Wireless Rear Derailleur – Project Final Report

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MR3016 – Project of Mechatronics Engineering

ITESM

Introduction

The project's objective is to research and develop a mostly universal wireless rear derailleur that can compete with available market options by being a cheaper yet good quality alternative with an added value by being easily serviceable on most of its components. The solution will focus on removing a cable connecting the cockpit to the derailleur and will try to keep the most original components possible, the shifter at the handlebar can be completely replaced if no universal solution can be applied to the existing shifter, however, the rear derailleur must be kept original for the solution to be cost effective.

Furthermore, a working prototype will be manufactured and attached to a bicycle. For the project to be considered successful, the drivetrain must be capable of shifting between cassette's positions and be tunable to compensate for slack on the shifter cable. Documentation to replicate the project and facilitate a mass production model will also be provided as part of the deliverables.

Implementation

The implementation would require two modules, a shifting module that could physically shift the rear derailleur using some sort of mechanism and cheap electronic components powered by 5 volts; and a shifter controller module, that could wirelessly send the signals needed for shifting up and down, as well as finely tuning the tension on the mechanism to account for the slack on the system. Both subsystems and their components are represented on Fig. 1, please note that this part of the project did not include how or what exactly was going to be implemented, it was just the first layout to get the ideas to start flowing, which is the ideal start for this kind of projects.

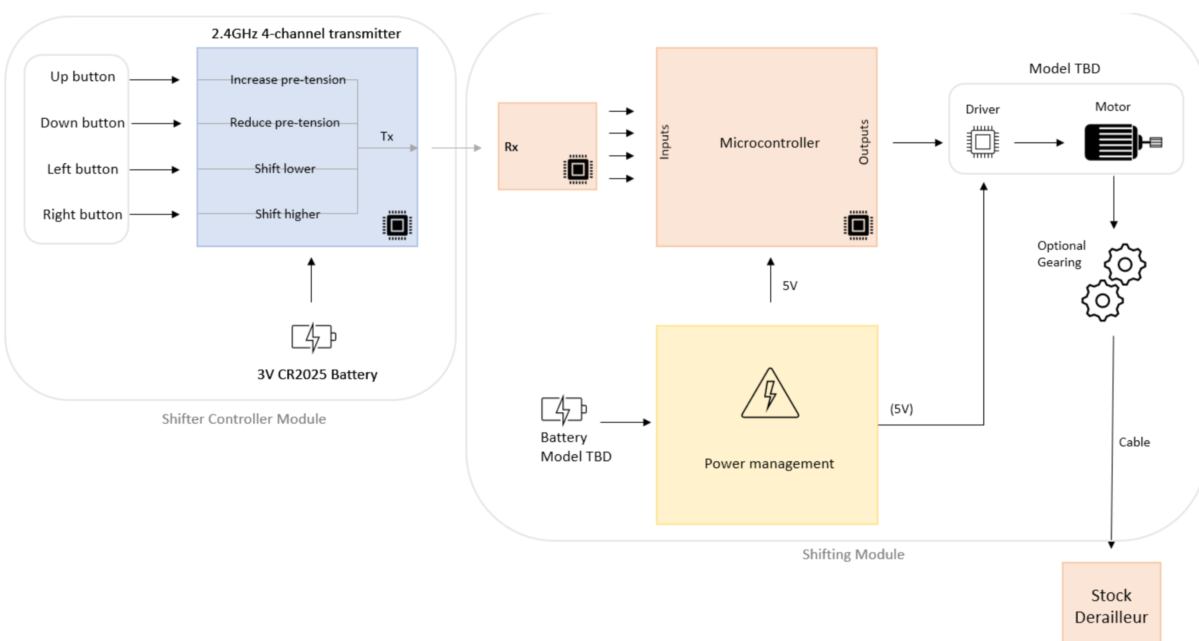
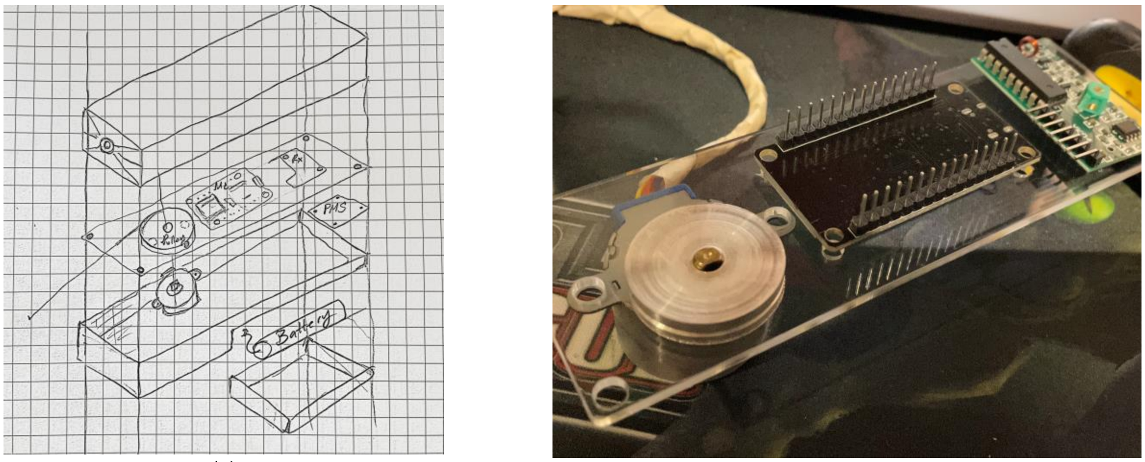


Fig. 1. System (and subsystems) diagram.

