Development Portfolio

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Product Name: Angel Eye

Module Code: DP603

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April 2019

Technical Layout

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Human Factors Pages

Product Design Specification

A1. Any surface that contact the baby's skin must have a surface roughness between 0µ and 0.4µ.

Babies are almost always wearing a nappy which is constantly rubbing on their skin without causing irritation, to not irritate the baby's skin all exposed surfaces must be less rough than the surface of a nappy which is often made from a synthetic material, this can range from approximately 0.4µ – 0.7µ (M.M. Mahmoud, 2016)

A2. The product must be at least 50% recyclable/ reusable.

6 out of 10 parents are influenced to avoid a product if it isn't recyclable (see section 2.1 of the appendix for the full results). To appeal to most parents, it is important to them that the product can be at least partly recycled one it has reached the end of its usefulness.

A3. The product must have adjustable parameters and allowances.

Before the age of 3 19.9% of children will have had at least one lower respiratory tract illness and troubles with wheezing (Fernando D. Martinez et al, 1995). There are many other conditions that could affect how the baby breathes and what is considered normal/ acceptable for one baby could be very different for another.

A4. The clip must weigh no more than 250 grams

The product must be easy for a parent to carry around. The average person carries a phone on their person daily with no problem, the Samsung Note 8 weighed slightly over 200 grams and didn't cause any issues.

A5. The data that is collected of the baby's vitals must be kept confidential and secure.

This product will be collecting data on a child to send it to the various outputs (such as the app), the GDPR laws are a set of rules that ensure any data collected on a person is secure and can't be seen by anyone unless the user consents to it (The General Data Protection Regulation 2016/679). To be 'GDPR compliant' this is one of the laws that are necessary to be put in place for the product, it also gives the user security that their baby's private data is being kept secure.

A6. The clip must be themed for the baby.

The clip is the part of the product the baby will be wearing, the clip should be themed appropriately, so the baby isn't afraid of the device and matches their aesthetic of being a baby. Making the clip look playful will also make parents more comfortable with attaching the device to their baby, making it look like a medical tool could scare parents from purchasing and using the device.

A7. The product must have no loose parts smaller than 1.5 inches in diameter and 1.5 inches deep that could fit in a cylindrical tube.

1.25 inches in diameter and 1.25 inches deep is considered a safe size that wouldn't cause an infant to choke in case they put the object into their mouths, slightly higher values must be considered to account for the 95th percentile child that could have a larger throat ensuring it safe for all children to use.

A8. The product must be able to fit into a pocket 12.5cm wide and 14 cm deep.

For the device to be portable and easy to carry around it must be able to fit into small coat pockets, women have significantly smaller pockets than men, so it must fit into the smaller options, women's pockets vary from 5-6½"/12.5-16.5cm wide by 5½-6"/14-17.5cm deep.

A9. The clip must be on and able to receive data for at least 8 hours.

The average parent doesn't take their baby out for longer than 1-4 hours a day, 8 hours should account for most outliers and long periods at night whilst the baby and the parent sleep, this should give the parents plenty of time of the baby being monitored before the battery needs changing/ charging.

A10. The product must attach to the baby's nappy with a force of at least 3 Newtons and less than 13 Newtons.

3 Newtons should easily hold a 250-gram object in place without it moving. Any greater than 3 Newtons will keep the object more secure but at the cost of it being hard to take off. The weakest pinch strength of the general population is males aged 55- 59 with a pinch strength of 21 Newtons, by being 13 newtons or less all age groups should able to take off and move around the object as needed.

Product Design Specification

A11. The clip must be able to sustain a fall from 1 meter without taking any severe damage that would prevent any functions from working optimally, the product must be able to take 2.45 Newtons of downwards force.

The product should weigh no more than 250 grams (= 0.25kg) and will fall from 1 meter (the average table is approximately 75cm tall, so 1 meter should be higher than either of than it will fall in daily use. 0.25x g (g taken as 9.8) = 2.45N. It is important that the product is sturdy enough to withstand a parent’s hectic lifestyle including any falls the product may endure when the parent removes the device (i.e. to change the baby’s nappy).

A12. The robot must be free standing and clearly display if the baby is safe within 3 seconds when sat at a desk.

The primary function of the robot is to alert parents in case of an emergency and provide assurance that their baby is safe at home, to achieve this the product must be free standing so it can be used on any type of desk without needing to be fitted, it must also clearly convey if the baby is alright within a short space of time (3 seconds has been chosen) to give the user instant reassurance for if they need it.

A13. The product must allow the parent to check their baby’s breathing rate within 15 seconds.

In order for the user to get the instant relief they need, they must be able to check their baby’s vitals within a short period of time, any longer than 15 seconds could make the parent worry more, in the research section of the report a potential user said “every second of not knowing is killing me”, to minimise this feeling the user must be able to check their baby in under 15 seconds.

A14. The app must require 4 or less interactions to navigate to the desired information/ section.

Humans are limited to a working memory capacity of approximately seven items, plus or minus two. (Miller, 1956). To lower to the cognitive load on the user, the app should be concise but clear and simple to navigate. Reducing the number of tasks, it takes the user to achieve something helps to make them feel comfortable and confident when using an app, the parameters section of the app shouldn’t be ‘hidden’ away, it needs to be easily accessible whenever the user needs it.

A15. The product must be reliable at least 98% of the time. Maximum 2% failure rate over service life.

This product needs to be reliable, if the product fails it might not be monitoring the baby during a time that it needs to be, this would make the parents think their baby is being monitored when they aren’t, this could put the baby’s safety in jeopardy. If the product loses data, it needs to be able to recover almost instantly to resume the baby’s monitoring. If 2% or less fails, the baby will safely be monitored.

A16. The product must be operable for at least one year before any servicing or maintenance is required.

The average baby will grow enough that they no longer need their heads to be supported after 3-6 months, within 9 – 12 months most children will already be walking, this product is aimed at people that are worried about their baby whilst they are too fragile to help themselves, by the age of one, babies are much stronger and there is significantly less need for concern. The product should last at least the first year without breaking as this is usually the most important time for this product.

A17. The product must have an alarm to alert parents if the child stops breathing for 15 seconds or more.

The average baby breathes between 20- 40 times a minute this can however be lowered even more when they sleep to approximately 20 times a minute, this means even when sleeping they breathe once every 3 seconds. If a baby does not receive oxygen for 1-minute brain damage could begin developing, after 3 minutes there could be serious damage done. 15 seconds allows for outliers in the baby’s breathing and periodic breathing (Stanford Children’s Health, 2019) without setting off the alarm whilst still giving the parents an appropriate amount of time to react to the situation in the case this occurs.

A18. The receiver must meet the international standard EN 60529 (British BS EN 60529:1992, European IEC 60509:1989) and have an IP rating of at least IP45.

The receiver clip will be in a position that it could get the baby’s waste on it. To protect the electronics within, the clip must have an IP rating of IP45 to have a fair amount of water resistance for its purpose. Being water resistant also allows the clip to be washed easily by the user in case it gets dirty.

Project Management- Methodologies

Waterfall Methodology

Some of the methods I used included waterfall project management, agile methodology and the use of the Gan t chart. A waterfall method was considered f rst and this has a very simple approach which values doing something once and doing it right and solid planning.

The reason it is such a simple methodology is because it just includes making a good plan and execu t ng it. Work is planned up front extensively and then performed in strict sequence which adheres to the requirement of delivering the project in a usually long and single cycle. It is a good methodology because it has a very rigid structure, and everything is planned in steps. There is only one thing going on at one t me and that way you are able to f t everything that needs doing into a structured t me line. So, you can see everything that needs to be done each week.

Requirements are def ned in full at the top of the waterfall before any work starts. The work then cascades down like a waterfall through di f erent phases of the project. One phase must be completed before the next phase can begin and there is no overlapping between phases. Typically, the outcome of one phase sequen t ally acts as input for the next phase.

A f er planning has been approved there's li t le scope to adapt the plan unless it is undeniably necessary. This is because of the single cycle process and there is not much of a chance to ref ect, revise and adapt once one stage is completed. The project then f ows through design, implementa t on, tes t ng and into maintenance. Once in the tes t ng stage it can be problema t c to go back and change a feature that was designed poorly in the concept stage.

The poten t al problems with this method are that it can be a risky way of managing a project. The reasoning for this can be that because the methodology is so rigid a single cycle process there is no chance to get feedback on the current stage being done before it is t me to move onto the next stage. There is no t me for improving previous sec t ons because once it is t me to move onto the next stage all e f orts ned to go into the next part of the project instead of trying to improve on a previous segment.

'Agile' Methodology

The next form of methodology that was considered being used is agile methodology, which is an itera t ve, f exible design and build process. There are four principles to consider when trying to assemble an agile methodology, these are: Individuals and itera t ons, working so f ware, customer collabora t on and responding to change.

When an agile methodology is used, they are usually characterised by a series of tasks that are conceived, executed and adapted as the situa t on demands. This is carried out rather than a pre-planned schedule and it can help teams respond to unpredictable circumstances through itera t ve, incremental work processes. It gives teams the chance to add missing components to the product as they go along. This type of project management process requires the team working on the product to cycle through stages of planning, execu t ng and evalua t ng as they go along.

This methodology is di f erent to other forms of project management which usually assume that circumstances a f ec t ng the project are predictable. Whereas this form of management allows for adaptability to changing situa t ons, permits ongoing and adequate communica t on between the project team and among them and the client. This method is best used in dynamic environments where the poten t al for changing or evolving environments is high.

Gantt Charts

The last method of planning considered is the Gan t chart and this is a visual way of se t ng out tasks over t me. It is a type of bar chart that illustrates a projects schedule.

They are used for planning projects of all sizes and are a useful way of showing what work is scheduled to be done on a speci f c day. They can also be used to look at the start and end dates of the project in one simple view. These can be used in many ways such as viewing: What the projects tasks are, the start and f nish date of the project, when tasks start and f nish, who is working on each task, how tasks group together, overlap and link with each other and how long each task will take.

Once computers produced new ways of managing a project it was found that t me could be saved when crea t ng and upda t ng Gan t charts. Gan t chart so f ware was created to automate the process to support more advanced Gan t requirements like adding milestones, iden t fying the cri t cal path of the project and crea t ng task dependencies. The so f ware being able to be used on desktop programs such as Microso f project enables anyone to create collabora t ve and shareable project plans and Gan t charts. There are huge advantages to using a Gan t chart as previously men t oned and you can also plan and schedule tasks, projects and tasks across mul t ple projects, plan sprints, team collabora t on, scheduling teams work, view tasks over t me and determine actual versus planned t melines on a project.

Gan t charts are a guideline however it is not set in stone and are bound to change they are a proac t ve approach. This means you plan what to do and then you can change the Gan t chart if the plan needs to change. It lets you see how you use your t me visually, helps the project manager see what they have got to do next in a visual sense and allows them to change features of the project as required, which also gives the method a f exible aspect to it because you can change your project as you go along.

Project Management- Application

How I Applied These Methods

Initally I started this project by using the waterfall methodology, I selected the frst and most important thing that needed to be completed and tackled that frst, the inital issue I was faced with was how the baby would work. This was a massive factor that had been preventng any thoughts on what I could do next because I didn't know where to start or if it would even be possible. I had initally planned to spend 2 weeks on learning how to make the baby and what components would be necessary to make something of that scale, however it was much more complicated than I had initally expected, as a result of this the use of the waterfall method had to be put on hold, I had taken on a lot more than was possible in the tme I gave myself and because this was a crux point for me I had to spend the extra learning about the topic and what could be done.

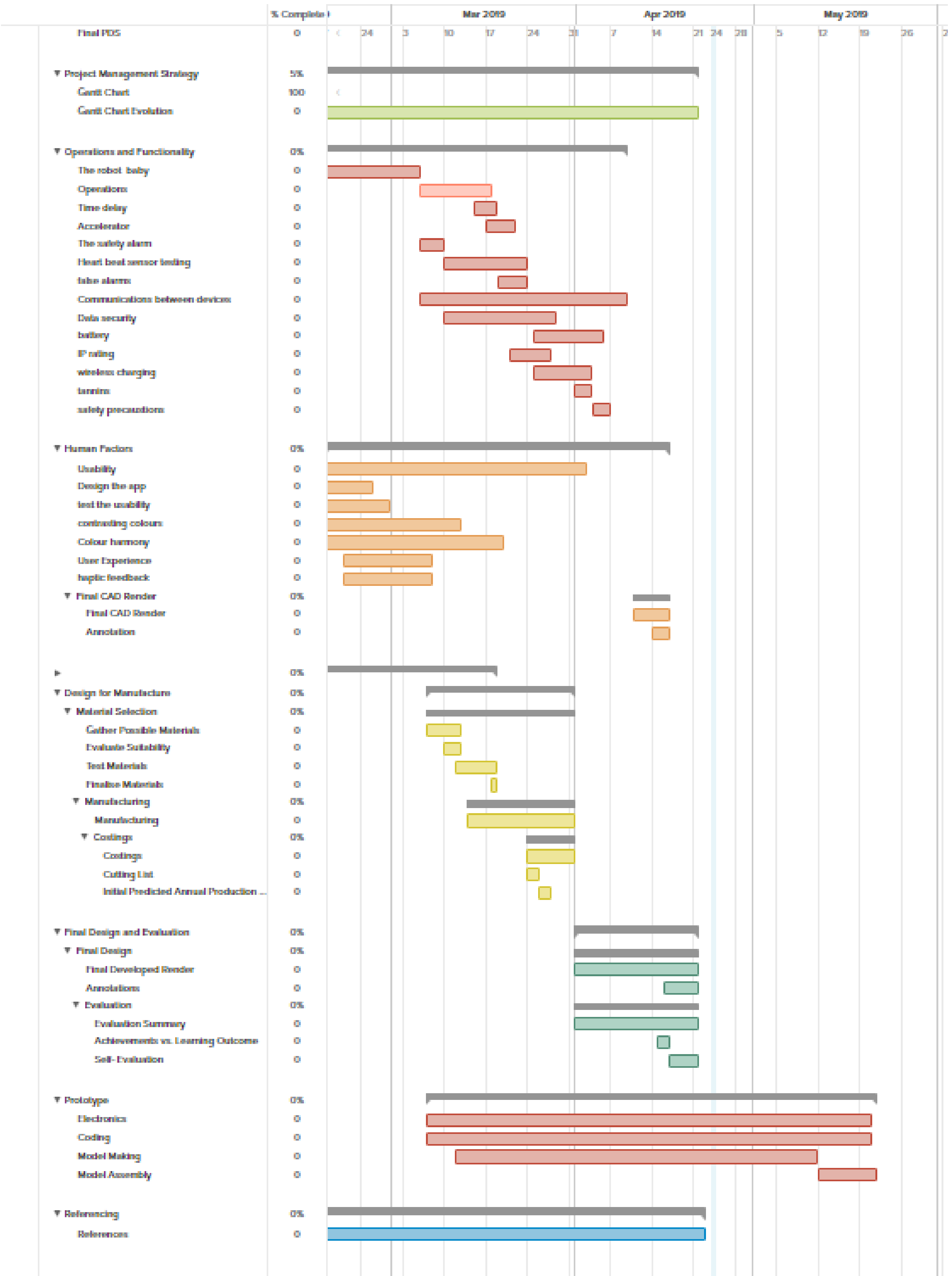
I spent far too long going into too much depth and it ended up taking approximately 6 weeks to get to a point where I understood certain nuisances that my product would have to deal with to evolve into a beter idea. In hindsight I had spent far too long on this topic, especially considering that the product changed very drastcally not long afer that, however during that 6-week period I did develop an amass of knowledge that was very useful for the rest of the process, so I wouldn't consider that tme wasted.

The robot idea drastcally changed afer the 6-week period, but now I was 4 weeks behind schedule of where I wanted to be. I utlised the use a Gant chart fair regularly to allow me to get a beter understanding of what I had lef to do and how long I had to do it, this was partcularly important towards the end of the project when tme was redistricted and there couldn't be any faults, or I would risk not getng everything done on tme.

I defaulted back to the waterfall method in order to get back on track however, the waterfall method was ofen too rigid and didn't allow me enough tme to explore everything I wanted to. So, I had the intentons of doing the waterfall method untl the end but occasionally ended up using the agile approach when I believed necessary or was curious about a topic and wanted slightly longer to explore it.

Throughout the project I always kept a notebook on my person , I would work any chance I got: on the bus, eatng out, even mentally putng things together when I couldn't sleep at night, having a notebook helped to make my work more efcient because I knew that I could spend the tme working on something and would be able to record my thoughts so I wouldn't forget about it later and could explore the thoughts in more depth when I was in a more appropriate environment to do so.

The use of Gant charts also helped me to coordinate multple topics at the same tme, for example: I was trying to fnd people that would help test the heartbeat sensor, I needed at least 3 partcipants but due to everyone's busy schedule it took a long tme to fnd these partcipants, during the day I was trying to fnd people to take part and later in the day I was researching data security and how I would keep each baby's data private. Overlapping certain events was necessary to get the best use out of my tme, otherwise I would have been stuck at a specifc point and wouldn't be able to be productve.

