Extended Project Qualification

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For my EPQ I am designing and manufacturing a robotic arm. I chose this as my artefact as I am interested in a career in robotics. The design and manufacture of the arm would also draw on skills that I have learnt in my Maths, Physics and Computer Science A Levels. I decided that an arm that can lift less than 0.8 kilograms would be sufficient for the applications that I might use it for, such as removing prints from a 3D printer or experimenting with different methods in control software.

I began by researching how previous robotic arms have been built mainly focussing on how modern industrial arms have been designed, for example Axis 4 through to 6. I was heavily inspired by the inner workings of the Vika-350 Industrial Robotic arm (Kesici, 2017). I also looked at open-source robotic arms such as the Annin AR4, designed by Chris Annin (Annin, n.d.). A lot of my research was into reducers, which are gearboxes designed to increase the torque of a motor. The most common type of reducer in robotic arm applications is the harmonic drive, named after the German corporation Harmonic Drive SE, the main supplier of harmonic drives in the industry (Harmonic Drive, n.d.).



Figure 1 Above left Vika-350 Industrial Robotic arm (Kesici, 2017). Above right Annin AR4 Robotic Arm (Annin, n.d.).

When I was designing the arm, I went through four iterations of the overall design. Mk1 to Mk3 all used the same metal arm pieces I had recycled from a scrapped screen soldering machine at Offshore Electronics where I had done my work experience placement. The design for Mk1 used many bespoke components for each joint increasing the complexity of the design. I soon realised that it was too complex to manufacture on a 3d Printer.

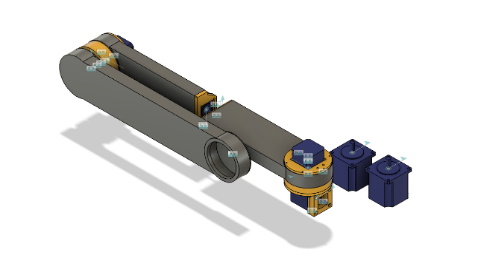


Figure 2 Mk1 Main Assembly CAD Design

In the design for Mk2 I used an increased number of shared components, and the design was lighter than the previous version. I spent a lot of time designing a harmonic drive reducer, which are also called Strain Wave reducers. Strain wave reducers work by rotating an elliptical plane that forces a flexible gear, called the flexspline, to mesh with a fixed internal gear. In an industry standard design, the flexspline is attached to the output of the reducer, however due to the nature of 3D printed materials this is not possible as the flexspline will crack and fracture. In a 3D printed design another non-flexible internal gear is placed on top and used as the output, this design is inspired by the work of both 3D Printed Life (3DPrintedLife, 2021) and Levi Janssen (Janssen, 2019). This iteration of the arm was still too heavy due to the weight of the shared components of the arm, which led to Mk3.