For the first delivery, a design consisting of a pulley to pull a cable and shift the derailleur's position was conceptualized, this pulley (see APPENDIX A) was designed to be manufactured on 6061 aluminum using a CNC milling machine to fit a 28BYJ-48 unipolar stepper motor that operates with 5 volts, such motor was meant to be fixed to a main frame so that the pulley could be held on the motor's shaft with a setscrew, this first design and its assembly can be seen on Fig. 2, note that the photo of it only includes the main frame, the radio receiver, the motor, and the pulley, so no other components are present and it can be easier to visualize. The sketch is only the first visual representation of its design.



(a) (b)

Fig. 2. Shifting module v1 subsystem as a (a) initial sketch, and (b) its component arrangement.

Since the beginning it was taken into consideration that this specific motor needs a special driver (ULN2003) to work properly, thus, additional considerations regarding space and components arrangement were taken, however, this was not an ideal situation, since readily available options in the market do not have mounting points to fix the driver's PCB, and buying the whole board was easier and cheaper than soldering it into a specifically designed PCB for all the electrical components that were to be included in the project.

This first design was used as a reference for further work on the project, so after undergoing a digital course on 3D-printed product enclosures, a casing was design; however, designing it before any kind of previous testing proved to be a bad idea since, under a simple test with an improvised mounting, the premature implementation of the batteries and, perhaps, factory defects on the motor gearing, which is made of plastic, caused one of the ESP32 microcontrollers and the motor itself to break. Thus, a second and improved designed needed to be implemented.

The second and final design swapped the stepper motor for a servomotor with three times the torque and it was easier to implement, as it only requires a PWM signal to operate, also, it did not require any additional driver modules, so some space regarding component arrangement was freed, however, the implementation of that motor would require a complete re-design on the main frame and the casing, since it was bigger than the first option. Additionally, this solution would require some small modifications to the main pulley, so it could fit the shaft with no issues. As seen on Fig. 3, not much was changed besides component arrangement and a new main frame.

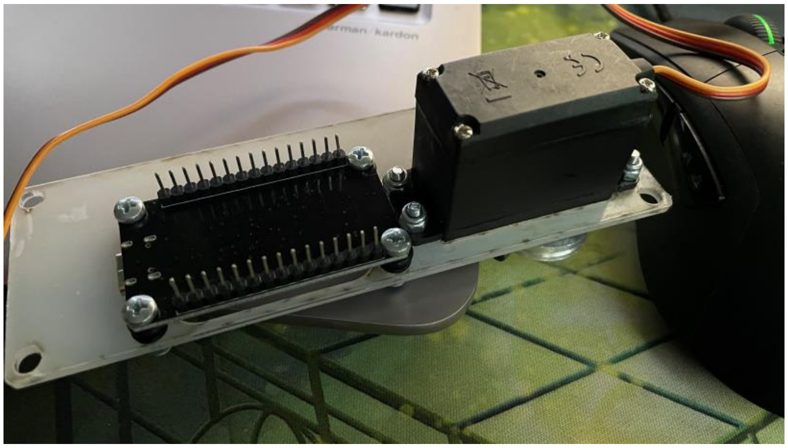
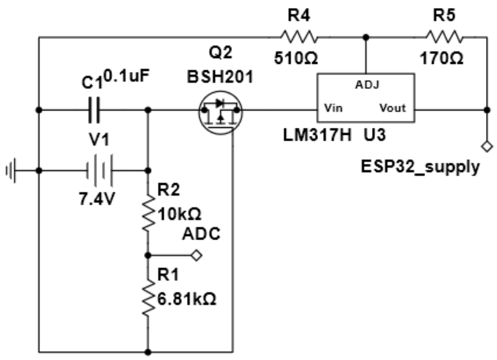


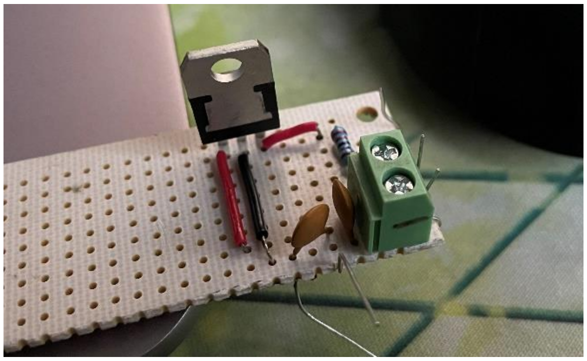
Fig. 3. Shifting module v2. With the motor and microcontroller fixed to the main frame.

Skipping to other subsystems and components, the shifter controller module was built using the board of a 2.4GHz 4-channel RC transmitter, which, with some small modifications and tuning was able to interface with the microcontroller with no major issues, since the implementation regarding electronics and programming was pretty straight forward, there was no need for changes in its design, the readily available board even came with a built in voltage regulator.

Then, the power management system was also designed and manufactured using a L7805 voltage regulator to reduce the battery voltage from 7.4 to 5.1 volts so both the microcontroller and motor could be powered, as well as a simple voltage divider to keep track of the battery level using the ADC on the microcontroller, a couple of capacitors were also included for noise suppression purposes. The design diagram of such circuit is shown on Fig. 4, as well as a photo of the perforated board with all the components. Note that a MOSFET and a LM 317H are included, however, they can and were swapped for the convenience of using the L7805 IC alone.



(a)



(b)

Fig. 4. Power management system (a) diagram, and (b) board unit.

For mounting and testing purposes, the main frame was held in place using zip ties and rubberized couplings, no modifications to the bike frame nor the cable routing were made; however, a custom cable with its housing was manufactured so it could be used with the new setting, its length and routing depend on the bike model, but any person with previous experience maintaining bicycles can perform this modifications with no major issues. Fig. 5 shows how the cable is attached to the main pulley, so it can be firm and secure to work properly, note that such is the first step of installation.