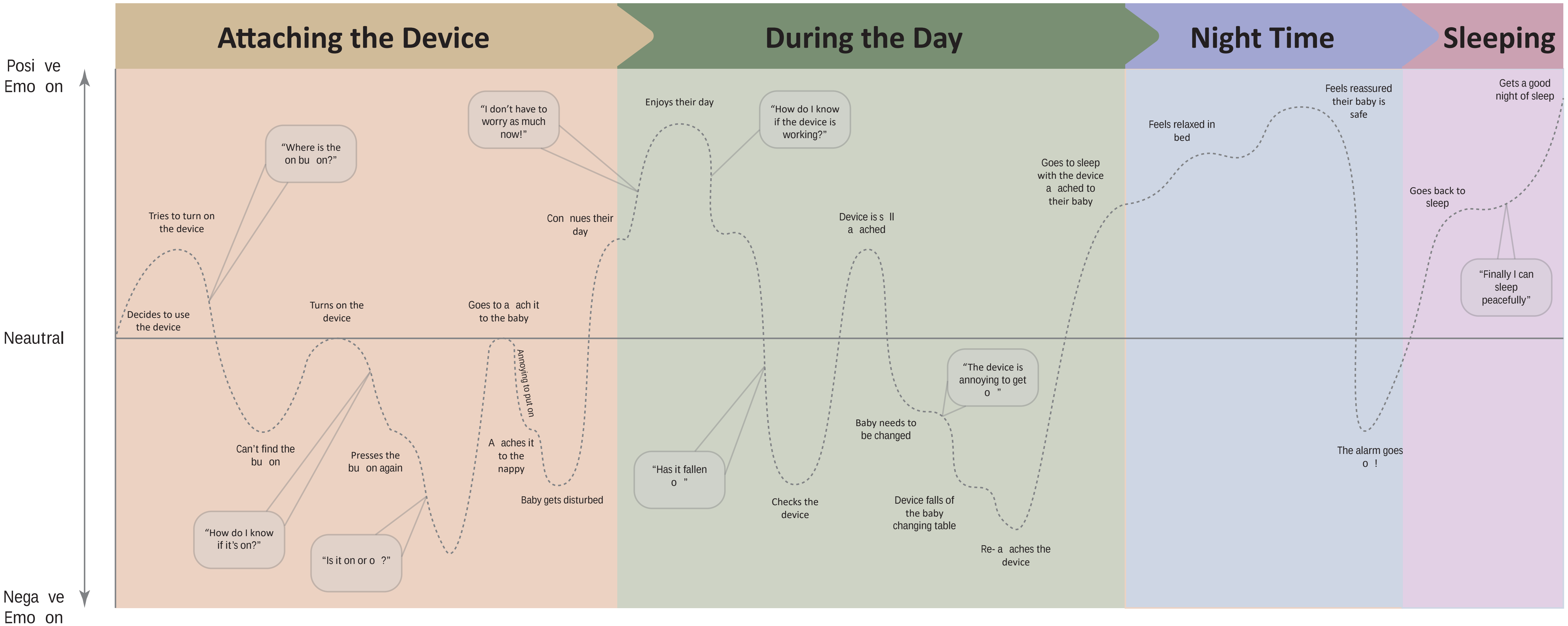


Journey Mapping

Poppy is a loving wife and mother of two, she **struggles** with **feelings of anxiety and stress** about living her day to day life and keeping her baby **safe**, she has a baby monitor in the house and tries to keep him **close at all times** whenever possible when he isn't in the cot, however she is still **afraid that something can happen.** She feels the worst **anxiety** when **separated** from her baby, unfortunately this occurs daily when she **goes to work**, and her anxiety hits its peak when she **falls asleep** due to the **feeling of the unknown**. The **stress** affects her performance at work and makes it impossible for her to get a good night's **sleep.**

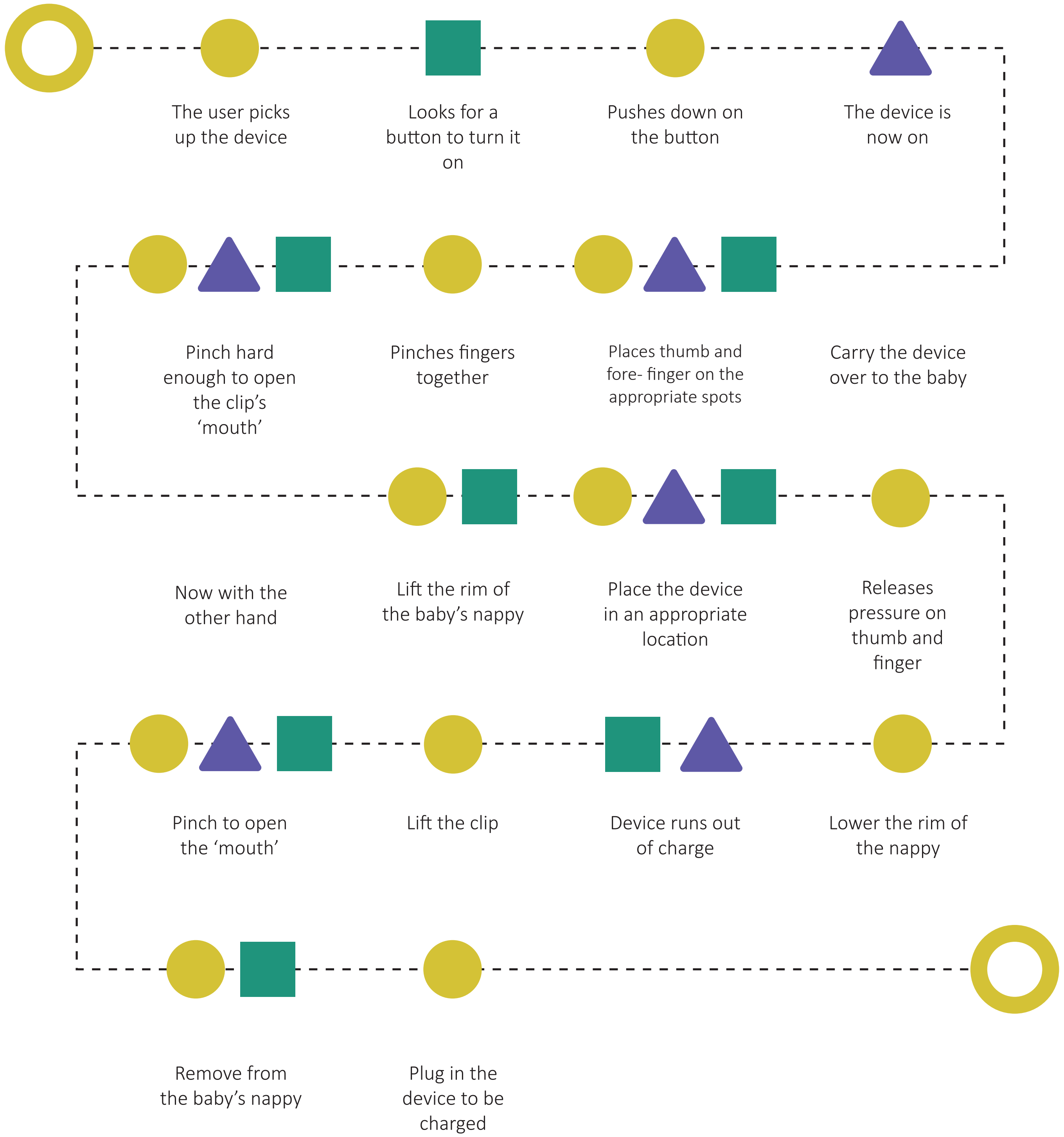
Pain Points/ Design Opportunities

1. The user finds it difficult to turn on the device.
2. The user is unaware of whether the device is turned on or off, this lack of features has caused confusion for the user and needs to be resolved.
3. The method used to attach the device to the baby's nappy could be annoying for many users.
- It could also disturb/ aggitate the baby.
4. There is currently no way for the user to see more in depth details about their baby's vitals.
5. During the day the robot isn't used very often, it is more suited for being on a table/ desk when someone will be sat there for long periods of time.

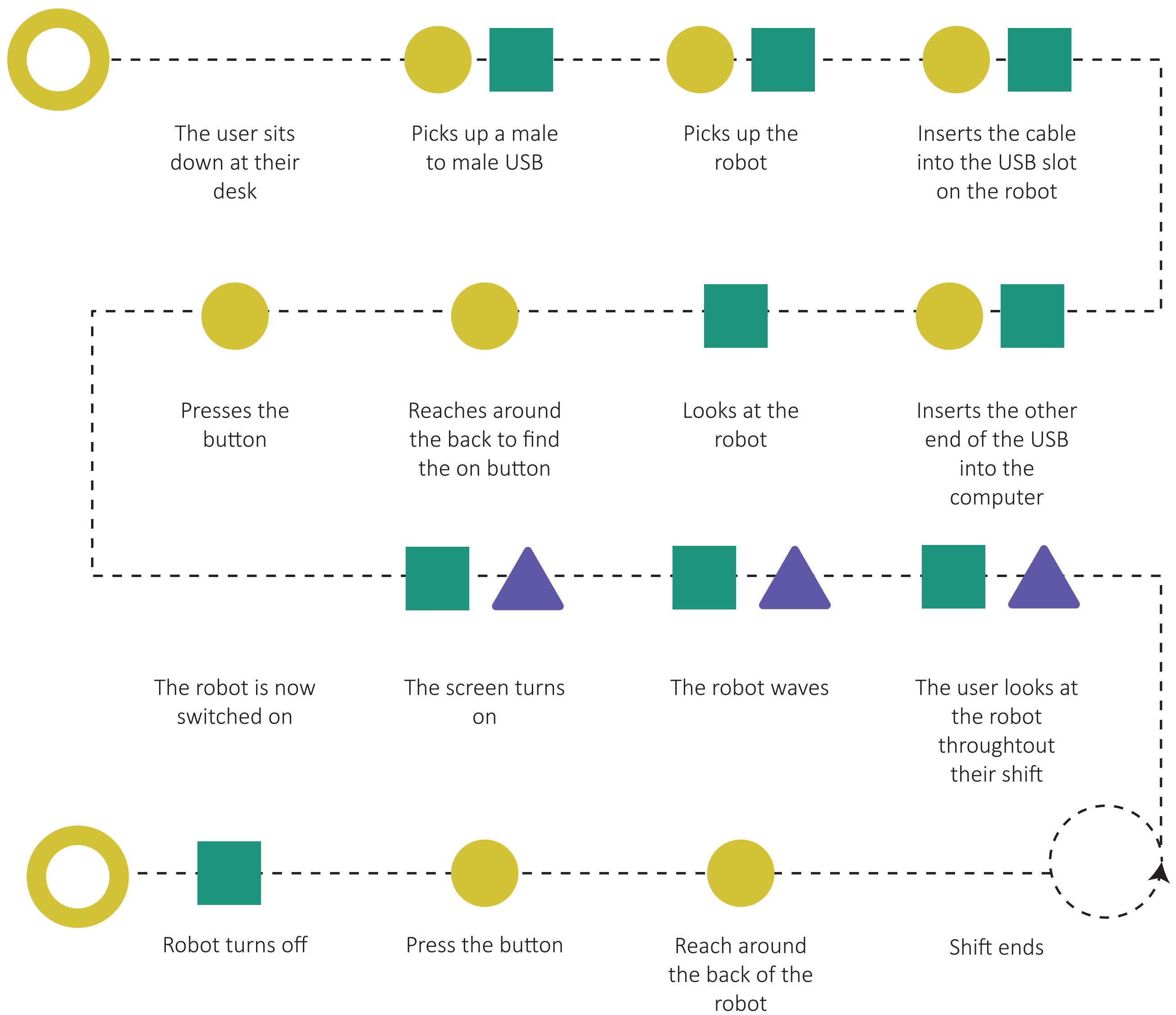


Task Analysis

The Clip



The Robot



Communications

Introduction and initial issues

The product has to consistently and constantly communicate between all three parts; The Clip, The App and the Robo tc Assistant. Many products that already exist such as the 'Fitbit' use a system that records the user when they are using the Fitbit and sync to the app and other devices once the user comes back into contact with open broadband (Fitbit, 2019). However, for this product the devices must be synced every couple of seconds, because it is important that is ful fls its func t on of monitoring the child constantly throughout ba t ery life. The Clip reading the baby's data must transfer that informa t on to the parent's phone as well as the Robot Assistant. The Assistant is primarily going to be used in either the home or the workplace and this dras t cally reduces the op t ons of communica t on between the devices. Since most workplaces are over 100 meters away, this rules out most short-range op t ons including but not limited to; Bluetooth, Zigbee and Wi-Fi.
There are two op t ons that I have considered, at this point; the use of either GPRS (General Packet Radio Service) or SMS (Short Messaging Service) communica t on using a GSM SIM Shield inside The Clip on the baby, to send the data from The Clip to both the phone and robot (Rouse, 2007). This would work over the long distance, however, and ini t al concern for GPRS was the amount of data that would need to be sent. Though as seen in the calcula t on below, the quan t ty of data being sent is surprisingly minimal. Even if assuming it would send the data every second (more than su f cient), the sum would be under 11 Mb per month (0.0107136 gigabytes).

1 int= 6 bytes
2 ints would be sent, one with the heartrate and the other will have the breathing.
2 ints= 12 bytes of data

60x 60= 1 hour = 3,600 seconds
3,600 x 8 (8 hours of active time) = 28,800 seconds

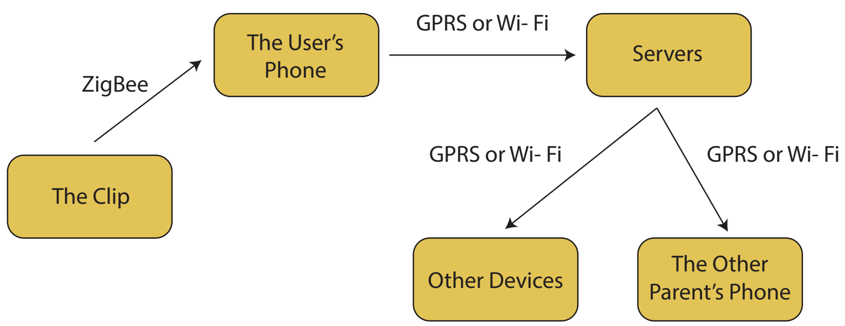
28,800 x 12 = bytes of data being sent during an 8-hour period (1 day of use) = 345,600 bytes
345,600/ 1e+6= 0.3456 mB per day
345,600 x 31 = Monthly data usage = 10,713,600 bytes = 10.7136 mB per month

SMS was found to be inferior to GPRS because it could crowd the user's phone with texts and no t f ca t ons, GPRS wouldn't do this. An issue to consider is the fact that both op t ons require a SIM card contract of some sort. The Clip would either have to have a plan that gives the user unlimited texts for SMS communica t on or a data plan for GPRS communica t on. I conducted a ques t onnaire for parents to see if they would be happy to have another rolling payment in addi t on to the cost of the product. The results were unanimous, this would not be a feasible op t on. The buyers expect there to be a one- t me payment for the product, unless there is a need to replace parts or get repairs.

I had to think of a way around having a payment plan whilst s t ll having a way to transmit the data long distances. I consider many ideas, including; carrying a small device that collects the data from The Clip and sends it to a server where it can be read from a phone. I tried to simplify this further by taking advantage of the contracts people already use on their phones and have their phone be the stepping stone for the data. I spoke to a so f ware Dexter Lowe (See Appendix 1) who is a so f ware specialist and he con f rmed that it would be possible to send the data straight to the phone, and have the phone send it to the server. By using the phone as the 'hub' to send the data, the clip can use a form of low energy Bluetooth called ZigBee (Zigbee, 2016).
ZigBee is derived from BLE (Bluetooth Low Energy) but has more bene f ts than just Bluetooth, that are useful for this project. Primarily, it has a longer range but a slower data rate. The loss of data speed isn't an issue as only a few bytes are being sent and completed within a hundredth of a second. With the extended range ZigBee has to o f er over BLE it becomes a viable op t on for communica t ng data whilst in the home. ZigBee covers 60 meters and is extendable with boosters if necessary (Zigbee, 2016). This is ideal for when the parents go to sleep and leave their baby una t ended. Other methods would not give the range necessary, however the method used with Zigbee works for most homes in the UK even without boosters as the average home is roughly 9m x 6m (LABC, 2019, See appendix one).

Time Delay

Once the data has been sent from the phone to the server, a web socket would directly push the data straight to the Robot Assistant with less than a 500ms delay (Oberstein, 2019). Assuming the phone is connected using Wi- f , the data should get transmi t ed within a thousandth of a second, giving a real t me reading on the baby's data. There is a concern, that when the phone is connected to GPRS instead of Wi-Fi, the GPRS is limited to how o f en it can send data. It can only send approximately 30 messages a minute which is 1 message every 2 seconds (FastSMS, 2017). This means it can't update faster than once every 2 seconds, however, this is not an issue as the parents will s t ll get updated constantly, which will leave them considerable t me to react in case of an emergency.



