Coursework Declaration and Feedback Form

The Student should complete and sign this part

Student Number : 2513298r	Student Name : Karol Rabalski
Course Code : EXT5164	Course Name : Product Design Engineering (T)
1st Supervisor Nikolaj Gadegaard	2nd Supervisor Nick Bell
Title of Assignment : Improving Video Game Controllers	
Declaration of Originality and Submission Information	
I affirm that this submission is all my own work in accordance with the University of Glasgow Regulations and the School of Engineering requirements Signed (Student) : Karol Rabalski	EXT5164
Date of Submission : August 10, 2020	

Feedback from Lecturer to Student – to be completed by Lecturer or Demonstrator	
Grade Awarded: Feedback (as appropriate to the coursework which was assessed):	
Lecturer/Demonstrator:	Date returned to the Teaching Office:

MSc Product Design Engineering 2020

Technical Report: *Improving Video Game Controllers*

By: Karol Rabalski

Executive Summary

The input layout for a standard video game controller has remained static for over 20 years. This means that issues with accessibility have remained present throughout several generations of video game consoles. There is a need to adjust the physical layout of the standard video game controller for a user with disabilities and provide access to all of the normal inputs.

The technical objectives of this project and report as agreed upon with the technical supervisor are as follows:

- Documenting of sound engineering decisions throughout the project
- Ensuring the final design is accessible, sturdy and feasible
- Appropriate selection of materials and components
- Appropriate selection of manufacturing process
- Approximate cost calculation of manufacturing the product

Due to the COVID-19 pandemic, access to proper testing materials, lab equipment and workshop machinery was limited. A majority of research was completed through internet searches, with some interviews with professionals. Physical testing relied on cardboard prototypes and a 3D printed model. These prototypes illustrate the physical layout of the product and how a potential user would interact with it.

The final design is a unique solution which is feasible. A 3D model of the product and engineering drawings were produced using the CAD software Fusion 360.

A cost estimate was created, taking into account the materials and manufacturing methods. Chosen materials and components for the final product were based on existing video game controllers. The final cost is comparable with what is currently available on the market.

Though the intention of the product is to accommodate different levels of accessibility in users, this project focused on one case in particular, which proved to be successful given the limits of available interactivity.

Table of Contents

List of Figures

1.0 Nomenclature

Notation	*Description*	*Unit*
ρ	Density	kg/m^3
F	Force	N
m	Mass	kg
a	Acceleration	m/s^2
C_{pp}	Cost per part	£
C_m	Cost per kg of raw material	$£/kg$
f	Scrap fraction	$dimensionless$
C_t	Cost of dedicated tooling	£
n	Number of parts produced over production life	$dimensionless$
n_t	Number of parts produced during tool life	$dimensionless$
$\dot{n}$	Cycle time	$parts/hour$
C_c	Capital cost	£
L	Load factor	$dimensionless$
t_{wo}	Capital write-off time	$hour$
$\dot{C}_{oh}$	Overhead rates	$£/hour$

2.0 Introduction

2.1 Background

Video games are a massive form of entertainment, appealing to an incredibly diverse user base. With over 31 million gamers in the UK [1] and a total market value of £152.1 billion in 2019 [2], it is an industry that is always evolving and growing.

Video game controllers, or gamepads, are the primary input device used to interact with video games and video game consoles. Standard gamepads range from £50 for first-party OEM products, to £150 for premium controllers that feature special inputs.

Although there have been some changes to the overall shape of a video game controller, the input layout across all platforms has remained roughly the same over the last 20 years (Figure 1). While some issues with anthropometrics and reliability have been addressed over time, the physical layout has never been modifiable to accommodate for users with accessibility issues.

Figure 1: Traditional inputs as seen on an Xbox One controller.

Disabled gamers have often relied on third party hardware and software solutions. These can be expensive and tedious to use. Options such as the Axis 4 Pro Controller are expensive, (sold for approximately £375 [3]) and quite large. Another option, the Xbox Adaptive Controller, is a step in the right direction, offering users the ability to attach their own inputs, creating endless solutions to a wide range of disabled gamers. However, additional components can be expensive, with a single button costing £50 [4], and may be an excessive solution for users with less severe accessibility issues. Software solutions can also be troublesome, with some hardware presenting compatibility issues and requiring fine-tuning.

2.2 Users

Three disabled gamers were interviewed for this project. They were asked about the different platforms they use, current solutions they rely on, and what they would like to see from an "ideal" controller. Each user also had a different degree of accessibility:

- User #1 suffered a stroke and is unable to use their left hand.
- User #2 experiences muscle tremors and has issues with activating inputs.
- User #3 has cerebral palsy and has limited use of their right hand.

Two of the interviewed users had tried to use the Adaptive Controller. Though they appreciated the product and it's features, they felt that they personally were not the target audience, because their movement was not restricted enough to invest in and make full use of the controller. In addition, a standard gamepad was more comfortable to hold and featured inputs that were easier to access, even if not all of them were within reach.

Figure 2: Left to right, User #1, User #2 and User #3.

All three users currently use the Xbox Elite Controller; a premium gamepad marketed at hardcore gamers. It retains the same shape and input layout as a regular controller, but features 4 additional inputs on the rear, and allows all buttons to be remapped through software. Though it has proved to be the most reliable solution for each user, it is not perfect, as there are still several inputs that they are unable to access.

Because of the interest in using a standard controller, there is a need to adapt the standard gamepad for users with accessibility issues, without introducing extensive reliance on expensive, additional hardware.

2.3 Aims

The aim of this project is to design a video game controller that allows for a standard layout to be easily adapted for a user with accessibility issues. A modular solution would allow users with a disability to purchase the same standard controller as everyone else, but customize it to their needs.

Ideally, this product would benefit a wide range of disabled gamers. However, for the scope of this project, much of the design and prototyping is based around User #3. This is because their level of accessibility is more manageable and could provide further insight to users with more severe limitations. The goal is to make this functional, and present a feasible product that would not fall apart during use, or that would be impossible to manufacture. In addition, a design goal was set to make this product usable with one hand. Allowing the user to feel a sense of autonomy is important.

3.0 Design Process

At the start of the project, the initial focus was on improving repairability and customization of video game controllers. It was speculated that if gamepads were easier to repair, the relationship between video game controllers and their owners would improve, and users would be less likely to discard them, reducing e-waste. Issues with accessibility were considered, but not fully understood until several weeks into the project.

A group of 25 gamers were surveyed online to get feedback about their controller use and repair habits. Though reactions were in favour of a modular controller, they were not as strong as anticipated, and very few users had actually discarded their controllers.

In addition, while re-evaluating the disassembly process of a DualShock 4, the standard gamepad for PlayStation 4 (Figure 3), it was noted that although the process was tedious, it was not impossible. Repairs for common issues, or general customization could completed by an individual of any skill level without significant trouble. Some improvements could be made, such as making the plastic shell easier to separate, or improving the security of internal components, however none of improvements these felt significant enough for a full term project.

Figure 3: Disassembled DualShock 4

At this point, complete focus of the project was shifted to accessibility, which has always been a concern in gaming. One-in-three disabled gamers have been forced to stop playing video games due to their disability [5]. The three users described in Section 2.2 were discovered through an online forum for disabled gamers. Audio and video interviews were conducted to learn more about their experiences.

Each user was asked about the most comfortable position for them to hold a controller (Figure 4). In addition to the Elite controller, User #2 demonstrated a comfortable grip using a canister, and User #3 showed a 3D-printed frame that they used to be able to control Nintendo Joy-Cons (the input device for a Nintendo Switch) with one hand. When considering these "ideal" positions, it was clear that they did not take form of a standard layout, hence the need for it to be changed.

Figure 4: Left to right, Users #1, #2 and #3 demonstrating comfortable hand grips.

The generative design module in Fusion 360 [6] was considered as a possible tool to determine a solution. Given the unique, preferred hand position of User #2, and considering the millions of other disabled users that may favour different positions, it was theorized that if a generative process could successfully be used to design a bespoke controller for at least one user, it could be easily replicated for other disabled gamers.