Fig. 5. How to secure the shifting cable to the main pulley.

And finally, the last step for the full implementation was programming and the design for the product enclosure. A simplified diagram that describes how the algorithm works is shown on Fig. 6. In short terms, a state machine tells the motor via PWM where to position itself depending on the current speed the derailleur should be in, using a preset of 9 speeds. Also, a preload is added to the motor's position if tunning needs to be made. Full code can be found on APPENDIX C.

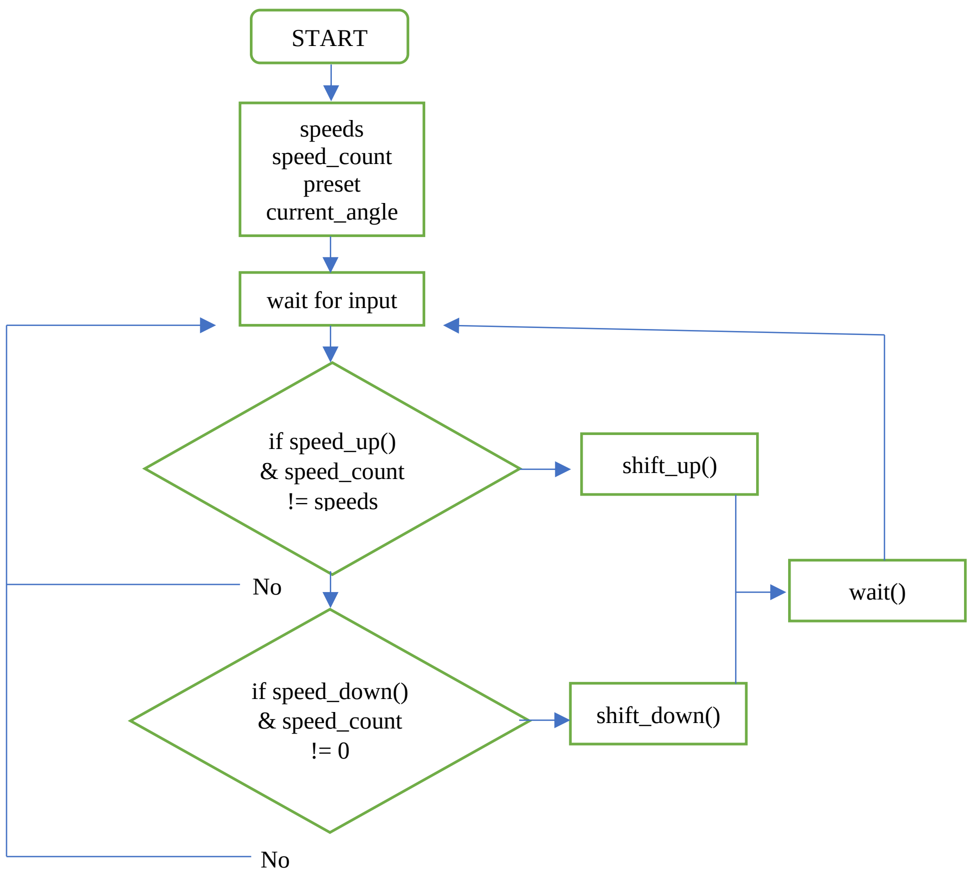


Fig. 6. Programming logic diagram.

An exploded view of the final model for the shifting module is shown on Fig. 7, no simulations were made for this project, however, videos of the products' system and subsystems functionality can be found on APPENDIX C.

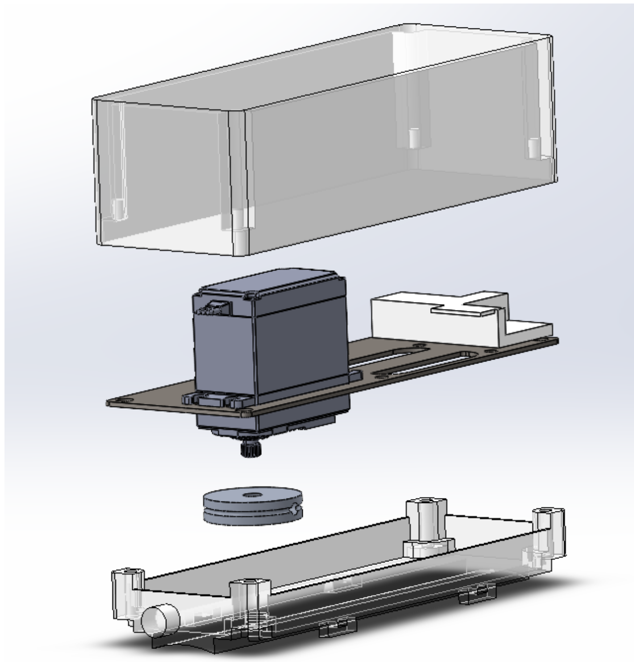


Fig. 7. Exploded view of the assembly for the shifting module.

Results

As mentioned before, video footage for the test results can be found on APPENDIX C, in short terms, the results for each subsystem can be defined as follows:

The power management system was tested using both virtual simulations on Multisim and a prototype assembled using a breadboard, as seen on the simulation's small scope on Fig. 8, the output voltage for the voltage divider assuming the battery is on full charge is close to 3 volts, the same works for the voltage regulator, however, the regulator always delivers 5 volts regardless of the battery's charge.