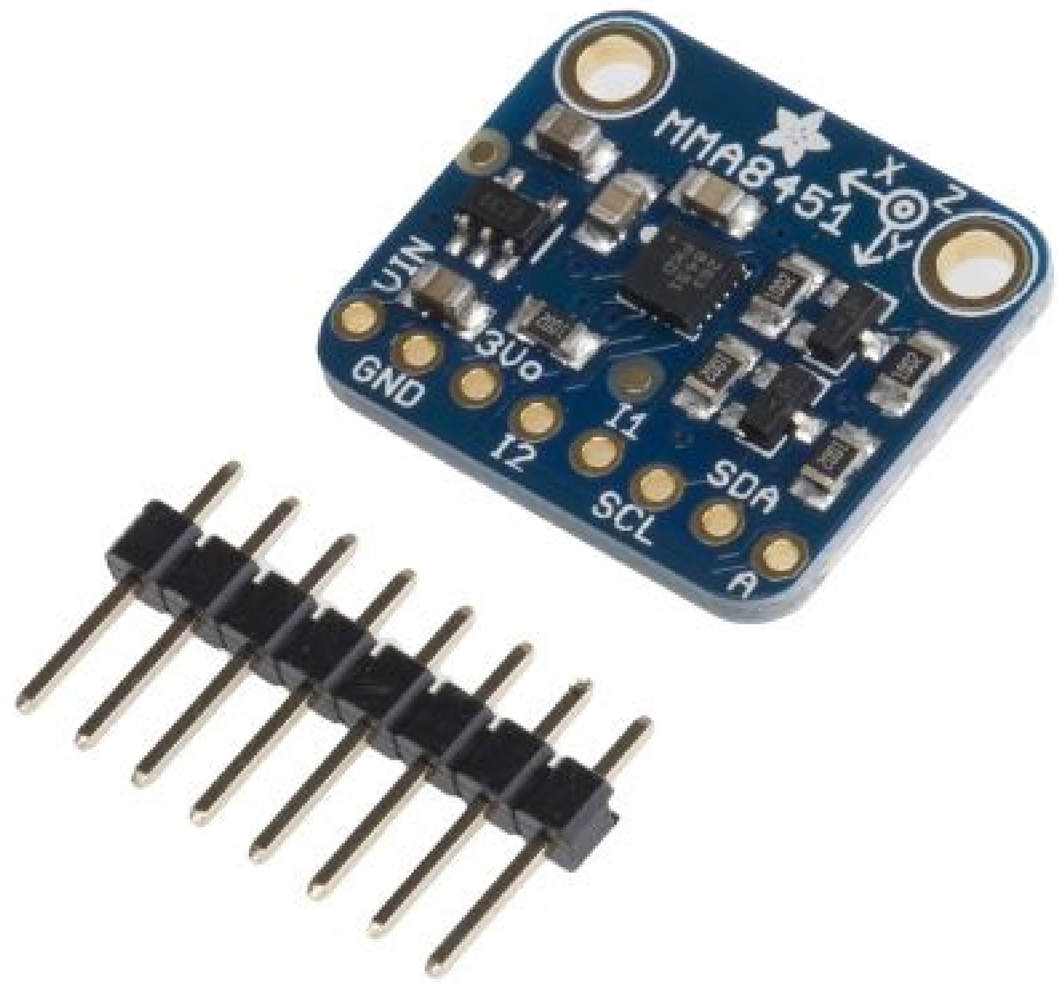
Measuring Breathing Using an Accelerometer

Introduction and why an accelerometer has been chosen

The accelerometer is an essential part of this product as it will measure (arguably) the most important factor of the baby's vital signs; their breathing. The baby's arithmetic mean shows the average of breaths a baby takes per minute (Cross, 1949) reference. This changes depending on what action the baby's body is doing. This is important as during different parts of a baby's REM sleep cycle their breathing may seem too low or too high compared to what it is like when they are awake (Healthy Children Orginisation, 2013). The product must set certain parameters to allow for this. Several options were considered, however, none of them were fit for this purpose. They either had to be strapped to the baby's chest or needed to be set up in advance such as a breathing mat. The product needs to work in any condition, to cater to the parent's hectic lifestyle (it must be usable on the go). Parent's also do not want anything strapped to their baby (see the Research report's appendix for the full collection of opinions). The only way I could find when measuring the breathing from the clip on the baby would be using an accelerometer and measuring the displacement of the baby's tummy/ chest.

How the accelerometer will measure breathing

The accelerometer being used is the 2019 ADAFRUIT INDUSTRIES, 3 axis accelerometer, I2C, 16 pin module. This component will measure acceleration in any direction which can be extrapolated to show the displacement (AdaFruit, 2019). The key to identifying the baby's breathing rate is by distinguishing the peaks and the troughs of the data, this will be primarily found with the displacement of the Z axis which is the vertical displacement. When the baby inhales the Z axis displacement will climb at a steady pace until it reaches a peak and will quick decline into a trough, each time this cycle happens is one breath, after 60 seconds the baby's breaths per minute can be displayed. The baby won't always be on their back, there will be periods when they are being carried. However, using this method of measuring should still work because the displacement will be drastically different, the peak and troughs should still show when the baby is breathing (AdaFruit, 2019).



Flip Detection

The accelerometer will also monitor if the baby flips over. If a baby rolls over and sleeps on their front or their sides, they could have problems breathing and it may cause them to choke. Sleeping on their back is the safest position for a baby and can even reduce the risk of certain conditions such as Sudden Infant Death Syndrome (NHS, 2018), therefore, it is vital that the product can alert the parents if this is detected. If the accelerometer gets rotated around the x- axis more than 45 degrees in either direction, then the product will notify the parents (AdaFruit, 2019). If the parents don't respond to the notification, the alarm in The Clip will be activated after ten minutes. This measure is in place to help minimise accidents whilst the parents are asleep.

Setting the parameters

The baby's arithmetic mean, during periods of being awake and being asleep are very different; when the baby is awake the average new born breathes roughly 40 times a minute, during sleep this can drop to 20-40 breathes a minute (Norriss, 2018). Every child is different; however, it can become dangerous if the breathing drops below 15 breaths a minute or if they breathe rapidly (more than 60 breathes per minute) (Stanford Children's Health, 2019). These calculations will form the product's default settings, however, the app will have a section that allows parents to set their own preferences. This will be particularly useful for parents that are more anxious, and for children that have special requirements due to breathing conditions such as asthma. There is a type of breathing pattern that seems irregular and worrying but is completely normal, the baby may breathe several times rapidly and then stop for up to 10 seconds, this cycle gets repeated whilst the baby sleeps. This pattern is called periodic breathing and is very common among new born babies (Husney, Francoeur and Romito, 2018). The device will be programmed to recognise this pattern and will not notify the parents or trigger the alarm. If the baby fails to take a breath after 15 seconds, the alarm will sound to allow the parents to respond promptly.

The Safety Alarm

Introduc on

There will be a speaker wired to the PCB on The Clip. This will sound an alarm in certain situa tons that have been iden t fed as being dangerous to the baby. This alarm is on The Clip to alert surrounding people that the baby could need immediate assistance. Primarily, meant for when the parents are asleep and may not be alerted otherwise. Sudden Infant Death Syndrome or choking can happen at any t me, so it is necessary to account for these distressing, although rare occurrences (The Mayo Clinic, 2018). The alarm is designed to alert anyone in close proximity to the infant, to enable a rapid response.

Reliability and I2C

The whole system will run with I2C which is a serial protocol for a two-wire interface. I2C is a simple system that helps ensure this product is reliable. The ‘brain’ is o f en referred to as the ‘Master’ and the other components are ‘Slaves’.   All the components will be connected using a serial bus so that when the Master sends data to one of the Slaves there can be two-way communica t on between them. This ensures the data has been received correctly (MickMake, 2017). Furthermore, packet switching can be used, by sending some meta data as well, e f ec t vely poin t ng to the device that the informa t on needs to go to. Things can occasionally go wrong, but this product must be reliable and do its job of protec t ng the baby. The two-way communica t on allows the device to know if something has gone wrong, once it knows what has gone wrong/ missing it can send the data again and resolve the issue (How to Mechatronics, 2015).

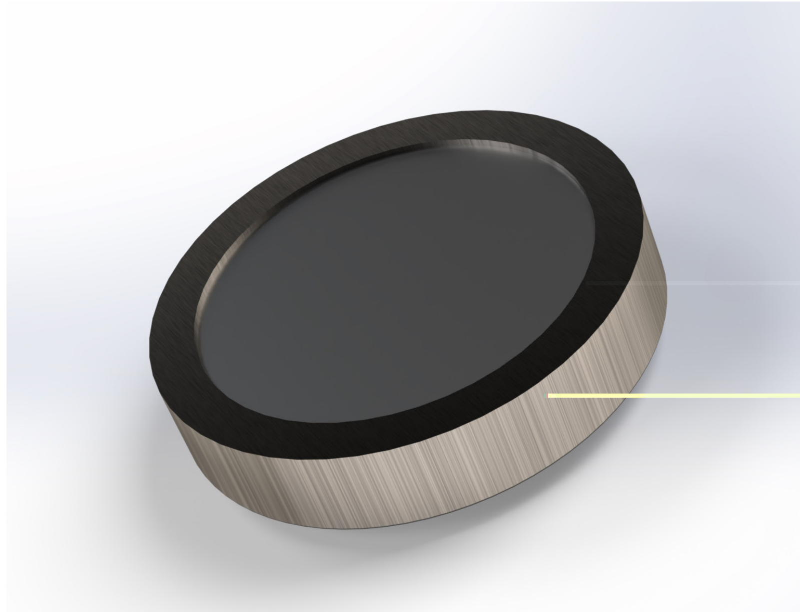
Immediate Alarm and Avoiding False Alarms

The Clip will ac t vate an alarm immediately a f er 15 seconds, where the baby has failed to breathe. The immediate alarm will only sound when a pulse is detected but there is no sign of breathing. This is important because the baby’s parent/ carer may have removed the device temporarily, for example; changing the baby’s nappy or cleaning The Clip. 15 seconds has been chosen as the t me before the alarm ac t vates as due to certain condi t ons and sleeping pa t erns such as periodic breathing, some infants naturally stop breathing for up to 10 seconds, before con t nuing to breathe normally (Husney, Francoeur and Romito, 2018).   If condi t ons like this weren’t taken into considera t on the alarm would constantly be sounded. It is important that the alarm does not go o f unless there is an emergency, or the parent may stop trea t ng the alarms as a priority. The alarm should only ac t vate in situa t ons that are poten t ally dangerous for the baby’s health.

Alarm with a 10-Minute Delay and Periodic Warning Beeps

There are several other reasons the alarm can go o f ;

- When the baby is rolled onto one side (if the accelerometer is rotated more than 45 degrees) or onto their back (180 degrees of rota t on).
- When rapid breathing is detected (more than 60 breaths per minute)
- When slow breathing is detected (less than 15 breaths per minute)
- If the clip has come loose/ fallen o f (no breathing detected, and no pulse detected for 10 minutes)



These scenarios have a 10-minute grace period before the alarm goes o f . During this t me the parents will receive no t f ca t on through; the app on their phone, the Robot Assistant and the device will beep once every minute. These scenarios have a delay on them to allow parents to react in a t mely fashion.   The scenarios may all be important, but usually, temporary and non-urgent.   For example; the baby’s breathing may become rapid if startled but will quickly decline as they begin to calm down. Having the alarm trigger instantly for these scenarios could devalue the true purpose of the alarm.

Batteries

Why Does the Clip Need a Battery?
How to optmise the clip? How would the baby's vitals be measured? The answer would dictate where the product could be used and who could use it. Optons included; using infrared cameras to detect various vital signs or using ultrasonic/sound waves - these were found to be too restrictve and would require set-up by the user. The clip that could atach to the baby's nappy was unanimously the favourite opton amongst parents due to its portability and minimal restricton on the baby. This product needs to operate without the need for a constant power supply because parents want to use this device when they are carrying their baby or taking them out for the day. A portable power supply ofers the user some freedom as to where they can use the product whereas in the case of using infrared cameras a fxed power supply would need to be used which limits the product to a fxed spot.

Other Methods Considered for Charging/ Changing the Battery
One Time Use Batteries: AA, AAA and Cell Batteries
AA or AAA bateries could be used to power the product but there are drawbacks. It would encourage the 'throw-away lifestyle' where the bateries would have to be disposed of and replaced on a contnuous cycle (Clean Water Acton, 2019). It would lead to inconveniences and a long running cost for the customer that would be expensive over the life cycle of this product. These bateries are also large and 'bulky' and would need to be housed safely, which would further increase the size of the clip. The aim is for the clip to be as small and unnotceable as possible.
A cell batery was an opton, but it also had several issues. A cell batery is considerably smaller than a AAA batery or AA batery, however they also have a much smaller capacity. The average amperage a cell batery holds is 200mAh- 300mAh, this would only power the product for approximately 2- 3 hours and would need to be changed every few hours. Therefore, ruled out as unsuitable (Bateries.com, 2019)

Both types of batery would also require a way to be secured onto the device. The cell batery would have a small compartment with a screw on cap, you would push your thumb fat on the cap and screw it in leaving it fush on the surface. To secure the normal bateries would require a removable panel that would clip back into place. Unfortunately, these methods would compromise the water resistance of the product due to the seams and gaps that would be present.

Rechargeable Battery
100% of the parents that were spoken to in my research agreed that rechargeable bateries are the way of the future and disliked the current throw-away life style with disposable bateries (see .... of the appendix for the full results). Most rechargeable bateries last years and can ofen be charged thousands of tmes before they even begin to degrade (Hagopian, 2008). These bateries also tend to have a higher power density than ordinary bateries. In partcular, the lithium ion bateries have a high energy density and capacity when compared to other Ni- Cad or NiMH bateries (Batery University, 2018). A lithium ion batery will be used in the product due to its high capacity and ability to recharge. The trade-of for choosing a high capacity lithium ion batery is that they are stll relatvely large and are an immature technology, this means that a superior form of this batery could be released at any tme as the technology is stll being developed (Batery University, 2018).

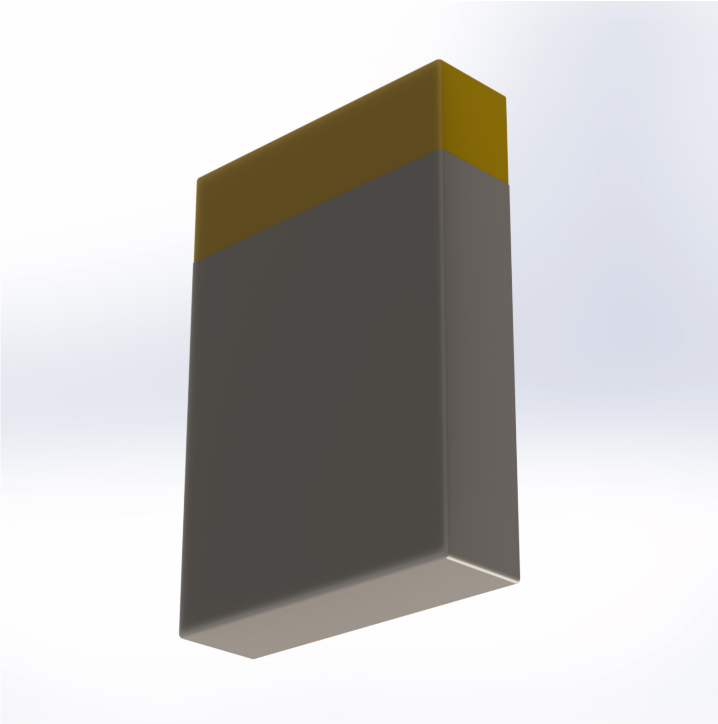
Size of the Battery and Lowering Power Consumption
ZigBee: 33 mA whist transmitng data
Speaker: 10mA when the alarm is actve
Bi- Colour LED: 10mA each whilst on, 20mA for two lights
Accelerometer:26mA in high power mode to measure data more accurately
Heartbeat Sensor: 20mA to measure the baby's heartbeat
PCB Operatng Amperage: 20mA taken as approximaton for what the fnal PCB would use
33mA + 10mA + 20mA + 26mA + 20mA + 20mA=
129mA Approximate Total Power Usage

These calculatons were based of an estmate for how long each component will be used in a day, for example, the speaker uses 0.5 wats as its nominal power, by using the equaton Power = Voltage x Amps I can ascertain that the speaker would use 200maH. This fgure is however not what the product would use, the speaker will only be drawing power when the alarm is going of, the alarm will have constraints set on it so that it only goes of in certain situatons, so assuming the alarm goes of for a total of 3 minutes a day, the batery will only have 10mAh drawn from it during the day due to the speaker. Doing these estmatons allows me to get a much beter understanding of how long the device would for and how much power is necessary to power the device.

To lower the power cost slightly of the components Zigbee will send the data every 2 seconds, this should cut the power ZigBee requires in half to 16.5mA. As mentoned on the 'Communicatons' page of this report, the mobile data on the phone will ofen limit how many tmes the data (of the baby's vitals) can be updated. In order to keep the rate that the User receives the data consistent the data will be transferred 30 tmes a minute (once every two seconds).

