cost-effective rapid prototype method available. The machine used to print out the part is called Lulzbot TAZ 6. It counts with a tool head TAZ Single Extruder v2.1, 0,5mm nozzle and a layer resolution of 0,05mm-0,4mm. It also has a print area of 0,28m x 0,28m x 0,25m and its maximum travel speed of 200mm/sec. The material used was PLA due to its compatibility with the Open filament system. The unit cost was USD 0,03 per gram.

Figure 49 Lulzbot TAZ 6 [Source: https://www.lulzbot.com/store/printers/]

Other materials as cork board and buttons were used in order to make some parts of the prototypes and the platform test. The total budget for this project was USD 200, figure 50 displays the waterfall budget. Around USD 60 were spent in 3D printing due to the multiple prototypes and iterations done, but, actually print the final design only cost USD 1.

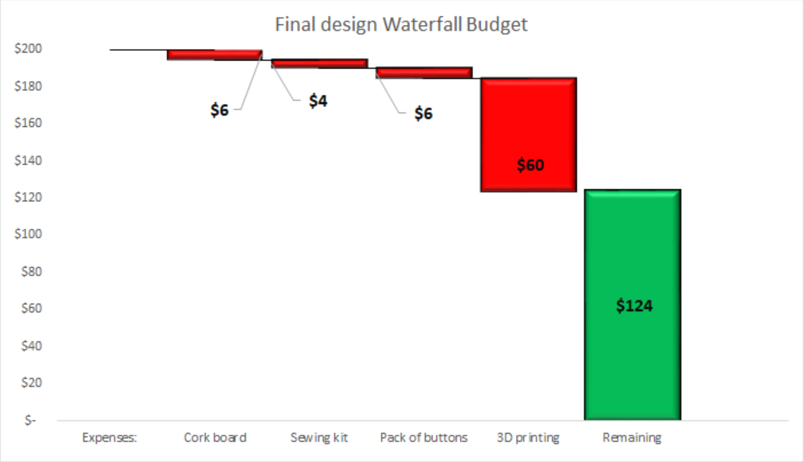


Figure 50 Waterfall Budget

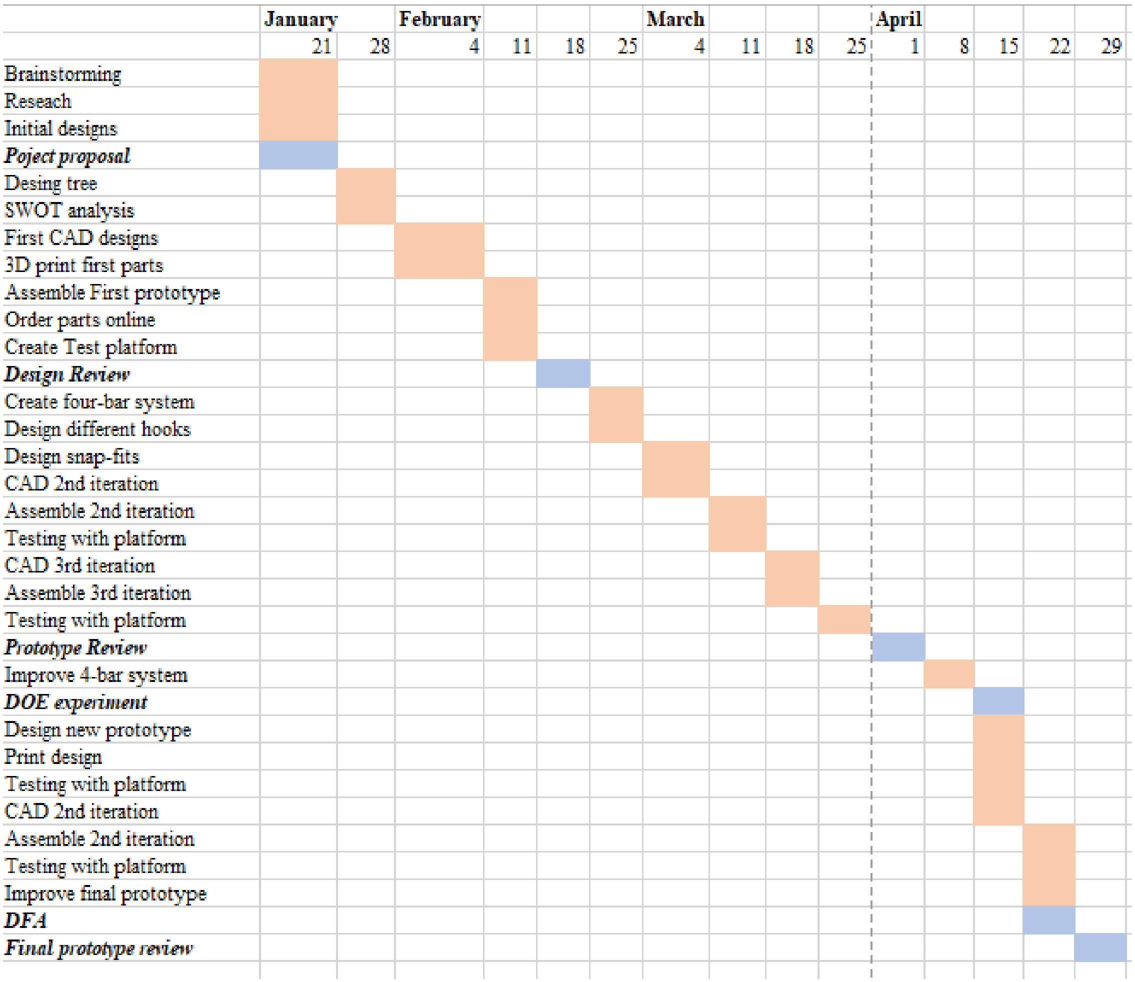
Management plan

During the second semester has been several presentations and deliveries to ensure the good development of the project. Table 10 displays the most outstanding dates. Table 11 shows a Gantt chart with all the progress realized during the semester.

Event	Date
Project Proposal	21st January
Design Review	18th February
Prototype Review	1st April
DOE test	15th April
DFA test	22nd April
Final prototype Review	29th April

Table 10 Outstanding dates

Gantt chart



	January		**February**				**March**				**April**				
	21	28	4	11	18	25	4	11	18	25	1	8	15	22	29
Brainstorming	🟧														
Reseach	🟧														
Initial designs	🟧														
Poject proposal	🟦														
Desing tree		🟧													
SWOT analysis		🟧													
First CAD designs			🟧												
3D print first parts			🟧												
Assemble First prototype				🟧											
Order parts online				🟧											
Create Test platform				🟧											
Design Review					🟦										
Create four-bar system						🟧									
Design different hooks						🟧									
Design snap-fits							🟧								
CAD 2nd iteration							🟧								
Assemble 2nd iteration								🟧							
Testing with platform								🟧							
CAD 3rd iteration									🟧						
Assemble 3rd iteration									🟧						
Testing with platform										🟧					
Prototype Review											🟦				
Improve 4-bar system												🟧			
DOE experiment													🟦		
Design new prototype													🟧		
Print design													🟧		
Testing with platform													🟧		
CAD 2nd iteration													🟧		
Assemble 2nd iteration														🟧	
Testing with platform														🟧	
Improve final prototype														🟧	
DFA														🟦	
Final prototype review															🟦

Table 11 Gantt chart