However, using the software proved to be troublesome. Generative design is typically used in scenarios where large static loads are applied such as the frame for a car. Figure 5 shows the result of one of the generative design solutions based on User #2's "ideal" hand grip. The solution would not compute until fixed surfaces were applied to the top and bottom of the object and the forces acting on each button were increased to 50 N (face buttons) and 100 N (analogue stick) which greatly exceeds the recommended 6 N maximum resistance of a push button [7]. In addition, the result would require custom internal electronics as well as custom shaped buttons for every single outcome. This would likely lead to an incredibly expensive solution, even beyond the price range of currently available premium hardware. 3D printing may be possible to create bespoke solutions as the one seen below, but with questionable structural quality.

Figure 5: Sample of generative design from Fusion 360.

In addition to the generative design model, a cardboard prototype (Figure 6) was created based on feedback from User #2. The result was a uniquely shaped controller, offering an input layout unlike anything that standard gamepads offer. However, similar to the generative model, many of the electrical components would have to be re-designed and would likely not have been able to be adapted from a regular controller.

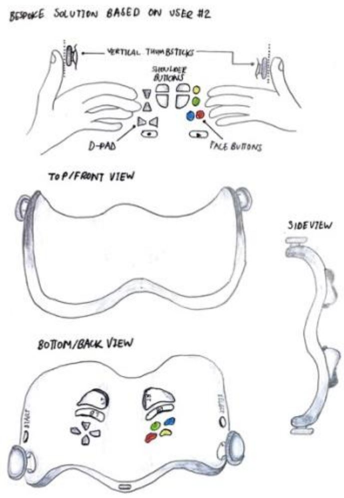


Figure 6: Sketch (left) and cardboard prototype (right) for User #2's bespoke solution.

The insights from the users showed that while products such as the Xbox Adaptive Controller are useful, its larger form factor is not always ideal. The insights from the generative design and cardboard prototyping showed that bespoke solutions are not easily adaptable from existing products. Each user liked their current controllers, they just wished that more inputs were accessible.

Creating an add-on to fit over top of the controller would have been a mechanical challenge, and would likely be cumbersome. For example, User #3 wanted all of the front facing buttons moved to the left side. In order to do this without adding inputs or physically moving the existing inputs, some kind of lever that would extend between the front facing buttons and the left rear (where their unused fingers rest) would have to be secured over the surface of the controller. Though this might work for buttons as they require a single press, controlling an analogue stick through movement with another object at distance is extremely difficult. A comparison would be a driver trying to shift gears, but is unable to place their hand directly on the gear lever. In addition, there is the issue of this mechanism interfering with other buttons as it reaches across the gamepad.

Sketches and 3D models such as those seen in Figure 7 were further developed and paved the way into the final design which would see a traditionally shaped gamepad with the ability to change the input layout. Faceplates on the front and rear could be swapped to accommodate a different setup, and the internal components could be moved about freely, as long as they connect to the PCB.

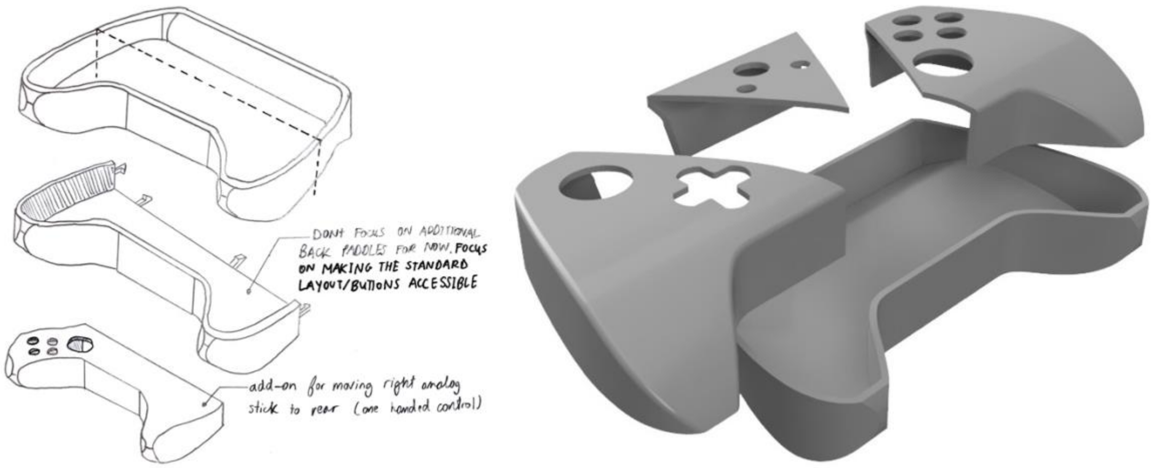


Figure 7: Initial sketches and CAD model for a modular shell.

Once a final design direction was selected, the next stage of the project involved research and selection of materials, components and manufacturing processes. The manufacturing of a video game controller is relatively straightforward, and wouldn't require specialized techniques; many components have remained the same for decades. Figure 8 compares components from a 2013 DualShock 4 controller to a 2001 third-party N64 controller. They are slightly different in shape, and are arranged differently on a PCB, but they are made of the same material and perform the same function.

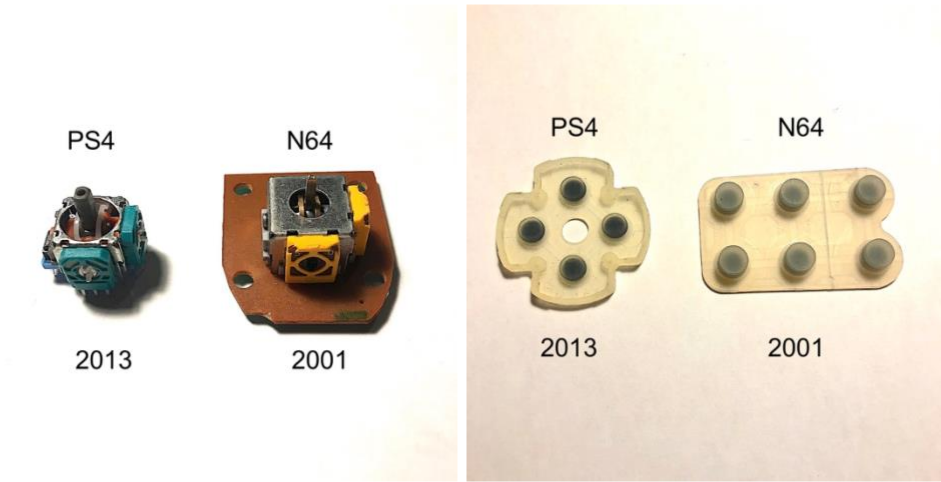


Figure 8: Comparison of analogue modules (left) and button pads (right).

As the materials and manufacturing were assessed, so was the feasibility of the design. The final product underwent some changes, and will be fully detailed in Section 8.0.

4.0 Materials and Manufacturing Process

4.1 Shell Materials

As with most electronics, video game controllers are composed of plastic and silicon. Disassembling both the DualShock 4 and Xbox One controllers revealed the material stamps on the inside of each shell, (Figure 9) with the DualShock 4 being made of ABS (acrylonitrile butadiene styrene) and the Xbox One controller being made of PC+ABS (a blend of polycarbonate and ABS).

Figure 9: Material codes on an Xbox One controller (left) and DualShock 4 (right)

A qualitative analysis was completed to compare the strengths and weaknesses of these two materials with a few others, and show why current production favours ABS and PC+ABS. In addition, not all potential advantages and disadvantages are relevant for each material, including some of those listed in Table 1. For example fatigue resistance is not entirely applicable to a video game controller, because the shell will likely never undergo cyclic loading. Insulation is also not, as most of the electrical components on the inside will have some additional form of insulation. All links to online resources may be found in Section 11 [8] [9] [10] [11].

Table 1: Qualitative comparison of different plastic resins.