To lower the power consumpton more; the speaker won't be actve unless one of theconditons have been met for either the alarm to sound or for the consistent beeps.
129mA - 10mA – 16.5mA = 102.5mA Approximate Total Power Usage

Using a 2000mA lithium ion batery the clip should operate for approximately 19.5 hours before completely running out of power.



IP Rating and Wireless Charging

IP Rating

Considering the environment that the clip will be used in, it is a priority to ensure the clip has some form of protection from liquids and other waste, to protect the electronics operating within. The clip must meet the British Standard (British BS EN 60529:1992) related to water resistance with an IP rating of at least IP45. It will have basic protection from liquids and waste. This product will benefit greatly from being as waterproof as possible, so the user is able to wash the product and not be concerned about it ceasing to function. In order to achieve this the clip is going to be completely enclosed.

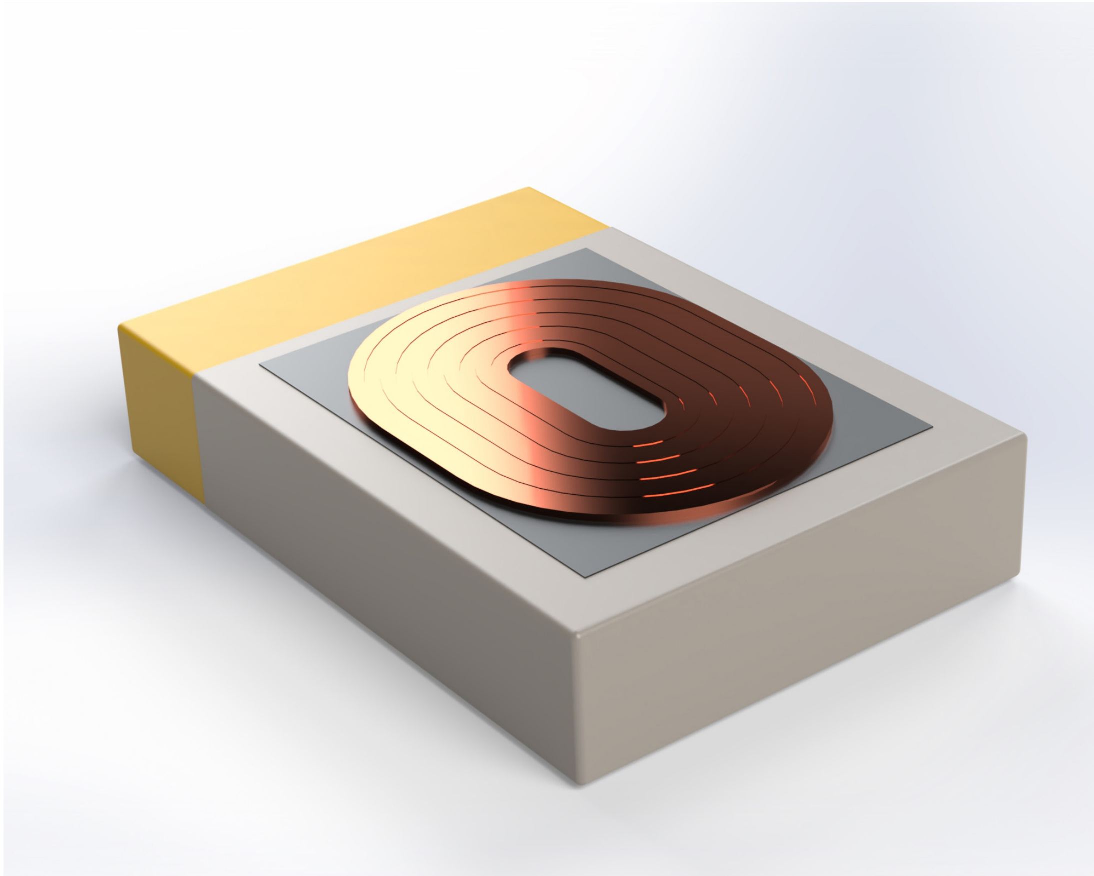
Wireless Charging

One method of charging the device would be by using a hole smaller than 0.5mm and have the surrounding material be a form of rubberised polymer (Fukuda, 2000). The hole would lead to the charging port for the battery which will allow the device to charge successfully. Downfalls for this method are; the charging port would add a considerable amount of size to the device, and the small hole will allow a lot of harmful bacteria to build up inside which could not be cleaned without risking the electronics inside. This option adds an element of risk for the baby, which is completely unacceptable. The highest priority of this product is the baby's safety.

An alternative method to enable charging is by using wireless charging. A copper coil would be embedded inside the device which will allow inductive charging between the clip and any wireless charging station. This is achieved by using the established electromagnetic field, to pass the charge between the clip and the charging station (Woodford, 2019). There are compromises, however; this technology is still immature and developing and will require the user to have a device that can charge the clip wirelessly. Most smart phones allow wireless charging, so this would be a requirement for the user. Also, Inductive charging is up to 50% slower at charging a device (Xiaolin Fang, 2017). The pros for this method far out- weigh the cons. It will allow for a safe, fully enclosed design. This is the preferred method of charging for the clip.

Tannins

Whilst researching ways to make this product safe I discovered tannins. Tannins are water- soluble polyphenols commonly found in woody plants. Tannins and tannic acid have a unique quality that is beginning to be implemented into products found in the kitchen. They have the ability to 'self- clean. The tannic acid produced by the tannins form a protective anti-microbial/anti- bacterial layer which neutralises bacteria (Hisanori Akiyama et al, 2001). This technology is starting to be revisited by companies such as Lignum that created the SKID knife. By creating their knife out of a wood that is rich with tannins, only warm water is required to sanitise the blade (Lignum, 2019). Currently there is little research to be found on tannins and therefore the affect it has on the human body is not confirmed. Nevertheless, it is looking positive and could potentially be considered for a future version of this design when there are fewer unknown variables.



Limitations of Making a Fully Robotic Assistant

Initally, for this project, I wanted to concentrate on creatng a Robotc Baby. It would allow me to see the challenges and limitatons of the Product idea.

I researched bone structure and muscle anatomy. I planned to use a series of servo motors with support struts (which act like the bones of the body) to mimic basic human movements (Jameco electronics, 2019). This process of trying to create a robotc person was an extremely long and expensive process that highlighted several key problems that needed to be resolved.

With a complicated system of parts and motors, it became harder to pinpoint failure issues. I atempted to make the face move but it required too many motors and became too complicated. I tried to focus on essental movements of the mouth, such as mimicking a smile. During this process I conducted a survey to see which movements the clients would expect a robot to be capable of. Surprisingly the public opinion was that the robot needed to do a lot less and not look so realistc. It was found to be quite 'creepy and of-putng' (see secton 3.1 of the appendix for the raw data).

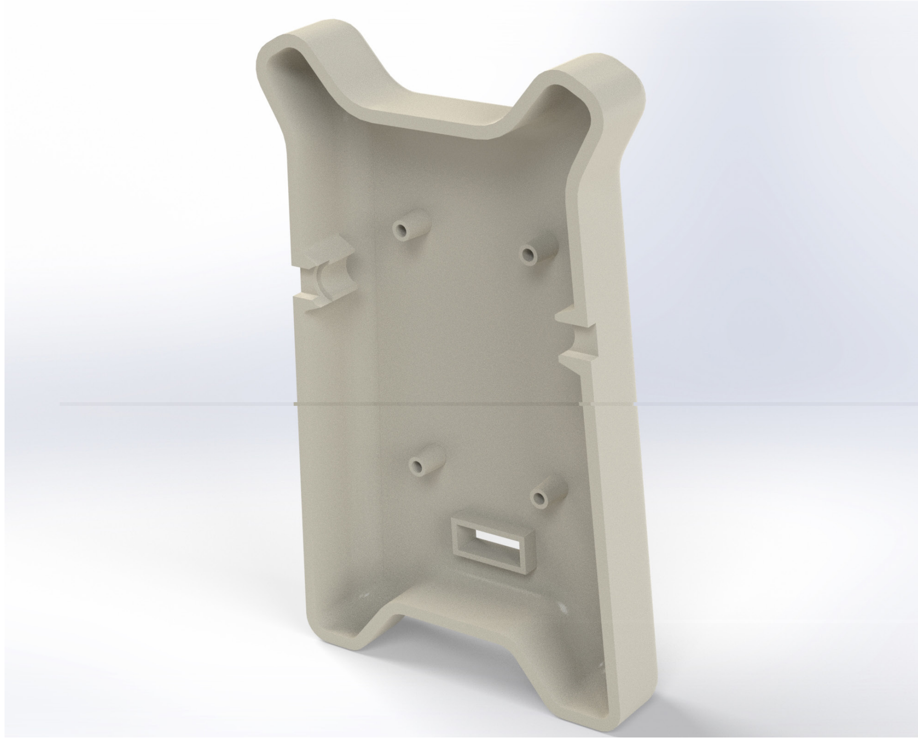
If I stll wanted to make the robot realistc, there would be many limitatons that would restrict the success of the product;

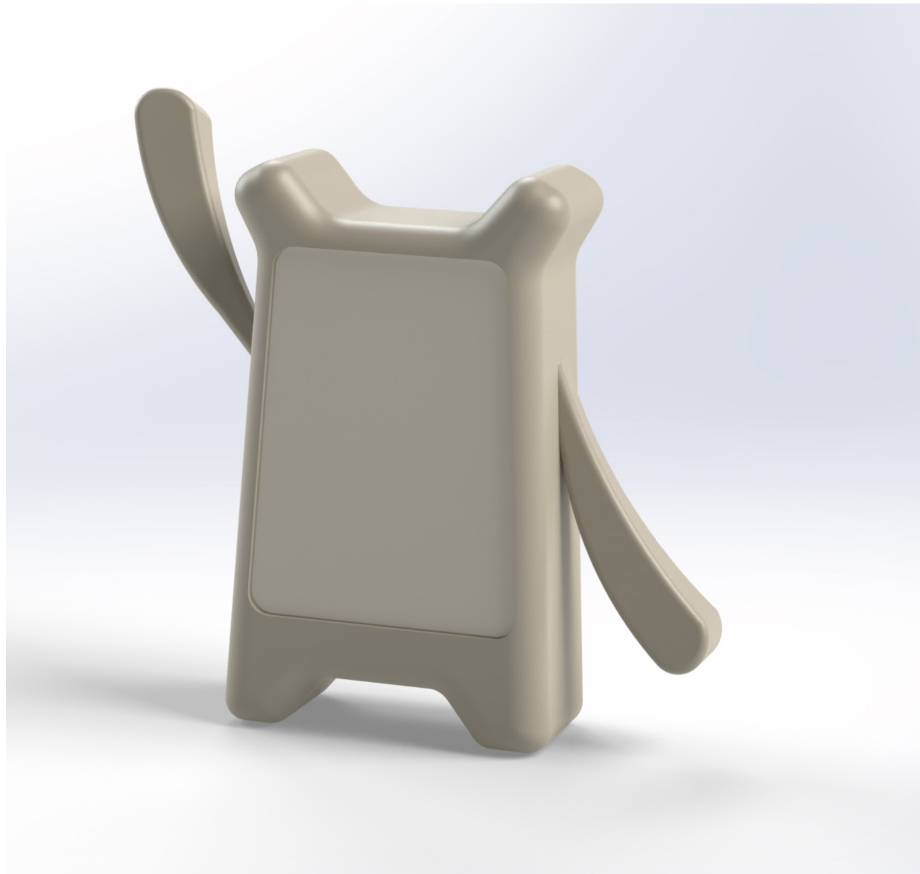
- Drastcally increase the costs per unit as well as the tme it would take to manufacture.
- The robot would be very fragile due to the machinery and moving parts operatng inside.
- Each motor required would add to the power consumpton of the device.
- It could scare of potental customers due to it being 'creepy'.
- The fnal retail price when the product gets to market will be much higher which would limit the number of customers that could aford the product.

For these reasons, the design has changed to look more like a robot and less like a human.
The quantty of moving parts has also been reduced. The robot will consist of two servo motors in each arm, one will be in the shoulder of the robot and the other will be elbow. This will allow the robot to complete the basic movements required such as raising their arms and waving to the user. A new method was researched to communicate with the user.

The face of the product will now be a low power LCD screen that displays an animated face, capable of displaying various emotons to the user based on the data of the baby's breathing and heartrate.

There will be a USB port on the back of the robot that will allow the device to connect and be powered by a computer. On the back will also be a power switch that will allow the user to turn the product on and of as required. Integrated onto the PCB inside the robot will be an ESP8266 wi-f module that will allow the robot to connect to an open source of wi-f so that it can receive the data being sent to the servers from the clip.





Additional Safety Precautions

Double press the on/ off button
During an interview the interviewee men t oned concern for the product accidentally ge t ng turned o f by the baby when they are moving around. In order to combat this concern, the power bu t on on the top of the clip will have to be pressed twice within close succession (within 2 seconds) to turn the product on or o f.

LED to show power level and connectivity to a device
There will be two LED lights on the clip with symbols.
One LED will display the power level of the device. The LED being used is a dual colour LED that will allow for an array of colours, it will shine green (00FF00) to show that the ba t ery is between fully charged (100%) and half charged (51%), 50% - 21% will be represented by an orange colour (F00F00) and <20% will be red (FF0000) which signi f es that the ba t ery is low and needs to be charged or will soon run out (SunFounder, 2017). This LED will help the user manage the device and prevent unfavourable situa t ons where the ba t ery is low on power.
The second LED will show the user whether or not it has established a connec t on with the phone, this will be solid green (00FF00) when the clip is connected to a phone, this shows the user that the clip is on and func t oning properly.

Data Security
According to GDPR laws (The General Data Protec t on Regula t on 2016/679), this product can only collect the bare minimum informa t on necessary for the purpose of the product; the baby's breathing and BPM data are essen t al as they need to be sent to a server where it can then be directed to the robot and any phone the user allows. There also needs to be some form of iden t f ca t on for the data to get stored under. This can simply be a random string of numbers and/or le t ers and is therefore anonymous. The product will only ever communicate using TLS secured channels as an ini t al precau t on, however this means I will need to apply for an X509 cer t f cate and/or an SSL cer t f cate.

Asymmetric Encryption
This is the process of using a 2-part key. The 2 parts are called public and private respec t vely. The users' data will be encrypted just before it gets sent. It will arrive at the server, encrypted, and the only way to decrypt the data is with the private key that would be housed with the server. This allows the data to be sent securely without risk of a third-party ge t ng access to the user's private informa t on.
There would be a separate server that operates as a medium between data queries and the robot/ app. This would also use asymmetric encryp t on (Cheap security, 2019). However, the server will encode a 'chain of trust' which sends the encrypted data along with the key to decrypt it over a separate trusted (and secure) third party (such as DigiSign), this will allow the server and the robot/ app to share the same symmetric key for each session.