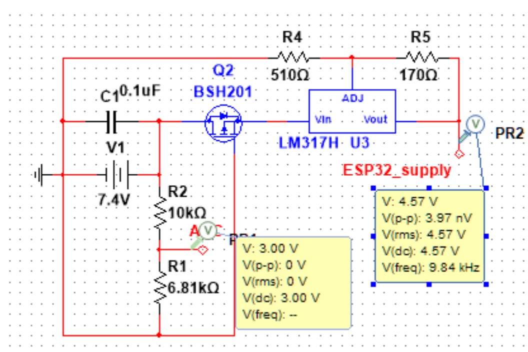


Fig. 8. Simulation results for the power management system.

Since the use of the wireless communication was pretty straight forward, video footage of its functionality can be found con APPENDIX C; where, with relatively low latency, good communication was achieved up to 1.2 meters; since a bicycle frame is hardly longer than that, this should not represent a relevant concern for the communication's performance, however, if the need arises, an external antenna mounted directly to the bicycle's frame or fork could significantly improve its performance, as it was demonstrated.

As for the results on the shifting mechanism itself, an early failure regarding the motor's torque capabilities was encountered, even if the motor's datasheet indicated that its torque was enough to withstand the shifting tension, maybe it was the methodology used to calculate such tension the reason it failed, since a luggage scale was used to approximate such tension on at least 10 different tests, it was not scientifically accurate, thus, the real tension was still unknown. To solve this issue, the motor was swapped to the servo MG995, which has a peak torque rating of 9.0 kg.cm at 5 V. Which is slightly more than double the torque of the original motor. The test results using this new motor showed the correct functionality this project was trying to achieve, did not presented a relevant strain for the motor nor the microprocessor, and was able to work with ease, since the PWM used for it to shift allowed the motor to keep working even on heavy loads.

The only result that was not achieved was the manufacturing of the product enclosure due to lack of time, since many changes had to be made to the design so it could work with the new servo motor, and new components had to arrive, however, a course on designing such enclosures was taken, and SolidWorks models were completed, so the model only needs to be imported to any 3D printing machine; also, the author's work schedule didn't work out with prototyping shops.

Recapitulating the original requirements list, a boarder understanding of what could and could not be done can be made, as shown on TABLE I, some requirements were cancelled because of complete failure of implementation, but those were replaced by the solutions that kept the scope with no changes, even with the product enclosure not being manufactured, the project scope can be considered to still be met, as enough documentation for it to be manufacture was provided.

ID	Requirement	Status
01	Tension rating	Not achieved *
02	Work using Stepper Motor	Not achieved **
03	Use the ESP32 Microcontroller	Achieved
04	Wireless transmission	Achieved
05	Gearing	N/A ***
06	Battery powered	Achieved
07	Mechanism	Achieved ****
08	Work using Servo Motor	Achieved
09	Product enclosure	Not achieved
10	Battery indicator	Achieved
11	Assembly	Achieved *****
12	Manual	Achieved

TABLE I. Original requirements list. [* Tension rating was approximated to 12.6 lb. ** The stepper motor had to be changed for #08. *** Was not necessary. **** It was slightly adapted to work with the new motor. ***** The assembly did not include every component because of manufacturing issues and not achieved components.]

The main challenges were the least expected or not even considered that could happen. For example, burning out a microcontroller was expected, so two were bought to prevent major delays, also, most of the components were ordered even before the author was even able to work on the project, so not much time could be lost. However, the motor gearing breaking was not expected because of the previous tension tests, which came out to be flawed, so buying two of the same motor could not have worked, and a new analysis of the situation and reusing most of the components that were already on stock had to be made, this way only the main frame plate and the main pulley had to be remanufactured or modified. Another challenge that was not expected, but welcomed, was the author getting hired for a full-time Software Engineering position, which ultimately caused the product enclosure. After all, it was the good and fast decision making following alternative solutions that prevented the project's advancement to stagnate.