Material	*Advantages*	*Disadvantages*
ABS	• Strong impact resistance and rigidity • Ease of processability • Machinable • Scratch resistance • Good dimensional stability	• Poor insulation • Poor fatigue resistance
PC+ABS	• Strong impact resistance and rigidity • Ease of processability • Good indoor UV light colour stability • Good dimensional stability • Easy to process	• Poor insulation • Poor fatigue resistance
PA (polyamide)	• Good strength and stiffness • Good wear resistance	• Absorbs moisture • Poor fatigue resistance
PP (polypropylene)	• High impact strength • Good moisture resistance • Lightweight	• Poor UV resistance • Difficult to paint

The two most important physical attributes for the final product to have are impact strength and rigidity. With a higher impact strength, the controller is durable so that the plastic does not crack if it is dropped on a hard floor. The rigidity is also crucial given the organic shapes of video game controllers. Though the controllers will not be used in intense heat, it is something that may affect the shape of the controller over time, especially if the faceplates are thin. CES Edupak [12] was used to supplement Table 1 to determine which material would be the most cost effective (Figures 10 and 11). Each material is coloured as follows:

- Red: PP resins
- Blue: PC+ABS resins
- Green: ABS resins
- Teal: PA resins

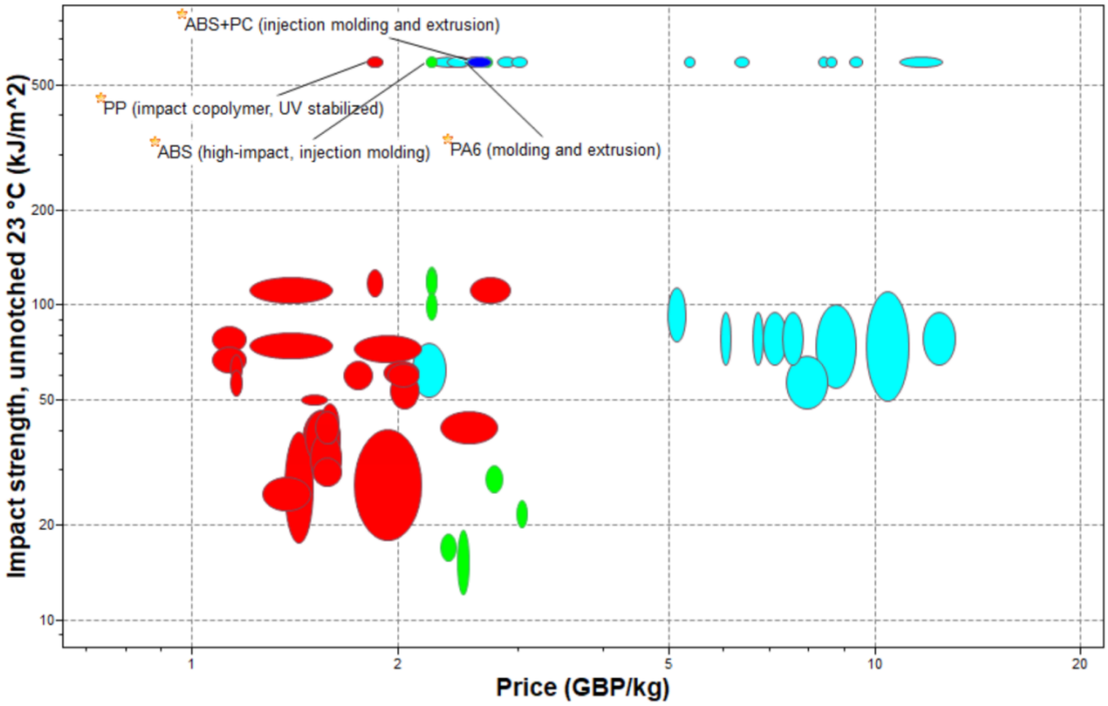


Figure 10: Comparison of impact strength and cost.

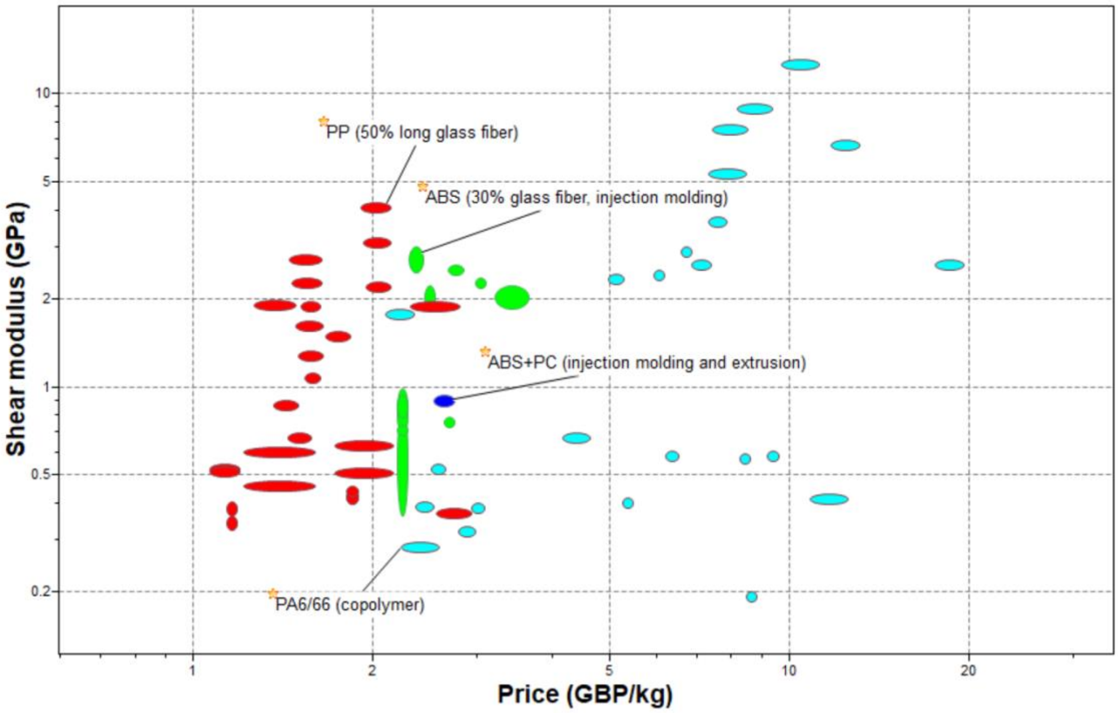


Figure 11: Comparison of shear modulus (rigidity) and cost.

The final choice of material would be PC+ABS. In comparison with the other materials in Table 1, it is fairly priced, and offers good rigidity and impact strength, and is easy to process. Additionally, the current use of PC+ABS in the Xbox One controller proves it is suitable for a mass market.

4.2 Electrical Components

Similar to the plastic used for the shell, most of the electrical components inside of the controller would be unchanged from what is currently used. A PCB manufactured and assembled by a supplier would be a purchased part and placed inside the controller shell. It would feature standard electrical components such as capacitors, resistors, a USB port, conductive pads and a central microcontroller to process everything [13]. However, the focus of this project was ensuring that each input could be easily swapped, rather than the specifics of the components themselves. The first idea was the use of spring-loaded pins (also known as "pogo pins") and magnets similar to a MagSafe connector as seen on older Macbook Pro models. A teardown was used as a consulted to further understand what kind of data transmission can be achieved through these contacts [14]. A grid of pogo pins would be connected to a PCB on either side (Figure 12), allowing the user to pick up and move inputs to the rear of the controller with ease.