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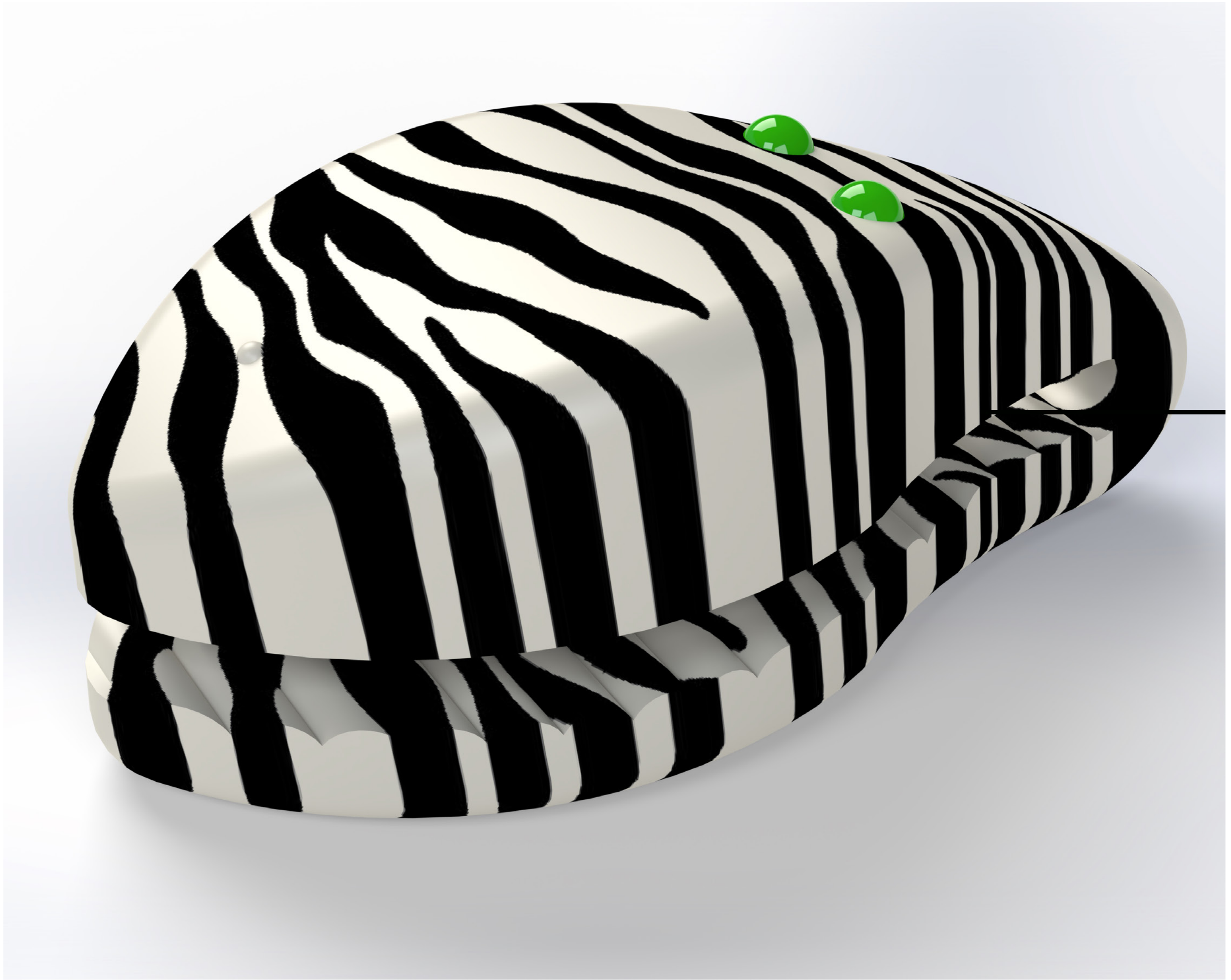

Peg style Clip

Ini tally the product was going to have a peg style clip, (like pegs used to hang out washing to dry). The user would be able to pinch the arms and the clip would open allowing them to slip it into posi ton on the baby's nappy and remove their f ngers to secure the clip into place. The mechanism required to make that movement would be a weak point in the design. The clip needs to be durable and not break apart. If it does break it could become a sharp edge that the baby could hurt themselves on or if any parts are small enough they could become a choking hazard. The mechanism could be hard for a large quan ty of people to use, 10 million people in the United Kingdom alone have arthri ts (NHS, 2019), and many others have common ailments could make this unnecessarily di f cult. The moving part could also cause the baby discomfort because hair or bunches of skin can get trapped and pinched. For these reasons, this is idea is not suitable.

Magnetic Clip

To counter the issues with the ini tal method I cons

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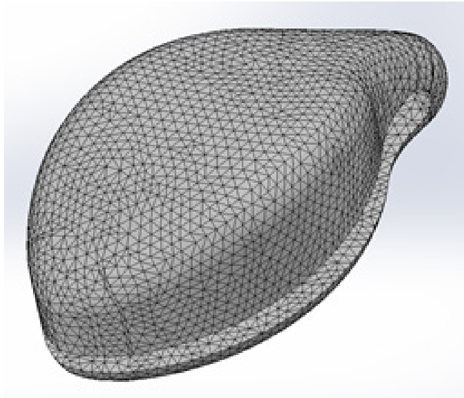
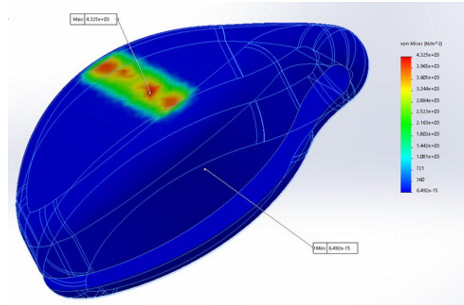
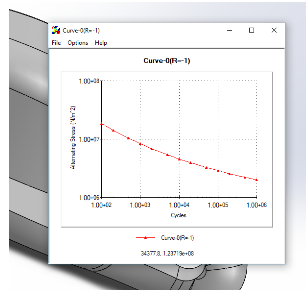


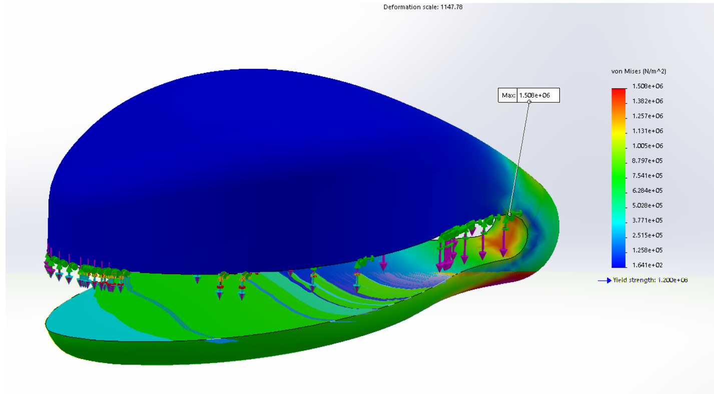


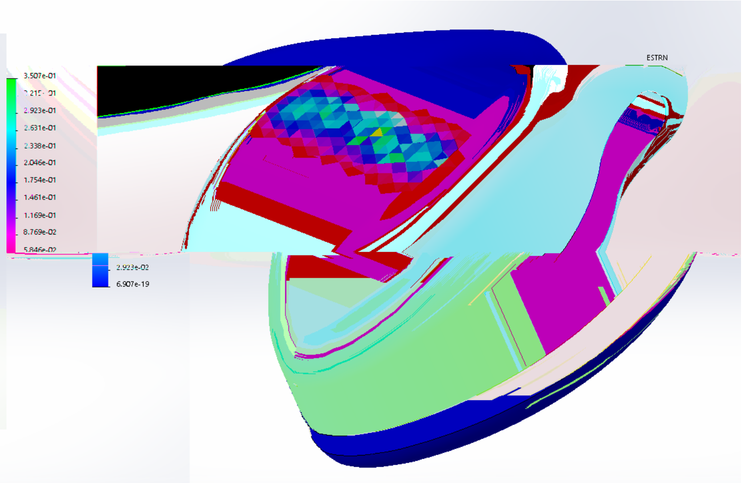


Several tests were conducted on Solidworks to test how durable the product would be in various situations. The mesh was refined as much as possible to get a more accurate result for each test.

Drop Testing

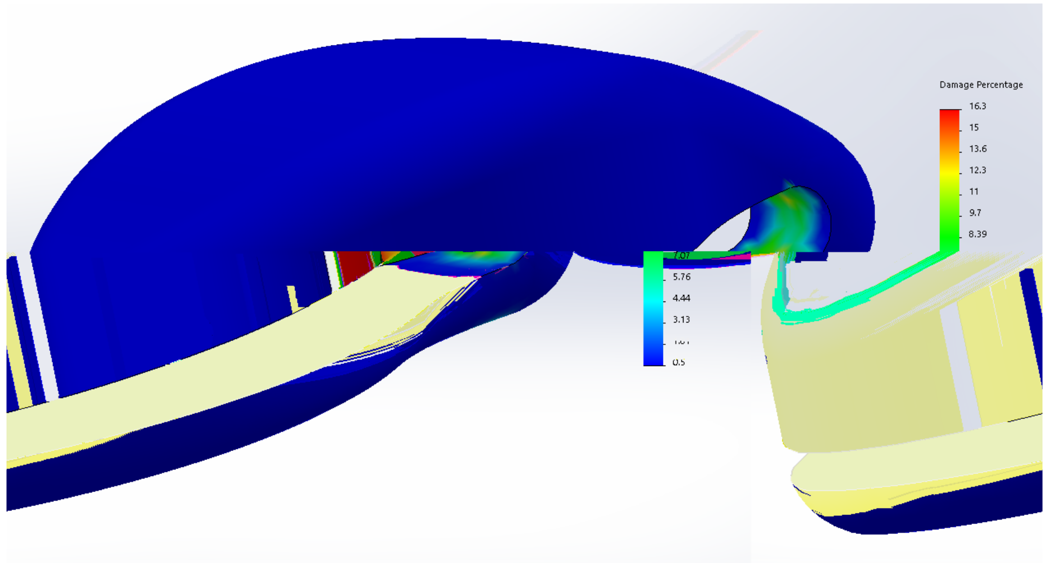
The first test that was performed was the drop test, as mentioned in the PDS, this product must be able to fall from 1 meter high whilst taking little damage and still being able to operate. This fall was performed several times, making it land on a different face each time. When landing on the bend it took the least damage, surprisingly the surface that was affected the most was the top of the clip, this could be due to the enclosure inside this part. No significant or permanent damage was done to the exterior of the clip during the tests, the stress and the strain never reached large enough to permanently deform the clip.





Static Nodal Stress Test

This test was performed to test how 5 newtons of force would affect the clip, because the clip will be slipped on and off. 5 newtons are a much greater force than should be necessary, however, this needed to be explored in case whilst the parent is taking the clip off, they could accidentally put more stress on the clip than what it took to slip on if it gets caught on the nappy. This was achieved by securing the top of the clip in place and applying a force of 5 newtons on the top of the bottom section of the clip. The results show that the arch of the clip had the stress placed on it during the push, there was extremely little stress on the area and should be able to take significantly more force than 5 newtons without buckling or deforming.
Due to the results from the previous study another study was ran with a force of 20 newtons, however this still had very little effect on the clip's structural integrity.



Fatigue Study

The fatigue study's aim was: to see if even whilst taking exaggerated force when the clip is slipped on and off the nappy, would the clip break from the fatigue damage within the life cycle of the product. Assuming the baby's nappy was changed 5 times a day, the clip would opened whilst being slipped on or off the diaper 12 times (including once for putting it on, and once for taking it off). The PDS requires that the product is still functional for at least 1 year, this means that with my earlier assumption, if this product is used every day that the clip will be 'opened' 4,380 times (12 x 365 = 4,380). Some parents will still want to use the product even after the first year when they are much safer, but for this experiment 2 years will be tested, therefore the 20 newton stress test that was conducted will be ran 8,760 times, and by using an SN curve for the appropriate material should give a fairly accurate understanding to whether it will still work after a year. The results showed that the clip wouldn't fail within the 2-year period, the arch did degrade by 16.3% in the weakest spot, this is a great result and shows that the product is more than durable enough to continue operating for its life cycle.

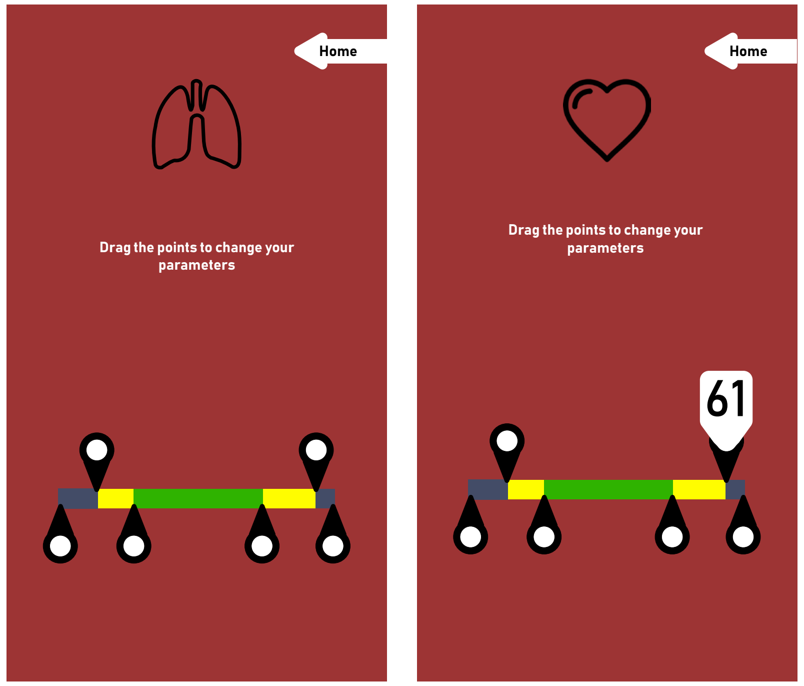
The App

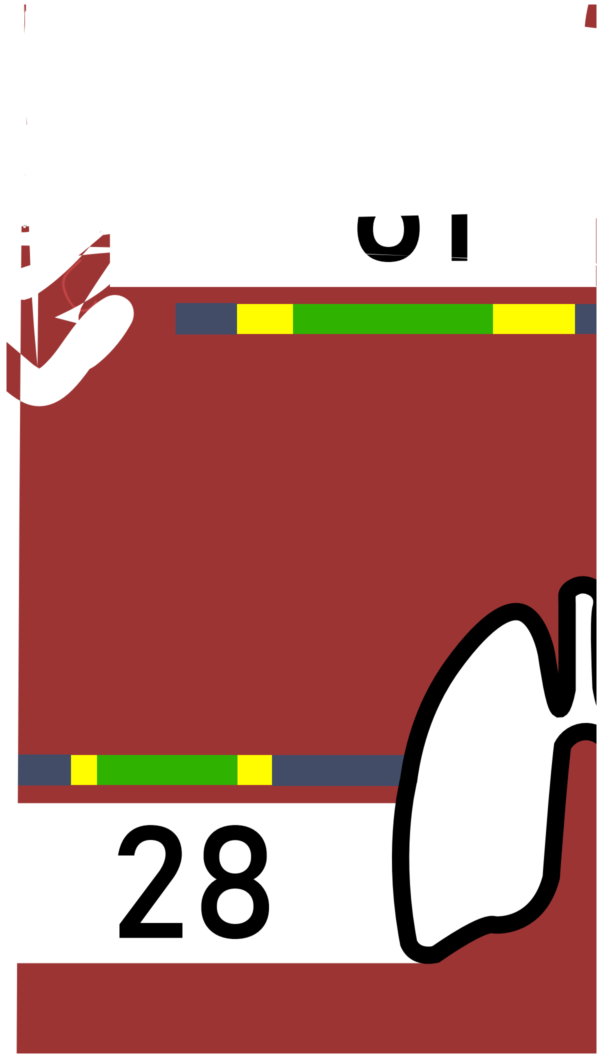
Why an App?
Based on the journey map it was clear that users want to have the op t on to check the baby's vitals 'on the go' that allowed them to see more in-depth informa t on on their baby, having to check the clip a t ached to the baby would be a hassle so the most logical op t on was to create an app. This conclusion was backed up further with results from a short survey that showed an app was the peoples' preferred method of receiving informa t on (see appendix 3.1). Having an app will allow the user to check on the baby wherever they are, this allows for several exci t ng op t ons to be explored: mul t ple people could have the app and see the baby's data (which is ideal for a couple/ parents). Parents can set acceptable parameters for their speci f c baby, this would allow the device to be customised based on their baby's breathing habits and sta t c heartrate, this is par t cularly useful for children that su f er from various illnesses such as asthma that can alter what is normal for them. It also allows the users to see an exact f gure, as discovered in the research sec t on of the report knowing the baby is safe isn't always enough, a signi f cant number of people need a form of instant relief to give them the assurance they need, seeing exact details will help contribute to calming all types of users.

Contrasting Colours
It is important to use contras t ng colours when designing an app, this can be achieved by complying with the WCAG AA test, this is done by having a contrast ra t o of at least 3:1:1 for larger text (Ben Caldwell, 2008). If colour contras t ng is done incorrectly then it can make things di f cult for users to dis t nguish and add to the visual demand, by u t lising the WCAG Colour Contrast Test the contrast of the app can be checked to ensure all the informa t on is clear for the user. In order to make the text as clear as possible, white and black were selected for the most important informa t on. The BPM and breathing rate is displayed in a sec t on of white with black text. The rest of the app's main page is covered in a bold colour in order to make the white stand out even more.

Clear font
To pick a clear font requires the typeface to have a high level of legibility and/ or readability. A long running maxim requires that the typeface be 'transparent' to the reader, this means that it doesn't bring any unnecessary a t en t on to itself. A posi t ve quality in some of the legible typefaces is that they have 'restrained design characteris t cs' but also contain 'big features' (Haley, 2019). The font that has been selected is Bahnschri f , the font u t lises 'big features' excellently and the serifs are subtle and not over- powering. By using this typeface on the white background, the important informa t on (the baby's vitals) will stand out from the rest of the app. Making an app clear will help the user navigate through the app, as well as helping them become accustomed to where to look for the informa t on they are looking for easily. This can help build trust that the app is quality and capable of monitoring their baby if the design gives o f a user-friendly vibe.

Presenting the Data
Presen t ng the numbers for the baby's BPM and breathing rate, is meaningless to a person if they don't know what it means. To present this data in a meaningful way a visual representa t on was created by using a scale under the number. This scale is colour coordinated in order to make it accessible to more people. The slider moves along the scale based on the baby's live data: green is good, yellow is ok and dark blue is bad. The scale starts from the middle and can slide either way to show if the BPM/ breathing is too high or too low.
This feature also synergises with the parameters feature, the scale will change to whatever the user sets. This means that the clip will also react to whatever constraints have been placed on it.