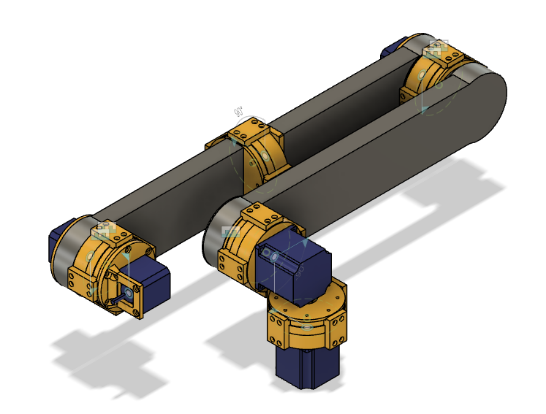


Figure 4 Mk2 Main Assembly CAD Design

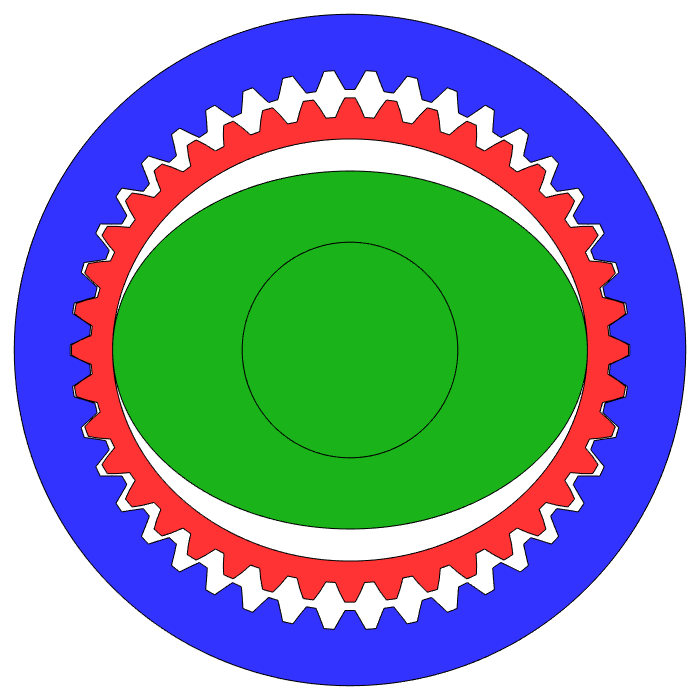
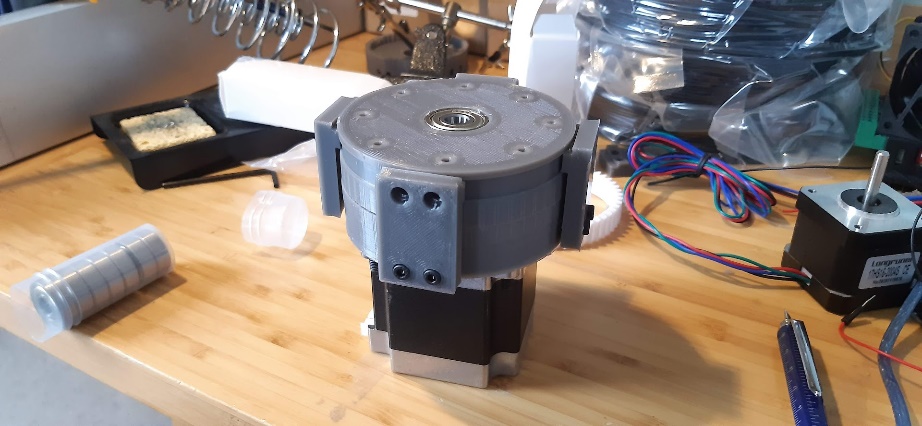
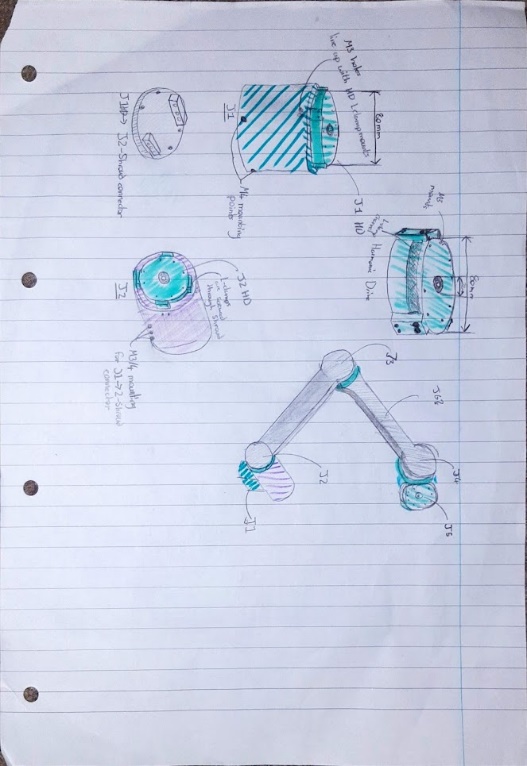


Figure 3 Diagram showing a Harmonic Drive interior

When designing Mk3 I further increased the number of shared components and further reduced the weight, however the drives I had designed for the lower axis were too weak to lift the arm when testing the design. It quickly became apparent that the metal arm was going to be too heavy for the 3D printed reducers and the motors that I had to be able to move.

Figure 5 Above left shows Isometric sketches of Mk3 before CAD. Above right is the main reducer of Mk3



A close-up of a machine

Description automatically generated with medium confidenceThis led me to Mk4, the final design of which took a lot longer to design than the previous iterations as I had to design the whole arm from scratch for this version. Mk4.1 had various flaws, it was too big, cumbersome and some parts didn’t work as intended. Mk4.2 improved upon these flaws I managed to reduce the size by 100mm and fixed issues where parts didn’t work correctly. Mk4.2 is the culmination of the whole project, with each component being well thought out from my experience with the previous versions.