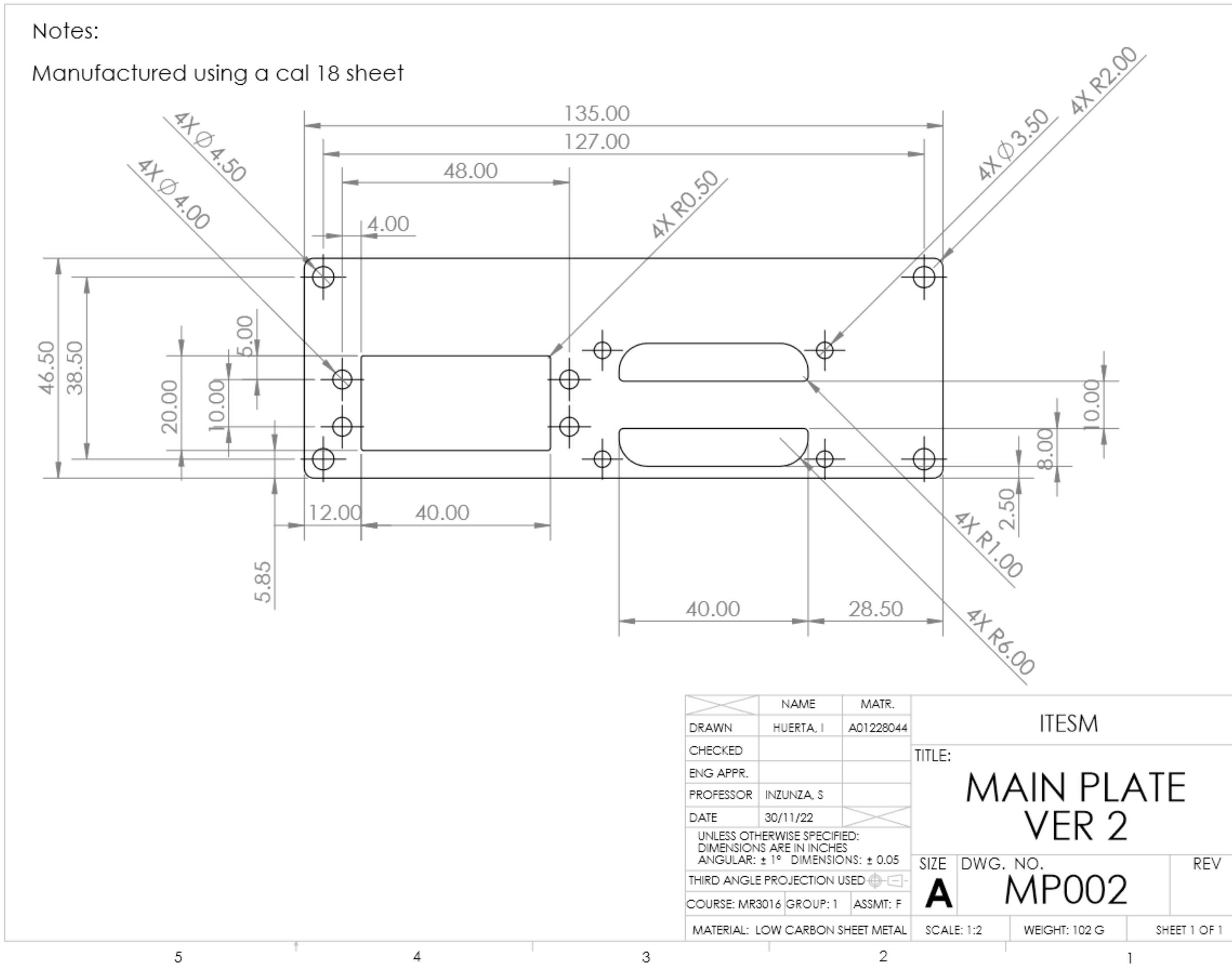
Conclusions and future work

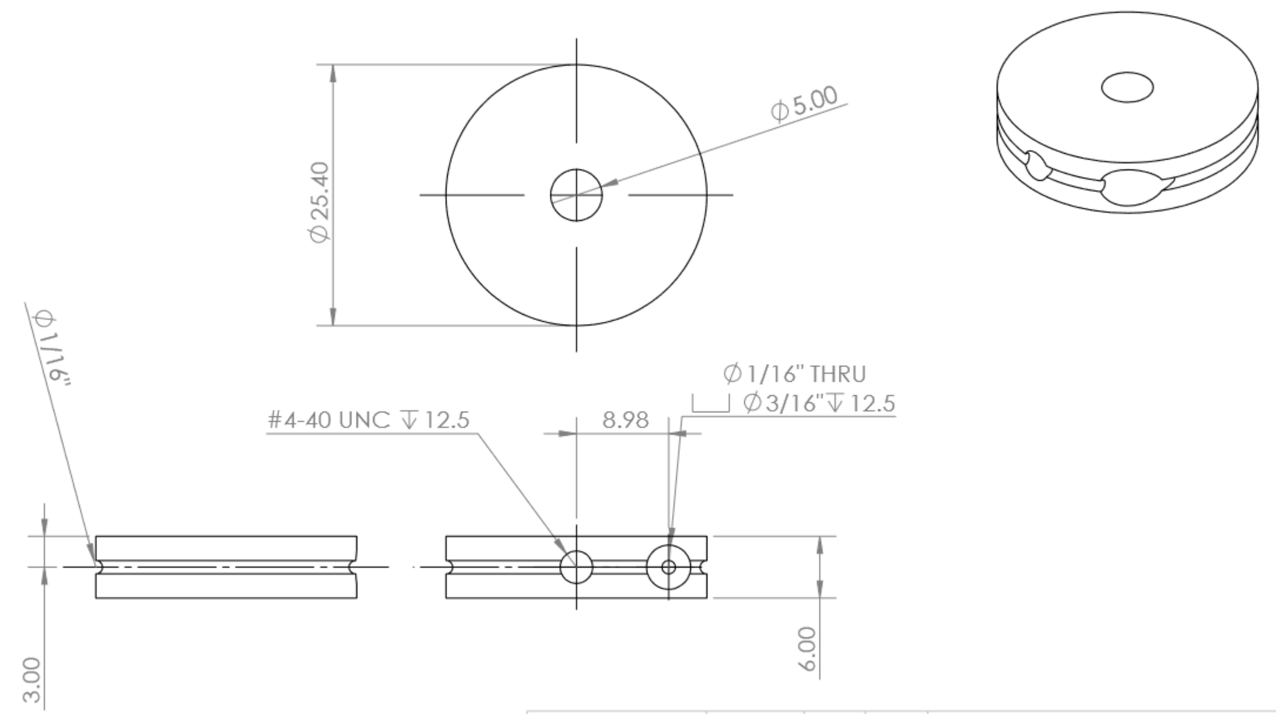
Since current market options for solutions regarding wireless bike shifting are above the thousands of dollars, and must use proprietary components to work within specific brand names, the idea of designing a cheaper solution without having to sacrifice latency and ease of installation was really appealing for the author; however, a month ago, a Chinese company called Wheel-Top, launched a $400 USD alternative and strong competitor to SRAM and Shimano wireless shifting, which could compromise the future liability of this project, so for it to be viable, would require to reduce cost to a maximum. According to calculations, it would cost close to $230 USD to manufacture one set of this project shifting system, excluding labor and logistic costs, so for this project to be viable on the market, it would require to cut costs, one alternative or solution for this would be not to manufacture machined components, instead saving time and money with readily available hardware, and perhaps that could not be enough, since the Wheel-Top option is meant to replace the derailleur, but it claims to be an universal derailleur as well, so no cables are needed for it to work.