Navigation
Working Memory and Minimising Visual Clutter
Humans are limited to a working memory capacity of approximately seven items, plus or minus two. (Miller, 1956). When designing how the user should navigate the app, one of the most central ideas is to keep it simple. When the user starts using the app, they shouldn't feel overwhelmed by lots of informa t on. Keeping each part of the app clu t er free helps to lower the cogni t ve load, which will improve the user's percep t on of the app. A series of paper design varia t ons were created to see what the users preferred in for the aesthe t cs, based o f the winning design the remainder of the app was created, a test was conducted to see how many errors it would take to navigate the app, how long it took and their overall sa t sfac t on, a f er the results the design was op t mised by reducing the number of errors and t me taken. Chunking helped to compartmentalise the parts of the app, everything to do with breathing was put together making a clear separa t on between the breathing sec t on and the heartrate sec t on. The parameters were also chunked into those two categories, this allowed for there to be two separate pages on se t ng parameters which helps to declu t er the app interface.
Visual cues have been used to help make it clear to the user what they are looking at, the lungs show which is breathing and the heart shows the BPM. The familiarity allows the user to know what they are looking at much faster by using words. It also lowers the cogni t ve load because they don't need to think about it due to their brain automa t cally associated the symbols with what they are.

Necessary Details

The journey map helped to illuminate an issue with the clip, it doesn't show much information which causes confusion for the user.

The clip will have a button under the surface that the user can press. In order to make this more apparent to the user, there will be a small raised bump just above the button, the user can use their sense of touch to feel where the button the is. This bump is a feature that many products use, by using the theory of association the user will know that the raised surface is an area to be pressed.

Once the user presses down on the bump haptic feedback is necessary as it allows the user to know they pressed hard enough to activate the button and turn on the product. Once the user presses down hard enough the button should make a clicking sound and sensation, this feeling will notify the user that they pressed the button. The combination of the bump and the auditory click will make the process more efficient for the user as it will require less time for them to turn on the device.

At this point the user still doesn't know if the product is turned on, there will be an LED that lights up to show that the power has been turned on. The LED being used is a dual colour LED, this allows the LED to change colour, to show the user how much battery is left this light will change from; green to yellow to red. Green is associated with 'good' whereas red is associated with 'bad', this sequence of colours is widely recognised and therefore should be self-explanatory to the user.

There will be another LED, this one will flash when it is connected to a device. Connectivity is a big part of this product, the clip sends data to the phone. From there it is sent to servers that can distribute the data where necessary such as; to another person using the app (the two parents) and the robot. If the clip isn't connected to a device, then it can't send the baby's data after it is recorded, this LED will periodically flash if it is connected to a device.

These small changes will significantly improve the product's usability, it makes things much clearer for the user and will reduce any previous confusion. It should also help relieve some of the parent's stress, because they will have a better understanding of how long the product can be used before it needs to be charged again. This will prevent situations where the user thinks it still has ample battery for the day/ night but unexpectedly runs out part way through.

Patterns

Children's clothing commonly utilises 'noise' on their designs. The patterns are usually friendly for the child, but the 'noise' created by using a pattern also gives the benefit of blending colours and shapes together in a way that others won't notice, because there is already a cognitive overload due to the pattern (Spoonts, 2017). This quality is excellent for this product; the clip will very likely get covered in the baby's waste on a regular basis which could cause some undesirable stains, having a pattern will help hide these stains until the clip can be washed.

The pattern needs to be unisex, this will allow the product to be sold to a greater audience. It is very common for parents to avoid buying their children something due to their gender and the stigma of that. For example; little girls get dressed as princesses, whereas boys are dressed in clothes with characters such as 'Bob the Builder' (Bainbridge, 2018). A zebra print has been selected as the unisex option, this print is gender neutral whilst still having personality. The lines used for the zebra print also add a significant amount of noise to the product which is ideal. Adding personality to a product makes it more desirable for use

The Robot

Changing the Aesthetic and Function

Whilst pitching the idea of the product to a poten tal future customer to get feedback on the good and bad parts of the design, they gave the feedback that making the robot look like a baby was terrifying. This was immediately inves gated further by conduc ng a survey to see what other people thought of the design idea (see appendix 3.1for the results). The results show unanimously that users f nd the human like aspect of the robot ‘creepy and o f- pu t ng’, another survey was then conducted to see what the user would like from the robot aspect of the product. The results show that the user would prefer the two parts to be separate. The person with the baby would use the app, and the person at work can have the robot as a reminder that their baby is safe to boost their produc vity at work.

They also believe that the robot should be exactly that, a robot, the product should not try to imitate a person, however, could be a robot with personality. The top two methods users found e fec ve to receive informa on was from an app and from faces. The robot idea needed a dras c change in order to meet the desires of the users. The most e f ec ve method of mee ng these requirements was a complete redesign of its shape and func ons.

Brand Language

By establishing brand values that poten al customers might desire from this product helps to give it more focus in the design inten ons. This product should strive to achieve quali es such as: gentle, friendly, caring, and reliable. These quali es will be projected into the next itera on of the design to make it more desirable for users.

Location and Size

A short test was conducted to see where the product will go on a desk that is the least intrusive but s ll large enough to be clearly seen while sat on a chair. This was an important test because it would help to set constraints for the robot overhaul. It can’t be too large that it obstructs the users monitor or blocks them from working on their desk, and it can’t be too small if it is out of the way because it won’t be able to alert the user if necessary.

Desks are can o f en rather small and don’t have much space. The robot should be tall instead of wide to reduce the amount of desk space that is required to use the product. The best place for the robot is next to the monitor, this will allow users to glace over without even needing to move or cancel their train of thought. This will give the users the instant relief they need without having to disrupt their work. To not be too large, the robot can be a maximum of 15cm x 10cm, any more than this was seen to be too large and intrusive.

Faces

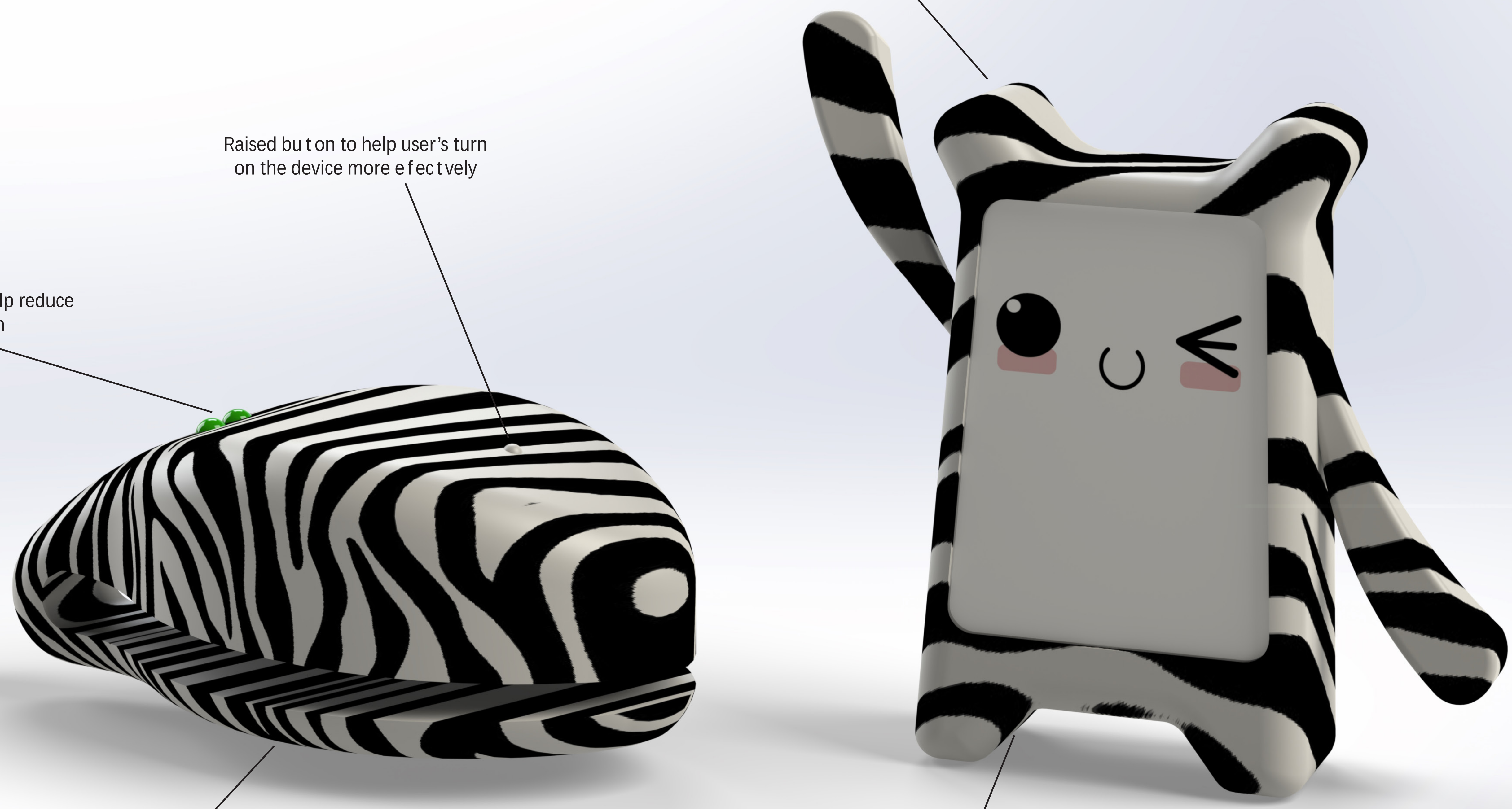
Various faces were tested to see how users wanted data communicated to them, the op ons ranged from: well-known emojis, to cute faces and even outrageous/silly faces. The results show that people want the style of the face for the robot to be ‘cute’. The comments made it clear that they are associa ng the robot with their baby. By having a ‘cute’ expression it made the users trust the product more because it was like the resembled their baby.

The Robot Redesign

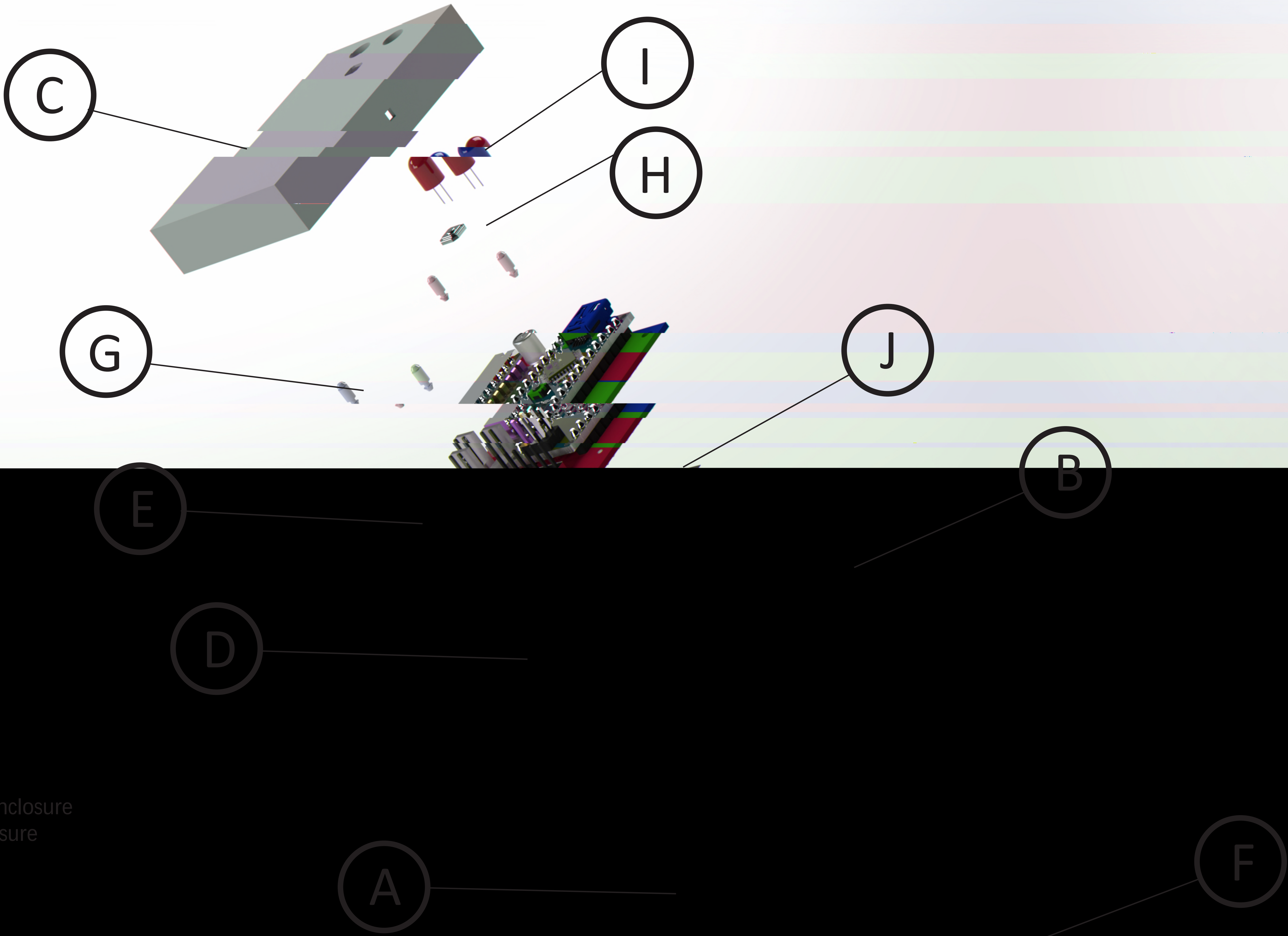
The robot has now been changed to a much friendlier, free standing design. The robot will no longer solely move to communicate with the user, a screen will be used as a face for the robot. This allows for less ambiguous feedback from the robot, the faces can give more detail in less me than if the robot moved around. The arms are the only moving part of the design, the arms will wave at the user when something important urgently needs their a en on. This will alert the user that there is an issue very rapidly.

Colour Selection

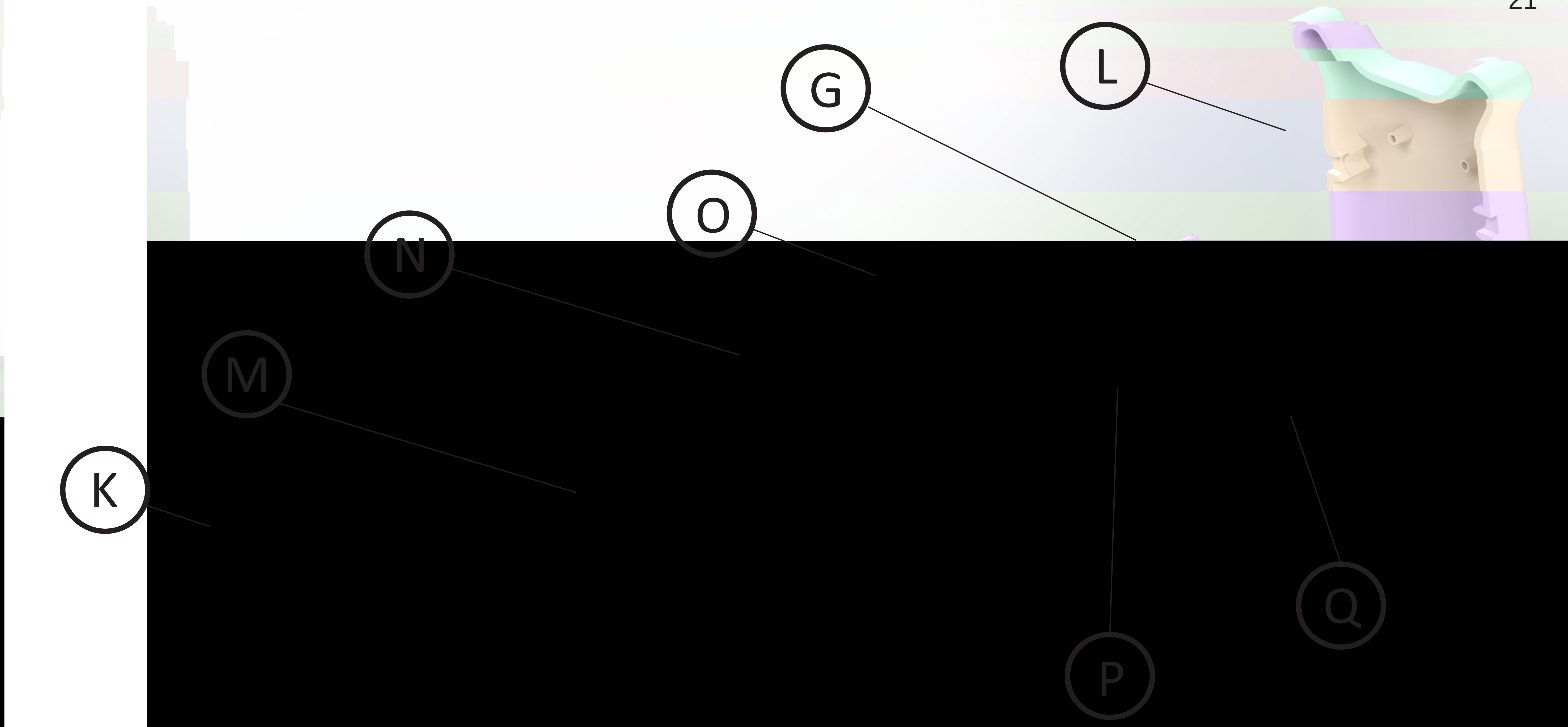
Feedback showed that the robot would be be er as a sta onary unit that stays at the user’s workplace or in their home. Due to this it was necessary to cater the design for a workplace or a sta onary posi on. Whilst at work the user cannot have any bright eye-catching colours that could distract them from their work or distract any of their colleagues. To establish a connec on for the user at work and the baby, it seemed appropriate to keep the consistency between the two parts and prevent it from feeling disjointed. To do this it needed to be something that could go on the clip but also on the robot, this was a factor when deciding the print and the colours. A zebra pa ern is ideal for both, it isn’t bold and garish, and it allows the robot to join the desk as a cute companion that is looking a f er their baby. Establishing a connec on with the product is important to ensure that the user keeps and uses the product in the future and it also increases the user’s overall sa sfac on.