Figure Mk4 CAD Assembly

Programming the arm was complicated, I couldn’t start the programming of the control software fully without the design of the arm being completed, components would sometimes just not seem to work when inputs were given. Through my research into how to control the stepper motors I found the Accel Stepper library for Arduino (McCauley, 2020), this software library allowed me to control the stepper motors in a convenient way. To tell the Arduino which motor to control I planned to develop a system that read commands from the serial input. This system would take the axis to control, the number of steps that the motor was making, and the direction of the steps. The Arduino microcontroller is programmed in C++ then would be fed commands via a python script running on a Raspberry Pi. This would allow me to have a remote access point to the arm where I would be able to control it from.

When it came to manufacturing the arm there were difficulties throughout the process. Originally, I planned to print the whole thing on the PrintRite Colido 2.0 Plus 3D printer, however as I began testing components for Mk3 the printer stopped functioning as intended and was messing up prints. With this printer being an old printer, I searched for a replacement printer online. I landed on the Voxel lab Aquila X2 printer, an Ender 3 clone with a few more functions. Setting up the printer was a breeze, and it printed fine for all of axis 4, 5 and 6 of Mk4.1. Then the printer began clogging due to the heat break warming up too much causing plastic to melt in the worst spot possible. This led to me disassembling the printer repeatedly with no avail on getting it to run again. In the end due to a tight timeline and the deadline drawing near I focussed on improving the CAD design to a functional model.

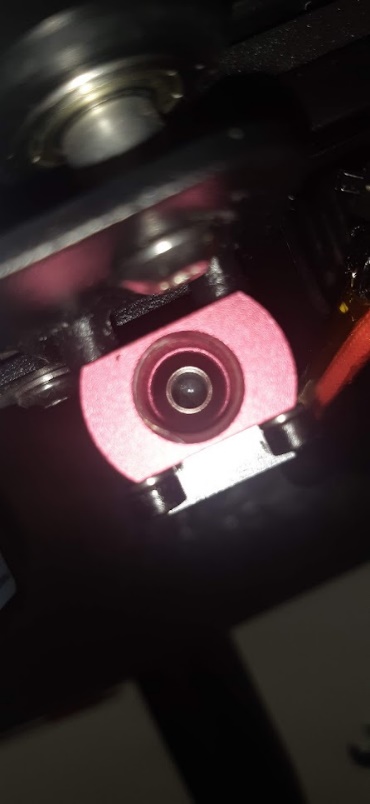
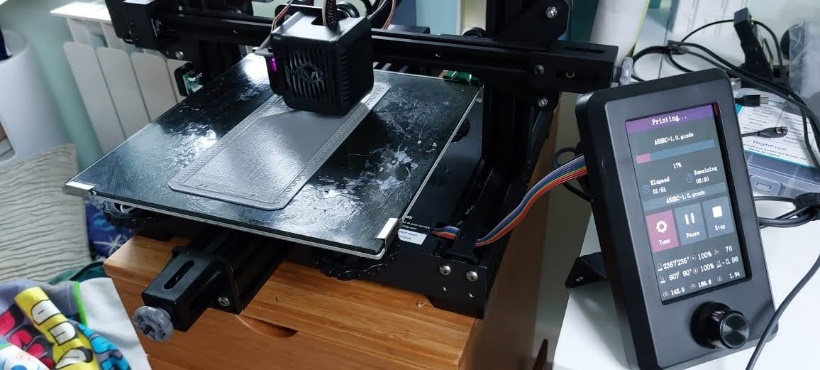


Figure Above left shows the clogged heat break through the heatsink. Above right shows the printer whilst it was working printing part of Mk4.1.

Overall, the project was mostly a success however one major flaw was the planning. I originally planned for the whole project to take around 210 days, in the end it took me 500 days. I overshot my estimated timeline by 138%. This drastic overshoot was mostly down to poor planning, with things such as not considering when I had exams, when holidays were, and generally not being able to work on the project. I think if I had been more pessimistic with my timelines, they would be far more accurate and reliable. The result of the project, Mk4.2, is a well thought out design built on the failures and shortcomings of the previous versions in addition to my improved skills surrounding CAD and 3D printing.

Chart

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Figure Gantt Chart showing both my planned timeline and the actual timeline

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