Some proposals that could give future advantages to this product would be to make the product considerably cheaper and innovate on having the user to spend less time setting up the whole system, however, for the time being, the author has not found any reliable solutions to such matter, so further research and a complete change on the product design needs to be made. Despite the need to create a new design being a hard reality, the fact that the project was developed gives the tools so another design process can be completed with less issues and be quicker.

APPENDIX A – Engineering Drawings

The drawings shown are for demonstration purposes only, more detailed/professional drawings can be found on APPENDIX C





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	Q.A.			
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FINISH: RAW				SCALE: 2:1 · WEIGHT: 7.17 g · SHEET 1 OF 1
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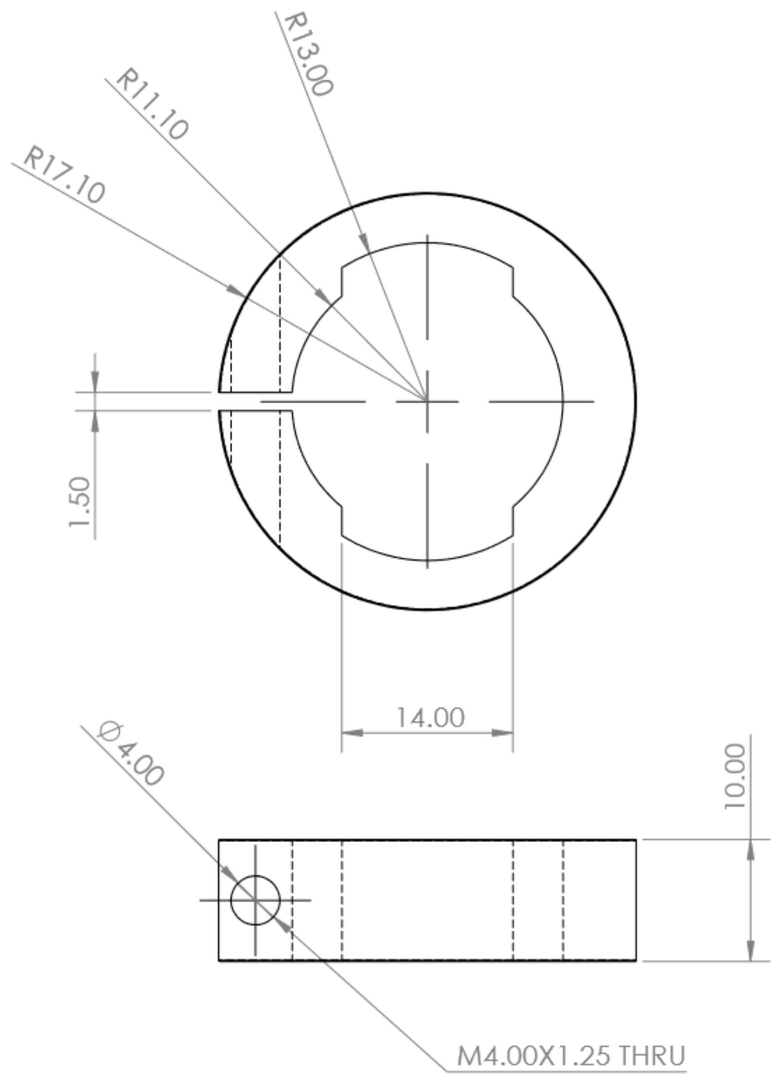

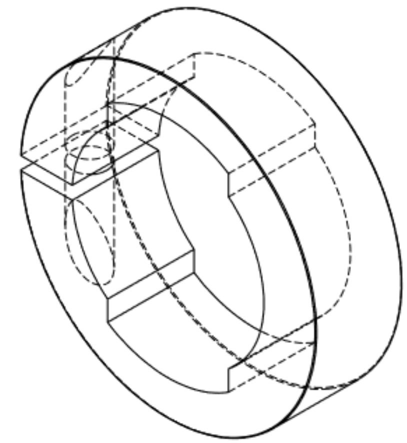

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THIRD ANGLE PROJECTION USED					
COURSE: M3016	GROUP: 1	ASSMT: F			
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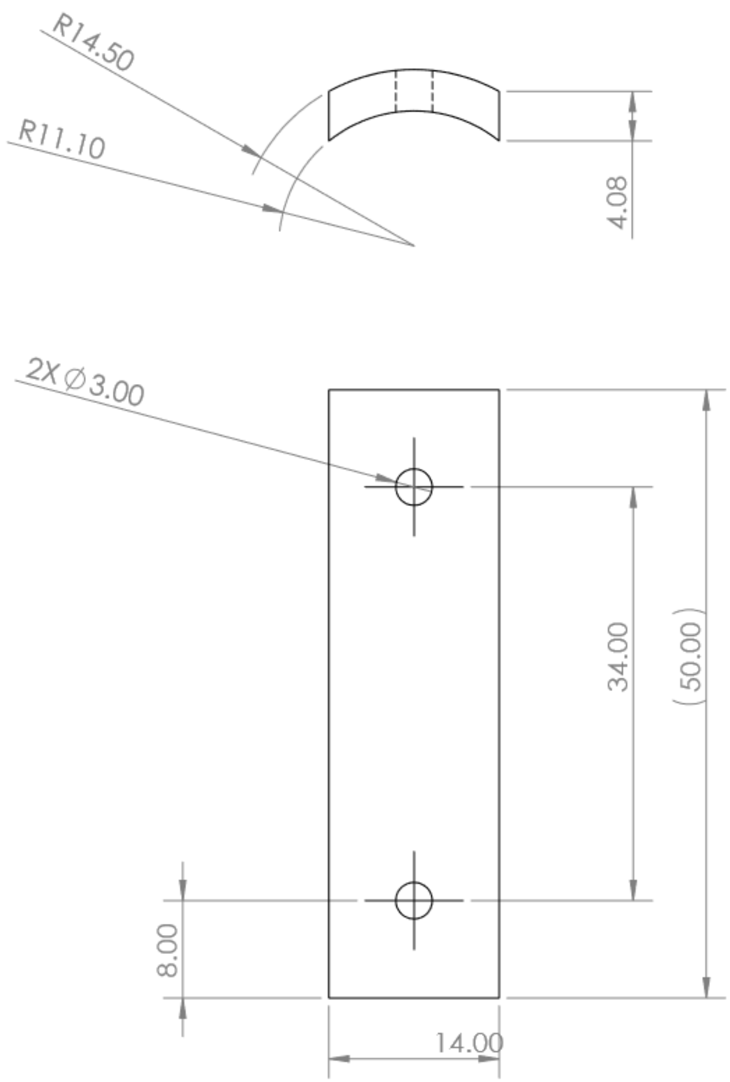