The face will change to show that the baby is safe
Audible and hap t c sensa t ons when pressing the bu t on
Much friendlier design
Raised bu t on to help user's turn on the device more e f ec t vely
Green LED's to help reduce confusion
Zebra pa t ern will appeal to the baby and matches the aesthe t c of the robot
The pa t ern is matching to make the user feel close to their baby



A. Body of the Clip
B. Bo om of the Clip Enclosure
C. Top of the Clip Enclosure
D. Ba ery
E. PCB
F. Heartbeat Sensor
G. PCB Connector
H. Bu on
I. Dual Colour LED
J. Copper Coil



G. PCB Connector
K. Robot Front Enclosure
L. Robot Back Enclosure
M. Robot Arm
N. LCD Display
O. PCB for the Robot
P. Servo Motor
Q. USB Female Connector

Design For Manufacture and Assembly

Introduction

This secton is dedicated to explaining and displaying the design choices that have been made regarding manufacturing each part of the product, this secton will also include optmisatons of parts and processes required to make them more e f cient and/ or efectve. The secton will be split into 3 separate sectons: optmising the design for manufacturing and assembly, material selecton and the ratonal on the choices made, and fnally costngs

Enclosures
Several of the parts will be encased in polymer, to ensure these parts will keep functoning they need to be covered and protected from the polymer in an enclosure. The parts that need to be covered are: the heart beat sensor that will be located at the botom of the clip, the other components for the clip will be stored together in a separate enclosure.

Minimising the Number of Parts

Reduced Number of Motors
The robot was planned to have a total of 3 motors in each arm; one for the shoulder, one for the elbow and fnally one for the wrist. The motor for the wrists were removed. This decision will limit the amount of manoeuvrability the robot has, however, there are several reasons for removing these motors that are benefcial: Fewer connectons will make the fnal product more reliable and easier to assemble on a producton line, this equates to a lower cost due to the reduced assembly tme. Reducing the amounts of parts also allows automaton to be implemented with greater ease and less issues with inventory control.

Removing Screws- Snap Fitng
Initally screws were going to be used to fasten parts together such as, the 2-part box enclosure for the clip and the robot assistant however screws lead to several issues during assembly. Having multple size screws ofen causes confusion on the producton line which leads to a higher producton tme. Another cause for increased producton tme is due to the workers having to put each screw into place and fasten them individually. To prevent these problems from occurring during producton, snap ftngs will be used where appropriate.

Ease of Assembly
Snap ftngs are being used not only to reduce the number of components but to make the assembly process; easier, faster and more intuitve, once the components have been assembled inside the 2-parts they can be snapped into place before beginning the next one, there is a slot on the side of the top piece and a tab on the botom piece, when they align they will clip automatcally which eliminates tme being wasted securing each screw.
The insides of the enclosures have support brackets for each component, this gives a guideline for where the components will go so the workers can quickly see what component fts where. The support brackets also help the workers get the components secured in tŞ t ÔM ˘ in o˥ ˘ f ThIl gŐnThe ʾ 3 r ╓ Džή א es Ŀ Ŕ ╓Džx seŁ Ŕ t

Design For Manufacture and Assembly- The Clip

Bottom Half of the Enclosure

Gussets and ribs have been used around the edges in order to give the walls extra support, this should prevent sinks in the wall and improve the overall strength of the enclosure.

Guidelines have been added for where the battery will go, there is several extrusions that show the workers assembling the product where the battery slots into, it also has the added benefit of adding support for the thin walls next to it.

The bottom part of the enclosure will also have the clip attached to it, this part will run along the side of the other half and clip into place to make everything secure. Chamfers and gradients have been placed on selected faces to make it more efficient for the clip to slide into place.

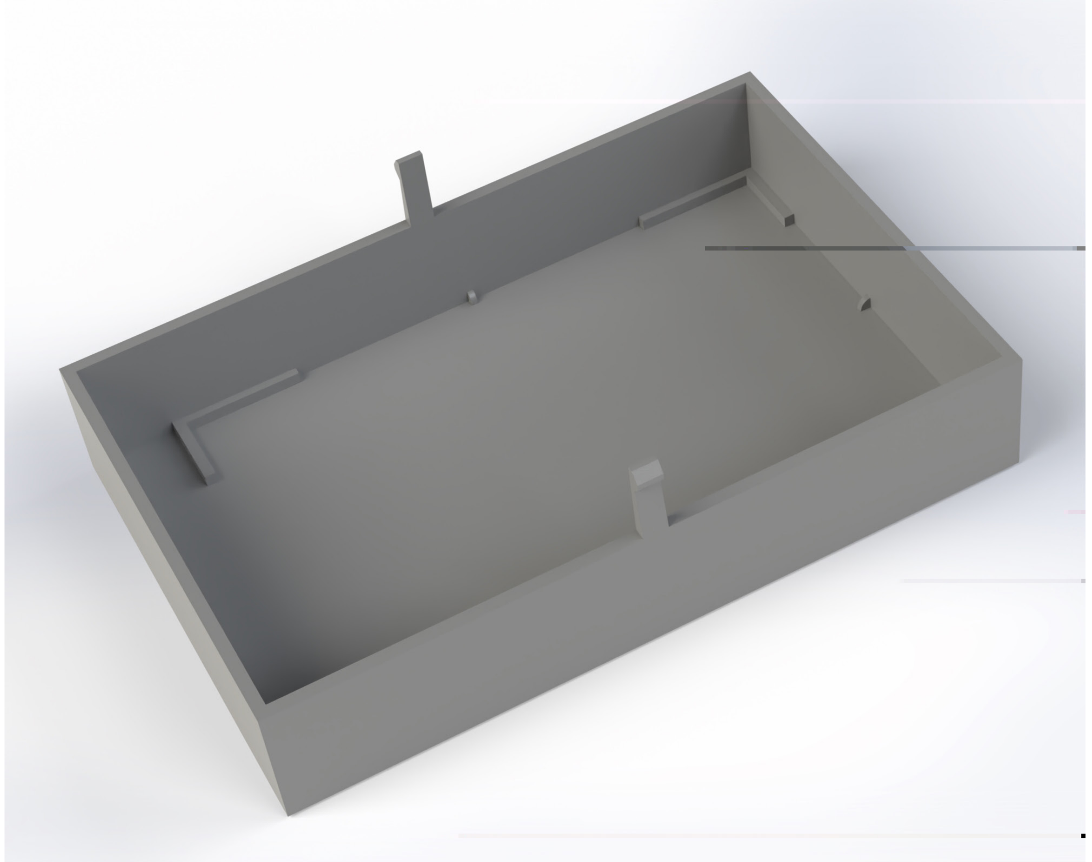
Top half of the enclosure

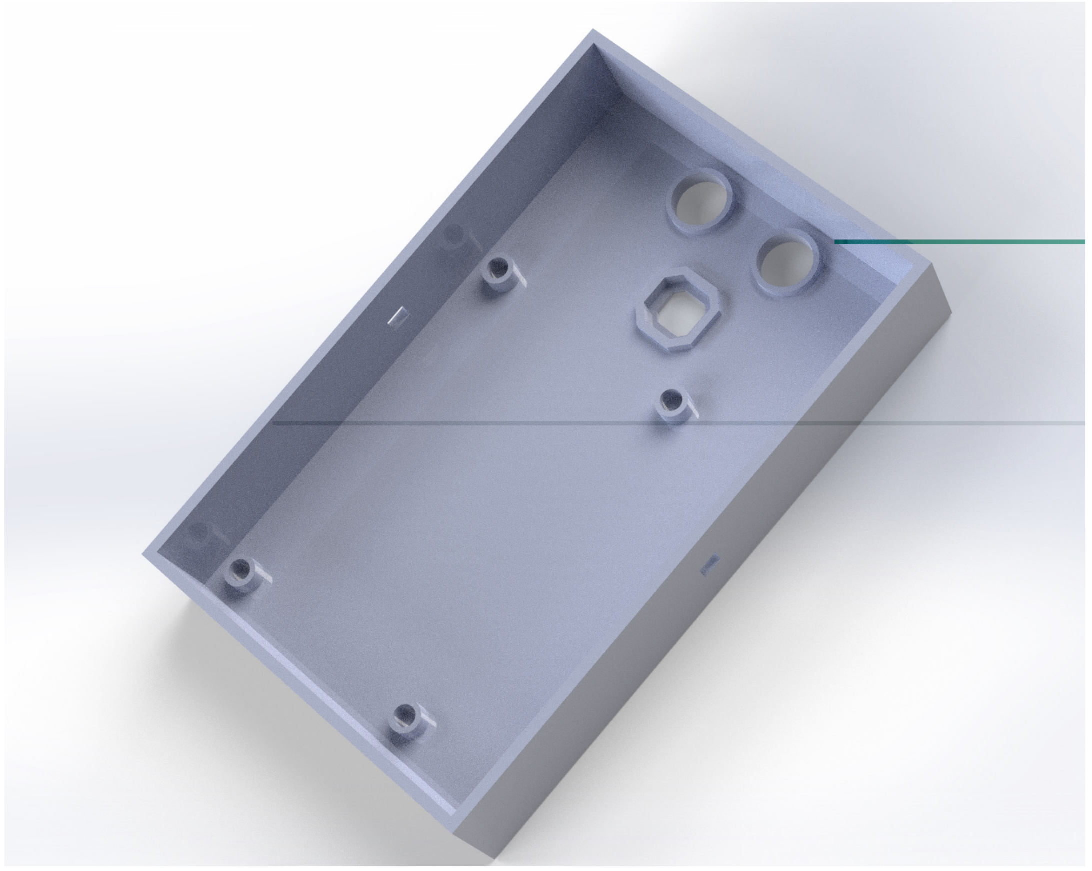
In order to improve the workers assembly time and reduce error during the assembly process snap fitting has been used to seal the enclosure together, to make this possible an incline has been added on a small section of the outside that leads up to a square cut hole, this will allow the clip on other half of the enclosure to run up the side and clip into place once it reaches the hole, the incline on the side also means that the clip will be flush with the sides. The overhang of this part would be an issue, but a small hole has been placed on the wall of the hole which will prevent the issue.

LED's have a designated small raised area to help the assemblers put the components in the correct places, the hole extends out of the enclosure to allow the LED to be exposed after being surrounded in material. The LED has a ridge at the bottom that makes, this makes the LED slightly wider at the bottom, the raised section has been measured to tightly allow the LED to fit through the hole, but the ridge get caught on the surrounding support material, this prevents the LEDs from falling out. The button has similarly got a guide for where it goes and a groove that allows it to slot into place without falling out.

The PCB will be snap fitted into place inside the enclosure, there are support pegs that stick out for a PCB connector to slot inside and extrude out towards the middle of the enclosure. The part that sticks out has a snap fitted head that will line up with the holes at the corner of the PCBs, the PCB can be pushed down onto the connector and they will snap into place firmly securing the PCB in the correct location.

The support pegs for the PCB have been drafted with an angle, this is to help the piece come out of the injection moulder move efficiently and with a better quality of finish.





Design For Manufacture and Assembly- The Robot

Front Half of the Enclosure

As much of the front half of the enclosure was hollowed out as possible, doing this allowed the walls to be thin which is ideal for obtaining a high-quality f nish with injec t on moulding. Hollowing out the inside also reduces the material costs as there is signi f cantly less material being used.

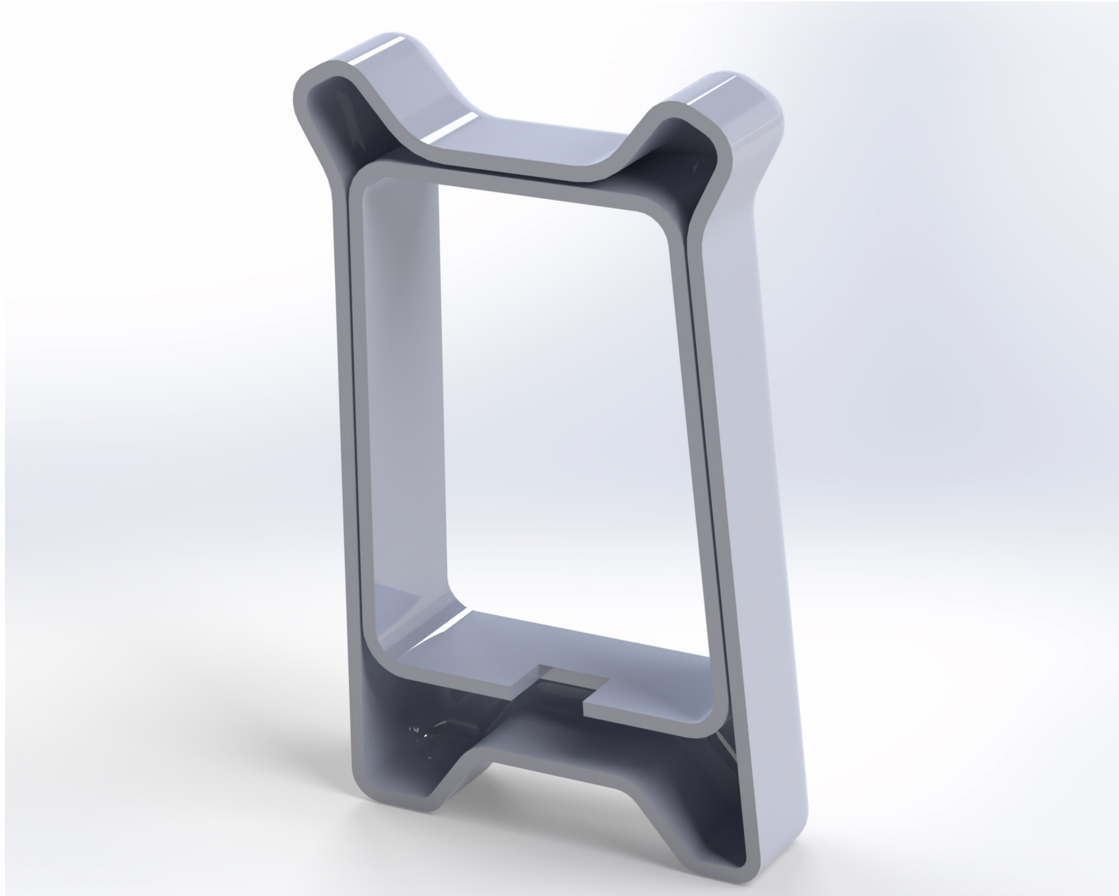
The screen will f t t ghtly inside the space allowed, the LCD screen will f t into the gap but the cables and the outer material on the screen will not, the parts that can't f t act as a stopper for the screen and prevent it from falling out and being unsecure. A gap has been le f for cables to trail behind the screen into the body of the robot, this gives a predetermined path for the cables to f t ed and prevents them from being loose or causing an exposed cable.