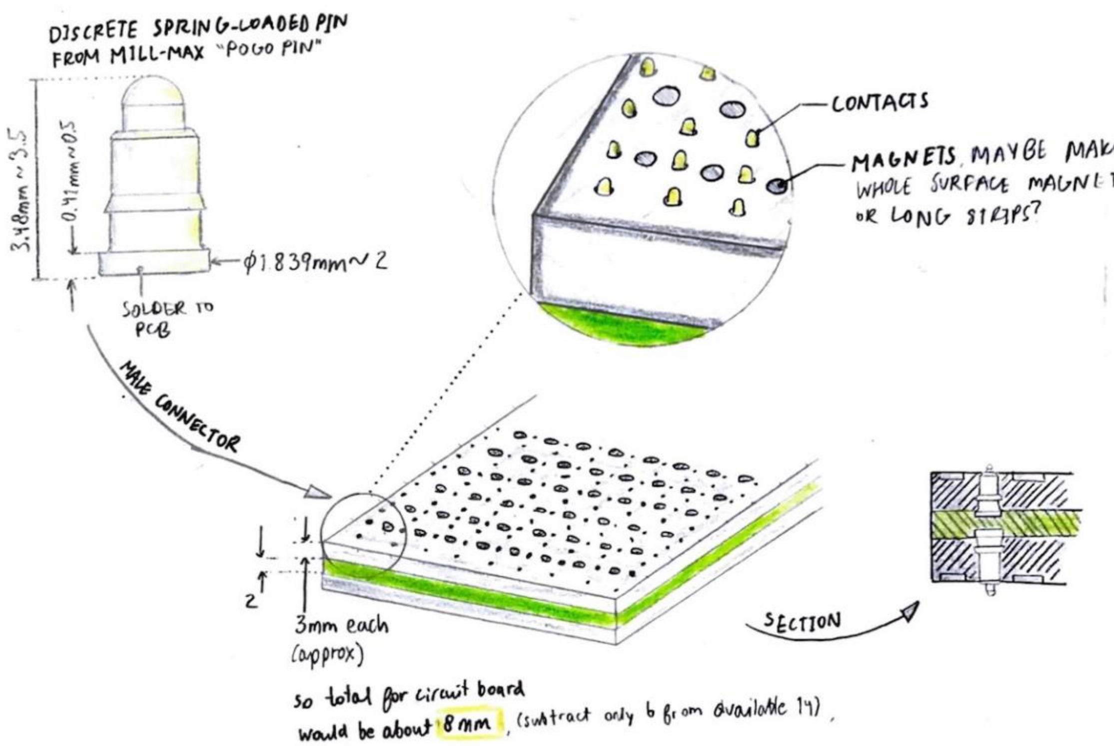


Figure 12: Sketch of pogo grid design.

The benefit to this dual-sided PCB design is that it allows for many different layout configurations. For example, if a user is unable to use the D-pad on the front, they can simply remove the faceplate, pick up the D-pad module and move it. The only additional part that would need to be purchased is a faceplate to accommodate the new layout.

Issues with this design arose when considering communication between the pins and inputs. One layout may result in connecting a pin which was previously used to communicate the input signal, to a new pin which was previously used to supply power. Specific firmware would be required for each layout that a user requires.

In addition, this solution would incredibly expensive. The grid would have feature at least 200 pogo pins on each side, for a total of 400. The pins, which are approximately £ 0.18 per piece [15] would result in cost of £72 per assembled unit, which is already beyond the price of a standard controller, and does not factor in any of the other hardware or firmware development costs needed to address different layouts.

In order to allow the freedom of a non-soldered connection that is more viable than the pogo pin grid, allowing each input to attach to the faceplate was suggested. A wired connection would lead back to the PCB, so that each component always plugs into the same place. If a component is being moved to another part of the faceplate, it only needs to be rewired. Flexible flat cables (FFC) could be optimal for this design, as they are very thin. They are already present in the DualShock 4 (Figure 12), used to connect an LED and touch pad.

Figure 13: Flexible flat cables in a DualShock 4 controller.

However, removing and replacing these FFC's is difficult with one hand, so a re-design of the cable would be required. The current DualShock 4 uses contact pads to secure a connection between the main PCB and an additional flexible PCB; a single screw fastens the main PCB securely to maintain this connection. By combining the low profile of contact pads with the flexibility of a ribbon cable, this connection could be secured with small magnets as seen in Figure 12. This allows for a user to easily take it apart with one hand, and reposition the input module.

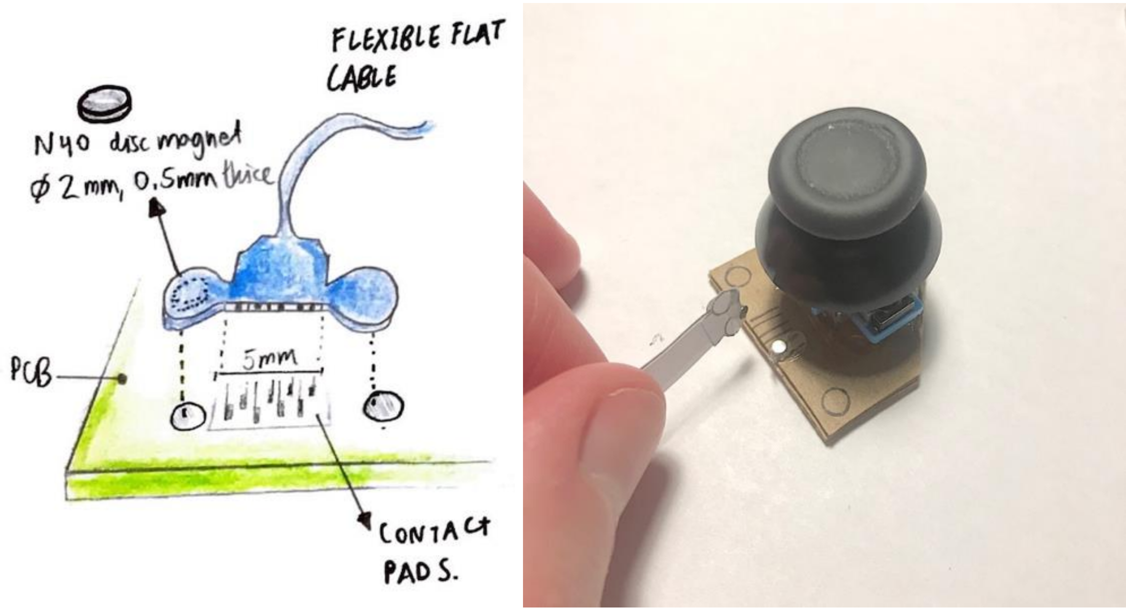


Figure 14: Sketch of the FFC (left) and paper mockup (right).

4.3 Manufacturing Process

All the materials listed in Table 1 can be processed with injection moulding. Though injection moulding has a large initial cost due to tooling, it is still the ideal process because of its low cycle time, low labour costs, and repeatability [16]. Alternatives to injection moulding are detailed in Table 2 [17] [18] [19].

Table 2: Comparison of additional manufacturing processes.

Process	*Notes*
Urethane Casting	Lower tool cost than injection moulding, however there is a much shorter lifespan. This process is more suitable for prototyping and small runs.
Compression moulding	With this process, it can be difficult to control flashing (excess material on edge of product). It may be possible to use it for the faceplates, but it is typically used for larger flat products. It also has a slow cycle time.
Extrusion moulding	May be used for the middle piece as it more or less features a constant cross-section, but as features are added, injection moulding is the better option.

5.0 Design for Assembly

5.1 Manufacturing Assembly

As mentioned in Section 3.0, the final product was designed around the plastic shell of the controller with its interchangeable faceplates and the internal PCB which is allows for components to be swapped around. A rear and front faceplate are attached to the middle frame of the controller with neodymium magnets. It provides a secure connection that will not disassemble during use, but is easy to take apart when accessing the internal components.

In order to secure the magnets to the plastic shell, two approaches can be taken:

- De-magnetized magnets can be embedded during moulding [20] which can be magnetized after moulding. This approach would likely be more expensive because of the unique technology.
- After moulding, applying an adhesive followed by the magnet. This is a more traditional approach. A functional prototype was created by assembling the adhesive and magnets by hand, but in manufacturing, this can easily be automated.

Figure 15: 3D printed prototype assembly (left) with magnets (right).

Appropriate engineering design was taken into consideration when designing the shell [21]:

- Draft angles and features to allow for easy part removal from injection mould
- Round corners are present where possible to avoid stress concentrations
- Rib thickness is less than 60% of part thickness
- Surface transitions are smooth

5.2 User Assembly – Shell

As mentioned previously, this product is designed for users with accessibility needs, so one goal was to allow any potential assembly to be completed with one hand. Unlike current controllers which feature plastic tabs that are difficult to remove and require pry tools, this product features an enclosure that snaps together using N35 neodymium magnets.

The COVID-19 pandemic restricted access to proper testing equipment so in order to test the exact force required to lift the faceplate off of the controller, a simple setup with a plastic cup (weighing approximately $10\ g$) and string (assumed to have negligible weight) was used.

Figure 16: Setup to measure the required pull force.