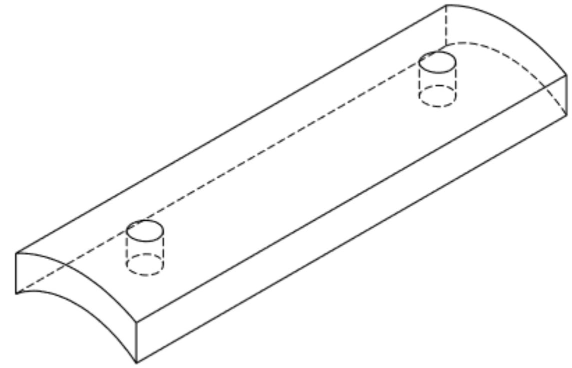

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PROFESSOR	INZUNZA, S	
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THIRD ANGLE PROJECTION USED

COURSE: MR3016 | GROUP: 1 | ASSMT: F

MATERIAL: POLYAMIDE 6

ITESM

TITLE: CONTROLLER FIXING BASE

SIZE	DWG. NO.	REV
A	CBB001	

SCALE: 2:1 | WEIGHT: 80 G | SHEET 1 OF 1

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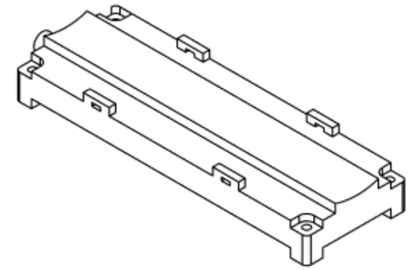
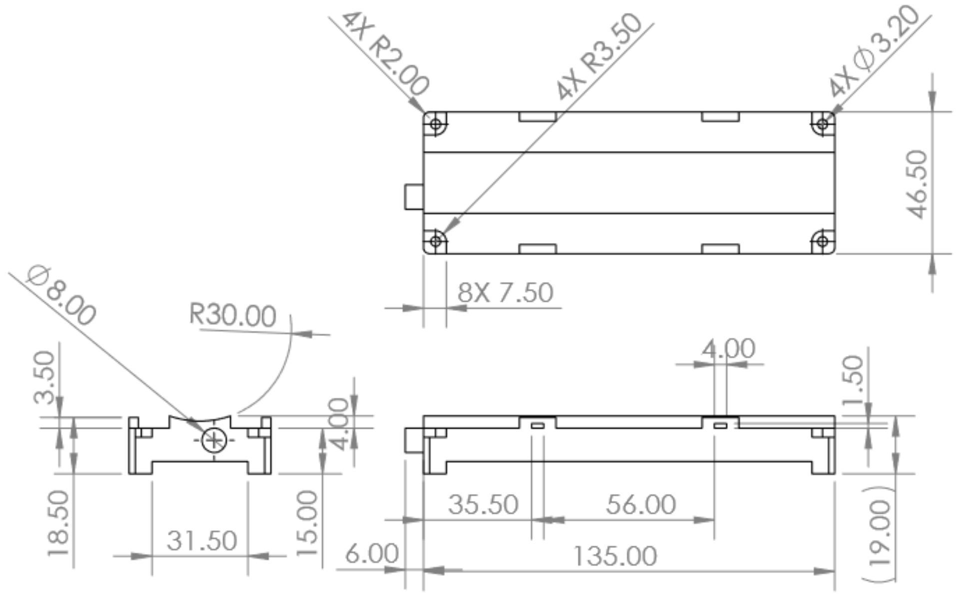
NOTES:
THIS PART IS MENT TO BE EITHER 3D PRINTED
OR BE USED TO DESIGN AN INJECTION MOLD