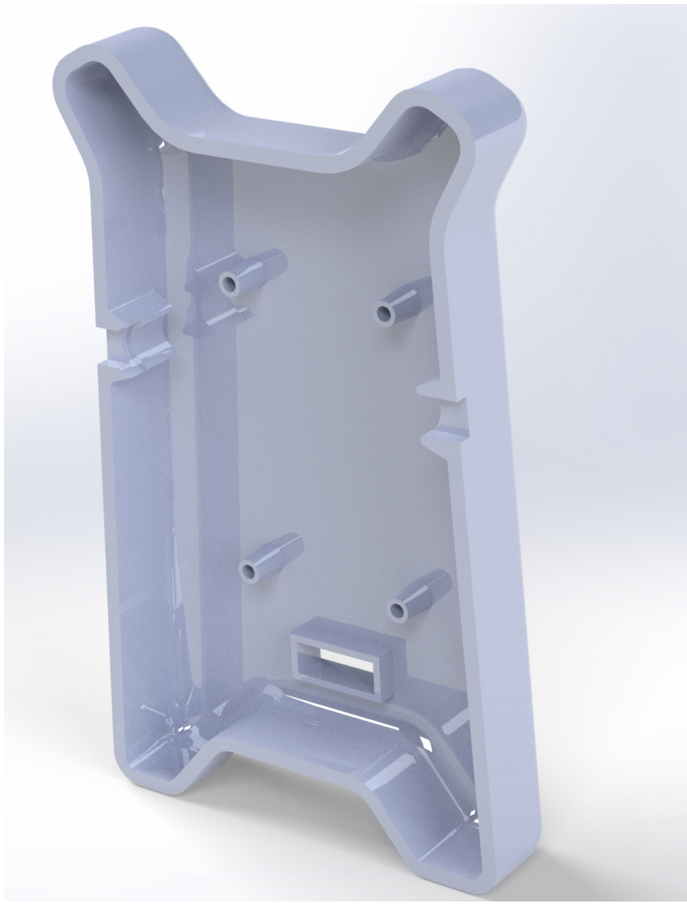
Back Half of the Enclosure

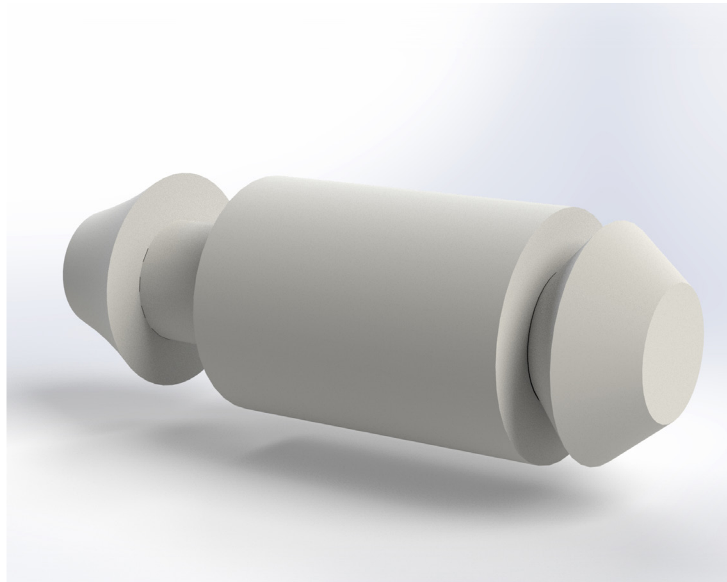
One of the only holes in this enclosure is on the back part, this hole is for the USB connector, this part will be used by the user quite roughly and as a result needs to be reinforced more than parts on the interior of the robot. The support walls that will help to keep the part in place as 1.5x thicker than the other supports and is slightly extruded more so the USB connector will run along the plas t c which will help it stay in place instead of having it suspended by a small amount of suppor t ng material.

The motors are being housed by a mount on the inside wall, the mount has a shape that arches more than 180 degrees, this slightly closed o f spot is required to snap f t the motor into place. The motor will be secured near the hole for the arm, the arm will protrude slightly into the enclosure where it will a t ach to the servo motor. Space has been le f behind where the motor will f t, this space is for the cables that will run to the PCB.

Similarly to inside the clip's enclosure, the PCB will be snap f t ed using 4 PCB connectors and the support pegs have once again been dra f ed with an angle.







Material Selection- Clip Enclosure and Body of the Clip

Important Properties

Tensile strength is one of the more important proper t es to inspect. The clip's enclosure is going to be surrounded by a tough polymer which is covered by a so f er rubbery material which will help to protect the enclosure and more importantly the electrical component inside of it, however the enclosure s t ll needs to be tough and durable to resist any falls and bangs this product will take throughout its life cycle that aren't absorbed by the surrounding plas t c. Higher tensile strength is necessary because it increases the products resistance to breaking under tension and prevents buckling.

Maximum Constant Temperature

The clip is going to house a lot of electrical components in a small space, the power consump t on is rela t vely low, this should prevent the ba t ery from overhea t ng due to drawing out a lot of power quickly, however the ba t ery will s t ll likely become warm during its t me of use, the enclosure needs to be able to resist the heat from both the ba t ery and body of the baby. The ba t ery operates between temperatures of 0°C and 45°C, assuming for the worst-case scenario, any plas t c being used for this enclosure and the body must be above this threshold to ensure the product doesn't melt.

Density

The clip needs to be as lightweight as possible so that it doesn't a f ect or make the baby uncomfortable, the baby will poten t ally be wearing the clip for long periods of t me and they need to be comfortable or parents won't be able use the product. There can be a trade o f with certain materials, one plas t c may have be t er quali t es and proper t es but might be denser, there will be a balance when the polymer is selected.

Which Polymer Will be Used

By looking at the polymers that can used for injec t on moulding f ve were selected and considered: Nylon, ABS, Acetal copolymer, polypropylene, HDPE. HDPE was immediately ruled out due to the material expanding when heat is applied to it, and that the material is prone to stress cracking. Polypropylene was ruled out due to its very low tensile strength, if the baby roles over onto their front and the clip it will be put under constant stress, the low f gure from PP and HDPE mean they are not appropriate to use to manufacture this product.

Acetal Copolymer is excep t onal, the polymers proper t es are much higher than necessary for this product. The issues with the material are that it goes through a lot of shrinkage during the injec t on moulding process which would cause a lot of di f cul t es and needless complica t ons. The material is also extremely expensive compared to the other op t ons and much heavier than any other op t on, compared to ABS this polymer weighs nearly 1.5 t mes more, ABS and Nylon are more suited for this product and cost a frac t on of the price.

ABS and Nylon are both excellent material op t ons for the enclosure, they both boast high tensile strength, can withstand high temperatures for a constant period and are lightweight op t ons. Nylon has a signi f cantly greater tensile strength however this is benign because the tensile strength of ABS is also far more than necessary to protect the components. ABS will be taken forward as the material of this part, nylon is slightly heavier and more expensive than ABS, when being mass produced the small cost di f erence will equate to a much larger cost over the en t rety of the manufacturing process.

ABS has been selected due to its excep t onal material proper t es, the polymer is also commonly used for injec t on moulding due to its low produc t on cost which helps lower the total costs of bringing the product to market. Low heat and electrical conduc t vity are added bene f ts to using the material because it helps to prevent the circuit from shor t ng out. The material also has excellent shock and impact resistance which is very important for assuring the product is durable.

Material	Tensile Strength (N/mm²)	Max Temperature (°C)	Density (g/cm³)	Additional Notes	Source
Nylon	90 - 185 N/mm²	150 - 185°C	1.15 g/cm³	Lightweight, exceptional strength, resistance to shrinkage, insulating properties.	(BPF, 2019) (KnowledgeTextile, 2019)
ABS	40 – 50 N/mm²	80 - 95°C	1 – 1.05 g/cm³	Very low production cost, sturdy, recyclable, lightweight, low heat and electrical conductivity, excellent shock and impact resistance, poor to UV exposure.	(BritishPlasticsFederation, 2019) (adrecoplastics, 2019) (upcinc, 2018)
Acetal Copolymer	140 N/mm²	165°C	1.41 g/cm³	High mechanical properties, good chemical resistance, high thermal resistance, very high cost, prone to shrinkage.	(ThePlasticShop, 2017) (Direct Plastics, 2019)
Polypropylene (PP)	0.95 – 1.30 N/mm²	80°C	0.905 g/cm³	Easy to process, good impact and stress resistance, low cost, some variants are flammable, poor to UV exposure.	(BPF, 2019) (CreativeMechanisms, 2019)
HDPE	0.20 - 0.40 N/mm²	65°C	0.944 - 0.965 g/cm³	Low Cost, good chemical resistance, easy to process by most methods, high thermal expansion, prone to stress cracking.	(BPF, 2019) (upcinc, 2018) (CreativeMechanisms, 2019)

Material Selection- Exterior of the Clip

Material Selection – The Clip's Exterior

One of the most important parts of this product must be comfort for the baby, the product must have a smooth surface finish as to not irritate the baby's skin whilst being used, the PDS states that the coefficient of friction of the material must be less than 0.4 µ to ensure that the surface isn't abrasive. Density of each material is also a concern because, the clip needs to weigh as light as possible whilst still having the desired material properties.

PVC was removed as an option due to its high density, this was the outlier in the material options as it was significantly heavier than any other polymer. Silicone rubber was also an outlier, the surface finish wouldn't have the required standard this product needs, the lowest the coefficient of friction (0.50 µ) can be is still rougher than the maximum allowance. ABS is strong material, it meets all the criteria, however it is a hard material, although it has an extremely low coefficient of friction the material doesn't feel nice, the other two options do have a soft texture and are therefore being taken forward. Both silicone and TPE are excellent options, however TPE has one main difference to Silicone which is why it isn't the selected material, TPE is porous which isn't ideal for a product that is certainly going to get covered in bacteria.

Food Grade Silicone and Medical Grade Silicone

Silicone has been selected as the material that will cover the outside of the clip. Unlike most of the materials that were examined silicone is a non-porous material, as well as being hygienic and hypoallergenic, this is extremely important because it means that there aren't impurities in the surface for bacteria to get inside and breed, once bacteria is inside a porous material, it is almost impossible to clean properly, and due to the nature of this product constantly being in contact with a baby it seems necessary that it doesn't harbour bacteria within its surface.

The two main types of silicone to consider are: food grade silicone and medical silicone, these two types of silicone are labelled as 'Body Safe' and phthalate- free, the main difference is that medical grade silicone has been thoroughly tested on how it interacts with (the inside and outside of) the body and is completely safe, whereas food grade silicone is safe to use but hasn't been as extensively tested as the former, medical grade silicone is more expensive but the guarantee that it is safe for use with the baby is worth the additional cost. Silicone also has the advantage of being inert, this means that it isn't porous and won't change over time, this gives assurance that the product will be safe for the baby to use during its life cycle. Inert materials also don't leak chemicals, when the parent needs to wash the clip, none of the chemicals will seep into the material and come out on the baby.

Silicone is durable, flexible and shatter resistant, this means that the clip will last a long time whilst dealing with daily wear and tear extremely well. Once the clip is no longer being used, silicone doesn't decompose but it can be completely recycled. It is also odour and stain resistant which is ideal considering that the clip is expected to be occasionally covered in the baby's waste.

Material	Coefficient of Friction	Density (g/cm³)	Additional Notes	Source
ABS	0.11 - 0.46 µ	1 – 1.05 g/cm³	Latex, BPA, and phthalate free making it body safe, hypoallergenic, non- porous, Very low production cost, sturdy, recyclable, lightweight.	(BritishPlasticsFederation, 2019) (adrecoplastics, 2019) (plastics.ulprospector, 2019) (thenookieshop, 2019)
Polyvinyl Chloride (PVC)	0.25 – 0.4 µ	1.42 – 1.48 g/cm³	Strong and lightweight, PVC is resistant to weathering, relatively cost effective, non- toxic.	(vinidex, 2019) (pvcconstruct, 2019)
Silicone Rubber	0.50 – 0.75 µ	1.1 – 2.3 g/cm³	Some silicone rubber can be Latex, BPA, and phthalate free making it body safe, hypoallergenic, can be non- porous.	(albrightsilicone, 2019) (mddionline, 2019) (Azom, 2001) (hypertextbook, 2005)
Silicone	0.25 – 0.75 µ	1.05 – 1.60 g/cm³	Latex, BPA, and phthalate free making it body safe, hypoallergenic, non- porous, can be expensive, very durable/ good quality can last a life time, can have a soft texture.	(albrightsilicone, 2019) (mddionline, 1999) (thenookieshop, 2019)
TPE	0.25 – 0.60 µ	1.10 – 1.50 g/cm³	Slip Resistant, soft texture, shock absorption, TPE is colourable, porous, very durable/ long life Phthalate free making it body safe.	(timcorubber, 2019) (thenookieshop, 2019) (ElisaSainz-García, 2014)

Costings

Understanding the Size of the Market

It is es t mated that there are 130 million babies born per year globally which means that there are 130 million poten t al consumers that the product could be sold to. Every parent cares for the welfare of their child so the product can be marketed to each and every new parent who is concerned for the child's health when they are carrying out their daily rou t ne. A similar product is the baby monitor and it is es t mated that in 2016 the baby monitor market was worth 897 million US dollars and this has risen to 1.1 billion US dollars in 2019. According to The World Bank (2019) within the next f ve years the already large market will rise to 1.7 billion in 2024 (see appendix 1). Data from the UN suggests (Sta t sta, 2016) there were just 1 billion people on earth in 1800, 2 billion in 1927, 5 billion in 1987 and 7.5 billion people on earth today. With the current rate at which babies are being born it is projected that there will be 11 billion people by 2100. This shows that the human race is ever growing and there are more babies being born than ever before. So, because the popula t on is becoming larger over t me there will be a growing market of people to sell the product to (Lamble. 2018).

The latest report from the UK's LV society reveals that parents typically spend £9,610 a year to give the essen t als to their baby. The average cost of a new cot can be anywhere from £70 to £700, The cost of a pram can soar to £2000 and cos t ng of a car seat can average at £100-£150 but can go up to £400. This shows that parents are willing to spend a lot more money if the products make the baby safer and more comfortable. The cost of having good quality baby monitors can start from around 70 pounds and this price can increase the be t er the monitor is (Davis, 2018). This shows that even if the cost of my product is on the higher end of the spectrum there will s t ll be a frui t ul market to target to.
Based on these f gures the product is trying to break into an already established market, however, the market size is very large and only con t nues to grow, in the f rst year the product should aim to produce 10,000 units.

Staff Required

So f ware Costs
There are several aspects of this product that require a so f ware specialist to complete such as; coding how the components will communicate to each other via Bluetooth/ Wi- Fi, a so f ware engineer will be needed to work on the security by adding, f rewalls and asymmetric encryp t on to keep the data secure. Based on a quote from a so f ware engineer they es t mated that it would require these workers due to their specialist skillsets that will be required:

Backend (Senior): £350-500 /day
Backend (Junior): £150-300 /day
Apple/Android Dev: £250-350 /day
Sysadmin: £200-350 /day
Systems Dev: £300-400 /day
Testers: £200-350 /day

Assuming the lowest range of the salary op t ons, having one of each person with a unique skillset working to complete this product it will take approximately 3 months (but could be up to 6 months) to complete, this equates to a total cost of £1,450 a day, which gives an approximate cost for the en t re 3-month period as £121, 800.

The remainder of the costs will be for a 6-month period, this means the 10,000 products will be made within this t me which equates to approximately 55 products will be made a day.

1 Injec t on moulding operator, base wage is £11.85/ hr
£11.85 x 40hr = £474 per week
3 assembly workers, base wage is £10.40/ hr
£10.40 x 40hr = £416 per week x 3 = £1,248 per week for all assembly workers

This equals £1,722 per week for the sta f, for the 6 month period it will cost £18,864 for the sta f

Part Name	Quantity	Price (£) With	Quantity x	How Many are	Price (£)	Source
[redacted]						
Robot						
Screen: 3.5inch 320*240 RGB interface tft lcd screen	1	£6.16	£6.16	10, 000	61,600	Alibaba.com
Motor: 8.5mm Dark and Black Edition small dc motor CL 820 CL-820	2	£0.96	£1.92	20, 000	9, 600	Alibaba.com
PCB	1	£4.06	£4.06	10, 000	40, 600	ScreamingCircuits.com (This is an estimation, see appendix… for the example quote I received, this is bound to change once a professional design the PCB)
Wi-Fi Module: ESP8266 WIFI Module PCB Assembly	1	£0.77	£0.77	10, 000	7, 700	Alibaba.com
Button: Stem Tactile Switch, Single Pole Single Throw	1	£0.449	£0.449	10, 000	4, 490	uk.rs-online.com
USB Connector	1	£0.25	£0.25	10, 000	2, 500	Alibaba.com
			£13.609			
			£48.4319		**478,460**	

Factory Overheads

A quote request was sent to Protomold to get give an approximate idea of how much the cast would take create however they did not respond (see appendix…). Moulds can cost anywhere from around £2000 – 20,000 for a very complicated mould, an averagely complicated mould is approximately £10,000. The product would require approximately 5 moulds to be made, varying from very simple to an average amount of complexity, I will es t mate that 2 moulds will cost £10,000 each, 2 moulds will be £5,000 and one mould will cost around £2,000.
With these assump t ons that would make the costs for tooling £32,000.

Electricity cost: (assuming the price of the electricity is 14p per KwH) in order to injec t on mould 10,000 completed products is es t mated to cost £5,000 over the period of 6 months.
Factory ren t ng: £15/ Sq Ft, for a factory 3, 711Sq Ft (Estates Gaze t e, 2019) would cost £55,665 for the year which equates to £27,832.5 for 6 months.
Including the cost of order all of the components will cost a total of **£683,956.5**

In order to get the cost per unit, £683,956.5/ 10,000 = **68.39(2.d.p)**

Zigbee. (2016). XBee and XBee-PRO, ZigBee Datasheet. Available: http://www.farnell.com/datasheets/2306718.pdf?_ga=2.57763496.324783859.1554938073-93031283.1554575232&_gac=1.191878488.1554938073.Cj0KCQjwnKHlBRDLARIsAMtMHDF6JRPiKA-jj_VZkMVqR0TgZHy5Slu-t6YZmY8VZhxtPo. Last accessed 19/02/2019.
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