Water from a measuring cup was slowly added until the plate detached after $250\ ml$. Using gravity, and the density of water, $\rho = 1000\ \frac{kg}{m^3}$, the force was calculated using Newton's second law:

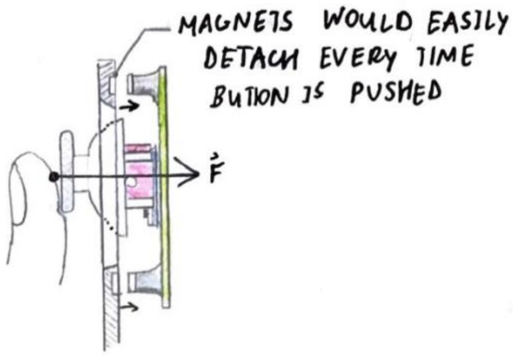
$$F = m \cdot a = m_{cup+water} \cdot a_{gravity} \qquad [Equation\ 1]$$

$$\left(0.25\ L \times 0.001 \frac{m^3}{L} \times 1000 \frac{kg}{m^3} + 0.01\ kg\right) \cdot 9.8 \frac{m}{s^2} = 2.548\ \frac{kg \cdot m}{s^2} \cong 2.5\ N$$

Without any momentum, a static load applied to the faceplate of approximately $2.5\ N$ is required to remove the faceplate. This is an easy force to overcome with one hand, and there are no issues removing and replacing the faceplate.

5.3 User Assembly – PCB

As mentioned in section 4.2, each input component attaches to the faceplates, and connects to the PCB with a magnetic cable instead of being soldered. Determining the best way to attach each component module to the faceplate was a challenge however. Using magnets would be easy to assemble one-handed but would just as easily dislodge every time the user presses down on the inputs. In order to attach the inputs securely, some kind of screw or clip mechanism would be required, however this would be difficult to remove and assemble with one hand.



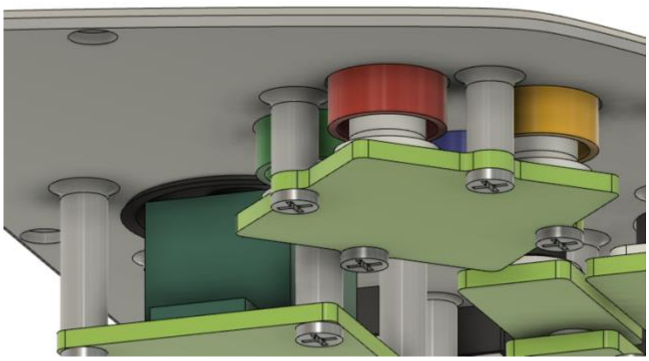


Figure 17: Sketch of magnetic component attachment (left) and final CAD model (right).

Plastic clip mechanisms can be frustrating to remove, even with one hand, and screws would allow for greater security. Removing them with one hand would require stability of the faceplate. Initially, a separate fixture available to purchase was suggested, however this would be another cost to add to the user, in addition to being completely unnecessary after the user adjusts their controller to their desired layout.

Drawing inspiration from the Steam controller and it's packaging, the idea occurred to use the box as the fixture; no need to purchase a separate item in order to secure the controller. This allows the user to confidently remove the screws with one hand, without worrying about balancing the faceplate awkwardly between two surfaces.

Figure 18: Steam controller box (left) and CAD model of project controller box (right).

6.0 Cost

When considering the cost of this product, it was important to try and meet the standard price of a controller. However there was some room for freedom, as there is a definite interest from gamers in premium devices. For example, the first iteration of the Xbox Elite Controller, which retailed at $150 USD sold over one million units [22].

Seeing as this product is targeted as the new "standard" gamepad, one would be included with every video game console. For the current 8th generation of video games (which after 7 years, will be coming to a close at the end of 2020), approximately 150 million consoles between the PlayStation 4 and Xbox One have been sold [23].

In order to estimate the cost, a formula [24] which considers the cost of material, cost of dedicated tooling, cost of capital equipment and overhead costs is used:

$$C_{pp} = \frac{m \cdot C_m}{(1-f)} + \frac{C_t}{n}\left\{Int\left(\frac{n}{n_t} + 0.51\right)\right\} + \frac{1}{\dot{n}}\left(\frac{C_c}{L \cdot t_{wo}} + \dot{C}_{oh}\right) \quad [Equation\ 2]$$

6.1 Material Cost

The material cost accounts for the raw material that is used in each part, in addition to potential scrap. The only part of the final product that would likely involve raw material costs is the shell itself. All other components would be purchased. The mass was derived from the 3D model in Fusion 360, and the cost per kilogram was taken from CES EduPack. The 10% scrap fraction was selected from personal experience working in an injection moulding manufacturing environment with PC+ABS. The first part of Equation 2 is the material cost:

$$C_1 = \frac{m \cdot C_m}{(1-f)} \quad [Equation\ 3]$$

Table 3: Material cost per part.

Part	*Material*	*m* *[kg]*	*C_m* *[£ per kg]*	*f*	*C_1* *[£]*
Top faceplate	PC+ABS	0.007385	2.53	0.10	0.03
Middle frame		0.026506			0.07
Bottom faceplate		0.007694			0.02
				Total:	£0.12

6.2 Dedicated Cost

The dedicated cost accounts for the cost of tooling which may include dies, injection moulds and fixtures. For injection moulding, the dedicated cost is typically quite high due to the expensive tooling. Just like the material cost, the dedicated cost for this product would be mostly affected by just the controller shell.

Due to the thin profile of the faceplates, and the fact that every controller would require one of each part, it would make sense to consolidate the faceplates into a two-cavity mould, rather than separate moulds. Because this is a more complicated tool design, the initial tooling cost may be more expensive, however it would still be cheaper than producing two moulds and would be more effective for production scheduling.

The cost of the tooling, C_t, is an estimate taken from an online source [25]. Both moulds would be roughly similar in size, due to similar part geometries and total weight. The complexity of the first tool (for top and bottom faceplates) would stem from the 2-cavity setup. The complexity of the second tool (for the middle frame) would stem from the part thickness and unique geometry.

The C_t value was also slightly increased due to the desired tool life, n_t. 1,000,000 parts is certainly possible, though it will require higher grade steel and proper maintenance. Given the large quantity of video game consoles sold over the 8th generation, it makes sense for a manufacturer to get as many parts from a tool as possible. The second part of Equation 2 is the dedicated cost:

$$C_2 = \frac{C_t}{n}\left\{Int\left(\frac{n}{n_t} + 0.51\right)\right\} \qquad [Equation\ 4]$$

Table 4: Dedicated cost per part.

Part	*C_t* *[£]*	*n*	*n_t*	*C_2* *[£]*
Top faceplate + bottom faceplate	50,000	150,000,000	1,000,000	0.05
Middle frame	50,000			0.05
			Total:	£0.10

6.3 Non-Dedicated Cost

Non-dedicated costs includes capital equipment costs and overhead costs. The write off time, t_{wo}, was estimated to be approximately seven years, which is the typical length of a video game console generation during which the same hardware is produced. Given the relatively small size of handheld electronics, smaller injection moulding machines were considered for the estimated capital cost of £40,000 based on Alibaba listings. Once again, the top and bottom faceplate pieces were consolidated into a single cost as they would be produced simultaneously. The cycle time in injection moulding is quite quick and was estimated be 30 seconds, which would produce about 120 parts per hour. This number is based on a mix injection moulding work experience and online resources [26]. A load factor of 0.33 was used which is a more conservative number. In a typical manufacturing plant with three different 8-hour shifts, a single part will usually run on only one of those shifts. Overhead costs, $\dot{C}_{oh}$, considers items such as research and development, administration and labour and was assumed to be 200% of direct labour costs [27], which are rounded up from the National Living Wage of £8.72 per hour to £10.00 per hour. The last part of Equation 2 is the non-dedicated cost:

$$C_4 = \frac{1}{\dot{n}}\left(\frac{C_c}{L \cdot t_{wo}} + \dot{C}_{oh}\right) \qquad [Equation\ 5]$$

Table 5: Non-dedicated cost per part.

Part	*$\dot{n}$ [parts per hour]*	*C_c [£]*	*L*	*t_{wo} [hours]*	*$\dot{C}_{oh}$ [£ per hour]*	*C_4 [£]*
Top faceplate + bottom faceplate	120	40,000	0.33	61,320	20	0.18
Middle frame	120	40,000			20	0.18
					Total:	£0.36

6.4 Cost of Components

Equation 2 does not consider additional components and hardware used in the assemblies. The prices listed in Table 6 are a mix of those encountered when parts were purchased for prototyping and estimates based on listings found on eBay and Zedlabz (a website that specializes in video game replacement hardware).

Table 6: Purchased component cost per part.