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NOTES:
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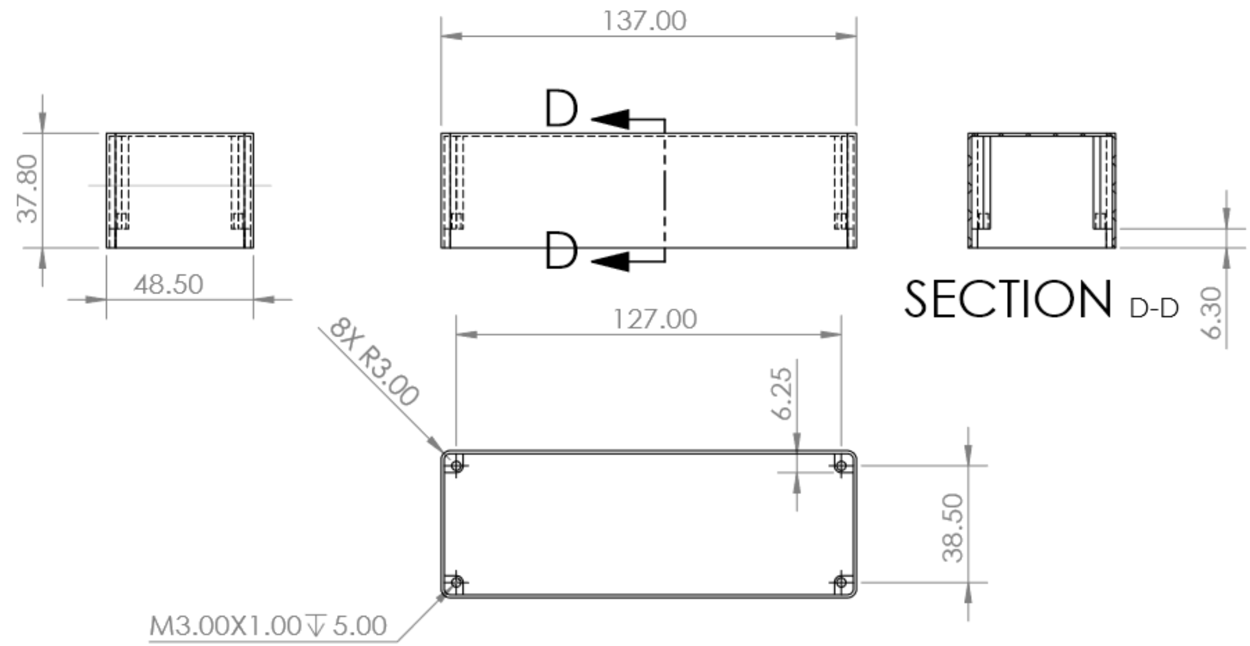

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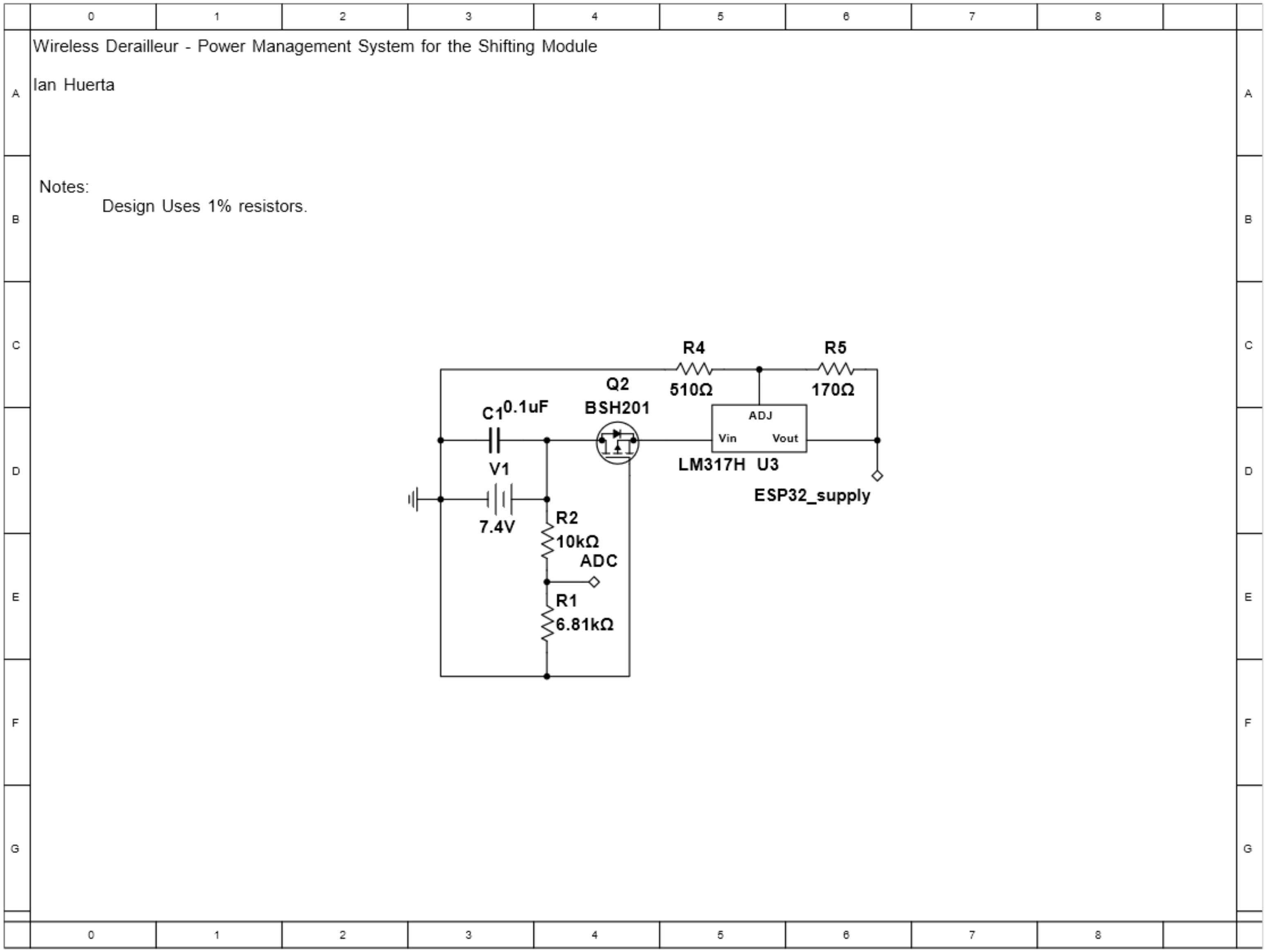
APPENDIX B – Electrical Diagrams



APPENDIX C – External Resources (Videos and project repository)

Link to the project's repository here.

Link to video footage of different tests here.