Part	*Quantity*	*Cost per item [£]*	*Cost [£]*
Magnets 4 mm x 1 mm	28	0.05	1.40
Magnetic flexible flat cable	9	3.00	27.00
Main PCB	1	12.00	12.00
Component PCBs (includes sensors and buttons)	9	5.00	45.00
M2x6 Screw	22	0.20	4.40
M2x10 Screw	1	0.20	0.20
Battery	1	6.60	6.60
		Total:	£96.60

6.5 Final Cost

The final production cost per part comes out to £96.18, with 99% of the cost being attributed to the purchased components. Because the smaller component PCBs and magnetic ribbon cables are unique to this design, estimates on their cost are likely higher than they would be if they were readily available. The manufacturing costs (a mere £0.58) are surprisingly low, but this is likely because of the relatively small weight and sheer volume over the span of a 7-year console generation.

With the addition of 20% VAT and a 30% profit margin, this brings the total to:

$$(96.18 \times 1.2) \times 1.2 \approx 151.29$$

A total of £151.29 lands the product right near the premium Xbox Elite Controller. Users would have to purchase additional faceplates in order to change the input layout, but given that there are no additional purchased components connected to the faceplates (other than 12 magnets, which would be £0.60), this shouldn't be a huge issue. As these would be a smaller quantity sold, it is also possible to use a cheaper manufacturing method with a lower tooling cost.

7.0 Final Design

The final design is a video game controller that can be modified for users with accessibility issues. Users that would like to change the physical layout of the controls can swap out the faceplates and re-use the internal components without use of additional peripherals.

The final product consists of a plastic shell, made up of interchangeable faceplates and a middle frame that holds onto a central PCB. Every single input (the buttons and analogue sticks) attach to the faceplates with screws, and can connect into the PCB via magnetic flexible flat cables.

The entire product can be assembled and disassembled with one hand. Magnetic connections between the faceplates and the middle frame allow for easy removal, but are secure enough to stay on during use.

The size and volume of this product is comparable to current standard gamepads currently available, ensuring that it is also suitable for users without accessibility issues.

Figure 19 shows a render of the final product, with two additional input layouts as an example. Detailed design drawings and a user journey can be found in the Appendix.

Figure 19: Final product with alternate configurations.

8.0 Conclusions

The final product succeeds in offering a standard video game controller that can be modified for a user with accessibility issues. The project was guided by insights discovered from user interviews, physical prototyping and online research. The final design received positive feedback from User #3, for whom an alternate layout was based around.

The technical objectives of this report as outlined in the Executive Summary were met successfully:

- Engineering decisions made throughout the project were detailed, such as the exploration of generative design to create a bespoke solution versus an adaptable shape as seen in the final product and use of ribbon cables instead of pogo pins.

- Ensuring the accessibility of the final design by making assembly possible with one hand. Tests with a 3D printed prototype showed the product is solid and easy to hold.
- Different materials were researched against what is currently used in gamepads.
- Alternate manufacturing processes were considered.
- A cost analysis showed that manufacturing this product is feasible.

9.0 Future Development

There is still much work to be completed before this product could be delivered to consumers. Primarily, construction of a prototype with functioning electrical components. Given the circumstances with the COVID-19 pandemic, there were some limits to prototyping. The most important item to try to design and test would be the magnetic ribbon cable to ensure that input data could be properly sent and received using this type of connection. In addition, proper size consideration of all the components such as microcontrollers, capacitors and resistors found on a PCB is required.

To make this project easier to design, there were two notable omissions: haptic feedback and the capacitive touch pad on the DualShock 4. Haptic feedback modules can be relatively small, so the volume occupied by them wasn’t a concern. However the touch pad on a DualShock 4 (which will also be present in the DualSense, the successor controller for the upcoming generation) is typically seen as a gimmick. Games that appear on multiple platforms often use the touch pad solely as an additional digital button press. Games that are unique to the PlayStation 4 (which require a DualShock 4) often utilize the touch pad in contextual events that do not actively contribute to gameplay throughout the course of a game. The goal for this report was to focus on the standard inputs that most games use. Future development into this product can take the touch pad, and other possible new inputs into consideration.

Allowing repositioning of the buttons also introduces the opportunity to change the buttons entirely (Figure 20). For example, the shoulder buttons are often the biggest and most uniquely shaped buttons on the gamepad. While it may not be possible to move the geometry of the trigger to another location, perhaps a user could change the shape of the button entirely? This would be an additional cost as it would require a new PCB module for the new component, however it would certainly be cheaper than a whole new gamepad that does not feature this level of modularity.

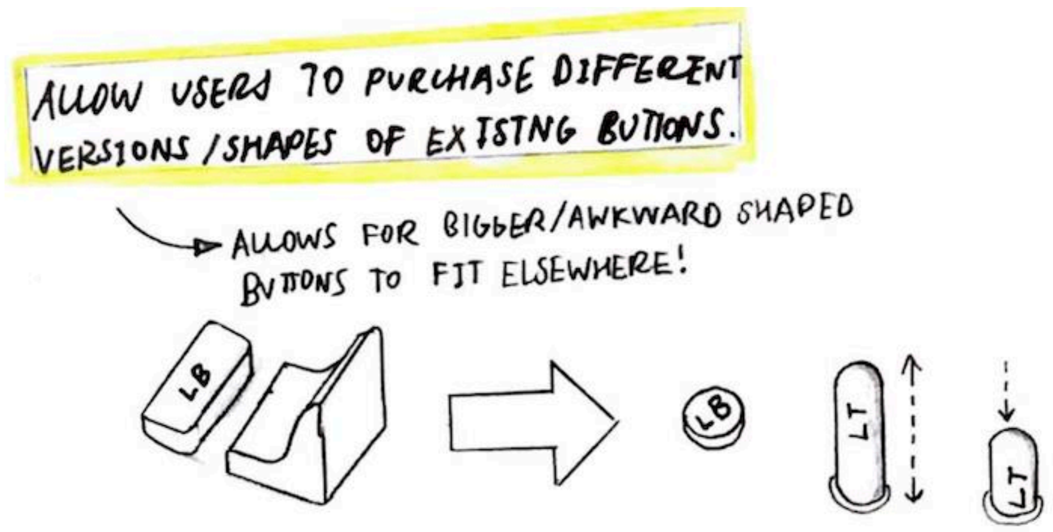


Figure 20: A sketch detailing alternate shoulder buttons.

Lastly, conducting further research and surveys to obtain more data on disabilities would be required to determine what are the most common accessibility issues present in gamers. This information would be used to determine some standard faceplate input configurations that users can readily order.

10.0 References

[1] McGonigal, Jane. (2012). *Reality is Broken. Why Games Make Us Better and How They Can Change The World.* Publisher: Vintage.

[2] James, Scott. (2020). *Playing to Win - Perspective Magazine Issue 06.* Distributed by GSA tutors. [Accessed 6 March 2020].

[3] Blue Tip Gaming. (2020). Axis 4 Pro. *Blue Tip Gaming*. Available at: https://bluetipgaming.com/product/axis-4-pro/. [Accessed 24 June 2020].

[4] Microsoft. (2020). *Xbox Adaptive Controller accessories.* Available at: https://www.microsoft.com/en-gb/store/collections/xboxadaptivecontrolleraccessories. [Accessed 1 July 2020].

[5] Microsoft. (2018). *Xbox Adaptive Controller welcomed by UK charities and gamers with disabilities*. Available at: https://news.microsoft.com/en-gb/2018/05/17/xbox-adaptive-controller-welcomed-by-uk-charities-and-gamers-with-disabilities/. [Accessed 30 June 2020].

[6] Fusion 360. (2020). *Autodesk* [Software].

[7] Henry Dreyfuss Associates & Tilley, Alvin. (1993). *The Measure of Man and Woman: Human Factors In Design*. Publisher: Whitney Library of Design.

[8] RTP. (2020). *RTP Company Specialty Compounds*. Available at: https://www.rtpcompany.com/products/product-guide/. [Accessed 29 July 2020].

[9] Star Rapid. (2020). *The Ten Most Popular Plastic Injection Moulding Materials*. Available at: https://www.starrapid.com/blog/the-ten-most-popular-plastic-injection-molding-materials/. [Accessed 29 July 2020].

[10] Techni-Mold Engineering Inc. (2020). *Materials*. Available at: https://techni-mold.com/materials/. [Accessed 29 July 2020].

[11] Wikipedia. (2020). *Acrylonitrile butadiene styrene*. Available at: https://en.wikipedia.org/wiki/Acrylonitrile_butadiene_styrene. [Accessed 29 July 2020].

[12] Granata Design Limited. (2018). CES EduPack. [Software].

[13] WellPCB. (2020). *PS4 Controller PCB Circuit Board – What You Need to Know*. Available at: https://www.wellpcb.com/ps4-controller-pcb.html. [Accessed 25 July 2020].

[14] Ken Shirriff's blog. (2013). *Teardown and exploration of Apple's Magsafe connector*. Available at: http://www.righto.com/2013/06/teardown-and-exploration-of-magsafe.html. [Accessed 24 July 2020].

[15] Digi-Key. (2020). *0900-0-15-20-76-14-11-0*. Available at: https://www.digikey.com/products/en?keywords=0900-0-15-20-76-14-11-0. [Accessed 24 July 2020].

[16] Craftech Industries, Inc. (2020). *The Top 10 Benefits of Plastic Injection Molding*. Available at: https://www.craftechind.com/the-top-10-benefits-of-plastic-injection-molding/. [Accessed 25 July 2020].

[17] ICO Mold. (2020). *Urethane Casting*. Available at: https://icomold.com/urethane-casting/. [Accessed 25 July 2020].

[18] ICO Mold. (2020). *Compression Molding*. Available at: https://icomold.com/compression-molding/. [Accessed 25 July 2020].

[19] Paul Murphy Plastics Company. (2019). The Advantages & Disadvantages of Extrusion Molding. Available at: https://paulmurphyplastics.com/2019/10/23/the-advantages-disadvantages-of-extrusion-molding/. [Accessed 26 July 2020].

[20] Amazing Magnets. (Year Unknown). *Injection Molding Magnets*. Available at: https://www.amazingmagnets.com/t-injectionmolding.aspx. [Accessed 26 July 2020].

[21] Shackleton, John. (2020). Design for Manufacture and Assembly. [Online via Moodle], University of Glasgow. Available at: https://moodle.gla.ac.uk/mod/resource/view.php?id=1449574. [Accessed 11 February 2020].

[22] Gamespot. (2016). *There Are Now 1 Million Xbox One Elite Controllers*. Available at: https://www.gamespot.com/articles/there-are-now-1-million-xbox-one-elite-controllers/1100-6441342/. [Date accessed 1 June 2020].

[23] Wikipedia. (2020). *Eighth generation of video game consoles*. Available at: https://en.wikipedia.org/wiki/Eighth_generation_of_video_game_consoles. [Accessed 24 July 2020].

[24] Harrison, Philip. (2019). *Lecture 10*. [Online via Moodle], University of Glasgow. Available at: https://moodle.gla.ac.uk/mod/resource/view.php?id=1378671. [Accessed 25 October 2019].

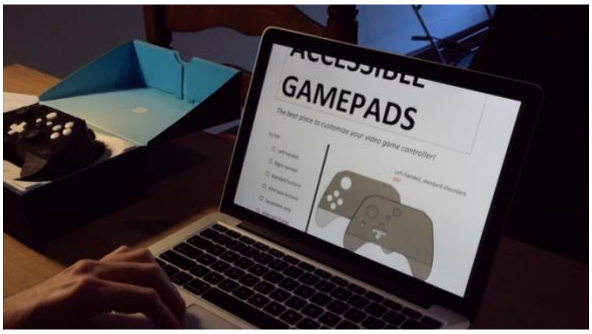
[25] Rex Plastics. (2020). *How Much Does Plastic Injection Moulding Cost?*. Available at: https://rexplastics.com/plastic-injection-molds/how-much-do-plastic-injection-molds-cost?. [Accessed 2 August 2020].

[26] Automatic Plastics. (2020). *The Cycles of the Injection Moulding Process*. Available at: http://www.automaticplastics.com/the-cycles-of-the-injection-moulding-process/. [Accessed 6 August 2020].

[27] Cook, Cynthia & Graser, John. (2001). *Military Airframe Acquisition Costs: The Effects of Lean Manufacturing – Chapter 9*. Available at: https://www.rand.org/pubs/monograph_reports/MR1325.html. [Accessed 6 August 2020].

Appendix A: User Journey

User enjoys playing video games with a controller, but can only use one hand. It is difficult to access all of the inputs and it leaves the user frustrated.

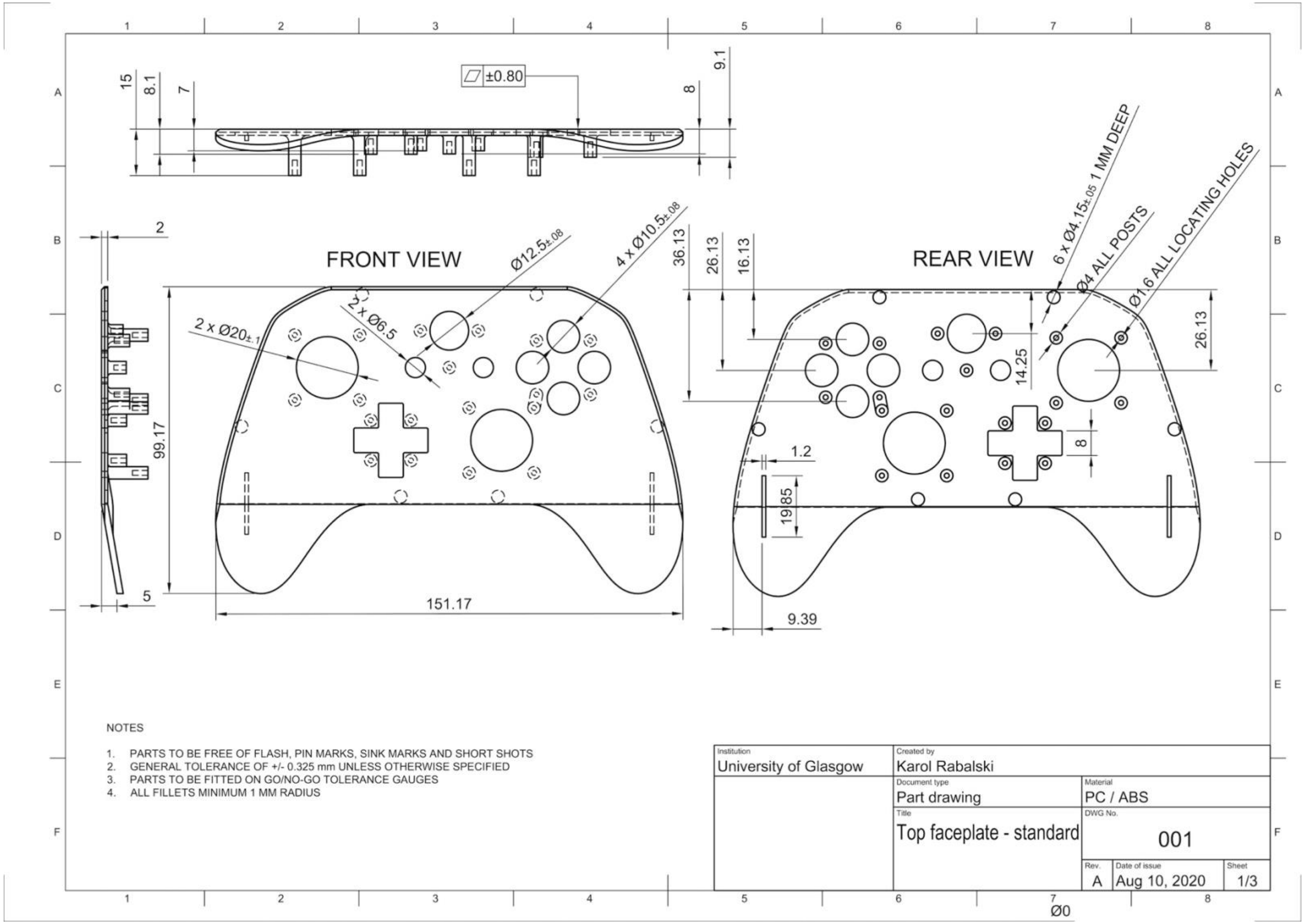


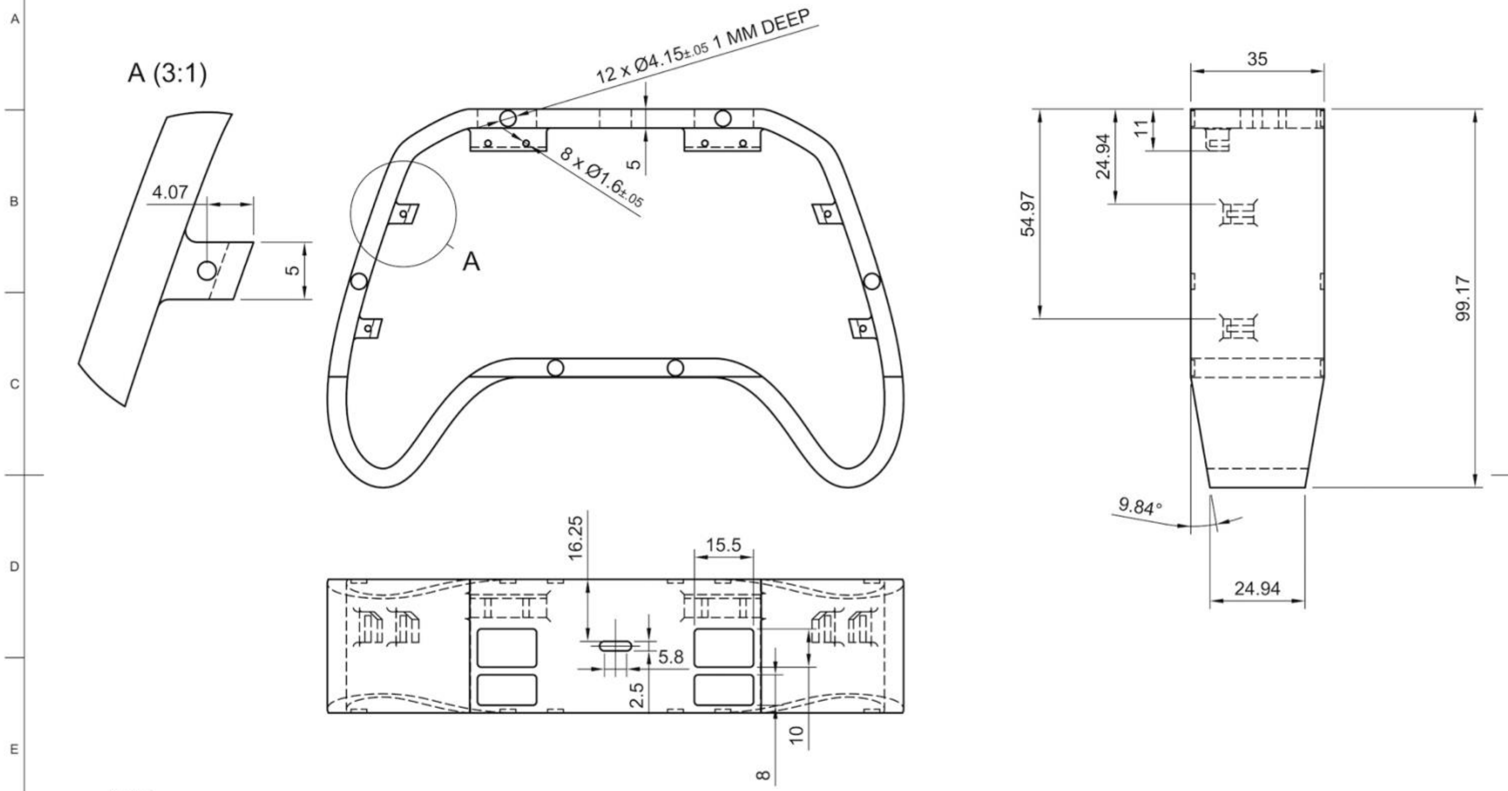
The user purchases the new, accessible controller, which allows for customizing the physical layout. Browsing the online store, they look for a faceplate that will best suit their needs.

The new controller is easy to take apart with one hand. The box acts as a fixture so the user is able to take components apart and re-use them in a new layout. A magnetic flexible flat cable is used to connect the components to the main PCB.

After reassembly, the user now has their desired physical layout and has a more enjoyable time playing video games.

Appendix B: Engineering Drawings

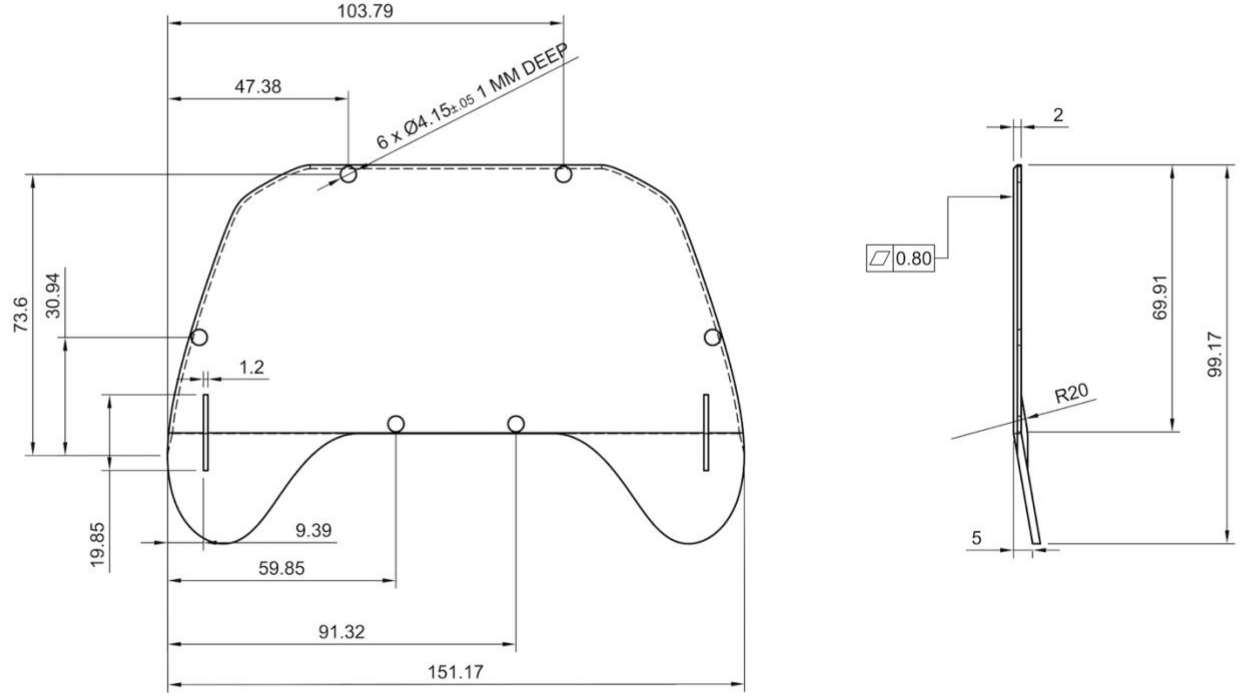




NOTES

1. PARTS TO BE FREE OF FLASH, PIN MARKS, SINK MARKS AND SHORT SHOTS
2. GENERAL TOLERANCE OF +/- 0.325 mm UNLESS OTHERWISE SPECIFIED
3. PARTS TO BE FITTED ON GO/NO-GO TOLERANCE GAUGES
4. ALL FILLETS MINIMUM 1 MM RADIUS.

Institution	Created by			
University of Glasgow	Karol Rabalski			
	Document type: Part drawing	Material: PC / ABS		
	Title: Middle frame - standard	DWG No.: 002		
		Rev.: A	Date of issue: Aug 10, 2020	Sheet: 2/3



NOTES

1. PARTS TO BE FREE OF FLASH, PIN MARKS, SINK MARKS AND SHORT SHOTS
2. GENERAL TOLERANCE OF +/- 0.325 mm UNLESS OTHERWISE SPECIFIED
3. PARTS TO BE FITTED ON GO/NO-GO TOLERANCE GAUGES
4. ALL FILLETS MINIMUM 1 MM RADIUS

Institution	Created by			
University of Glasgow	Karol Rabalski			
	Document type: Part drawing	Material: PC / ABS		
	Title: Bottom faceplate - standard	DWG No.: 003		
		Rev.: A	Date of issue: Aug 10, 2020	Sheet: 3/3