Semi-Automated Diffraction Grating Efficiency Measurement Station

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***Abstract* — With computer-aided motor controls, the Semi-Automated Diffraction Grating Efficiency Measurement Station aims to improve the accuracy of data collection in the field of spectroscopy. As measurements with optical equipment requires a high level of precision to get reliable readings, we opted to take the human error element out of adjusting the spectrometer in the hopes of improving the work-flow and reliability of the via a programmable interface that will allow for the grating angle to be changed mechanically with ease.**

I. Introduction

The Semi-Automated Diffraction Grating Efficiency measurement Station is a spectrometer that, with the help of computer controlled motorized elements, will allow more accurate and reliable measurements to be taken with this tool. The project will utilize an optical table to hold the light source, lenses, rotation stage, grating, and photodetectors in the desired positions to take the measurements. In addition, the AVR ATmega Microcontroller in conjunction with a touch screen display will allow the user to view and control the real-time data flow of the measurements being taken. In order to keep the record on file for later use, a USB connection can then be added to store the output to a device of the user's choice if it is equipped with the necessary software.

As diffraction gratings rely on a high quality standard, making sure the data is collected both precisely and efficiently can be accomplished with the use of computer elements that will have faster computation times and levels of accuracy than hand-made adjustments. This is of course assuming that the correct input is given as the system can only be as good as the user. Semi-automated spectrometers are not a widely used product, so in an effort to try and merge the gap between the spectroscopy and computer automation this project will aim to combine these two fields of operation.

II. System Components

To communicate the idea of the project better, this section will be used to break down the major parts being used in the full project build design. The software will be considered in a later section. A general overview of the hardware will be covered here and then detailed further in a later section as well if a deeper explanation is needed.

A. Light Source

This project system will function around how well the incoming light source can be directed and measured by the surrounding devices. The range of the light source being used will be from 300 nm to 700 nm, the visible light spectrum. With the use of a monochromator, the system will be able to span over this entire wavelength range of light individually.

With the help of lenses in different key areas, the system will also be able to make sure the light stays focused enough to give usable measurements to the two photodetectors collecting the light. It is vital that these measurements be made as accurately as possible to avoid relaying unreliable information to the user of this device. A broadband light source is essential to the functionality of the monochromator so there is a variety of wavelengths to choose from.

B. Grating

For the scope of this project the focus is on reflection-based diffraction gratings as these are what is primarily used in fiber-optic spectrometers. A variety of grating characteristics are functional for the project. This means the user can input the blaze wavelength and groove density and receive the efficiency data for that particular grating. The grating is aligned at the fixed blaze angle determined by the manual rotation stage. Additionally, if there is a particular angle of incidence of interest the user may utilize that angle as well. After scanning the grating at the range of interest, the overall efficiency of the grating can be determined. The equation to determine the diffracted angle as it relates to the groove density and order is as follows:

$$dsin\theta = m * \lambda \quad (1)$$

The above equation will determine the motorized rotation stage's ability to capture the diffracted light from the grating. The user will determine both 'd', the groove density and 'm' the order of interest to be measured. Pictured below is a sample output for a particular grating.

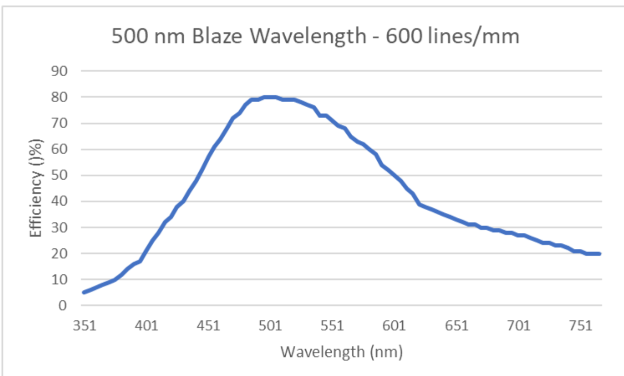


Fig. 1. Sample output for grating efficiency measurement.

The blaze wavelength is the point of highest efficiency and is of great interest not only in the context of spectroscopy but in any applications for diffraction gratings.

Blaze Angle = Incident Angle (Degrees)	Groove Density(lines/mm)	Blaze Wavelength(nm)	Diffracted Angle Violet Light (405nm) (Degrees)
2	300	300	4.96
5	600	300	8.96
10	1200	300	18.2
13	1200	400	15.132
4	300	500	2.96
8	600	500	5.96
17	1200	500	11.165
13	600	750	1.03
26	1200	750	2.73

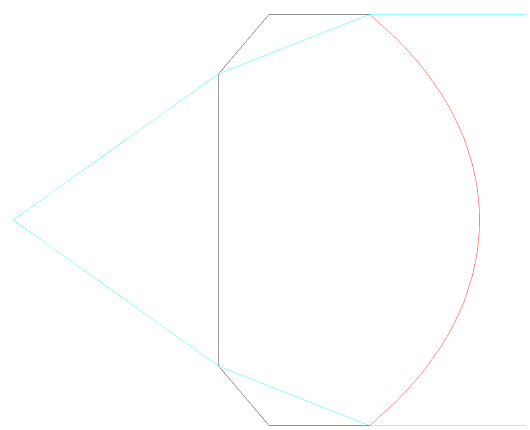
Fig. 2 Angles of Diffraction for varying wavelengths of light based on groove density of Grating.

C. Optics

The optics of interest in this project are the fiber collimator, linear polarizer, beam sampler, and achromatic doublet.

The linear polarizer allows polarization dependence to be observed as it relates to the grating. This is the first element in the system to ensure that all light in the system has the same polarization. The second element of interest is the beam sampler which allows for a reference value measurement. There is a 95/5 split that allows the input light intensity to be compared to the different orders of the diffraction grating. The use of a beam sampler instead of a traditional 50/50 beam splitter allows for more light to be measured by the diffraction grating. By extrapolating the data it is possible to compare both the incident and diffracted light values and the relative efficiency of the grating.

Choosing lenses to provide the system with the appropriate amount of light traveling through the system is an important process. A spot size smaller than the size of the photodetector for the purpose of focusing is essential. Additionally, the spot size of the collimating lens must be smaller than the active area of the photodetector. With both these in consideration picking a lens becomes an easier process. Using ray-tracing software and lens design it is possible to obtain an idea of the spot size and wavelength dispersion of the lenses of interest.



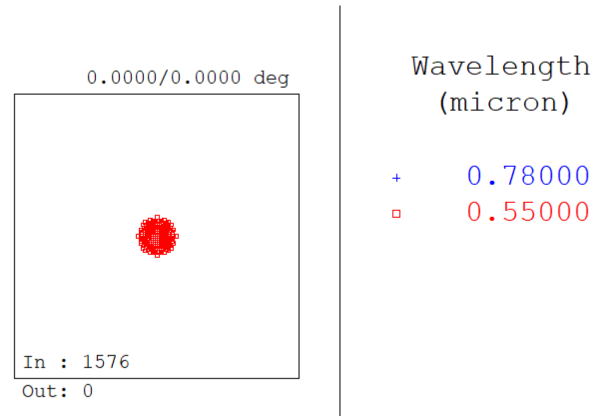


Fig. 3. Collimating lens design, detailing how the light is being passed through the lens. The bottom half of the image shows how the light is spread over a 0.2mm overall scale.

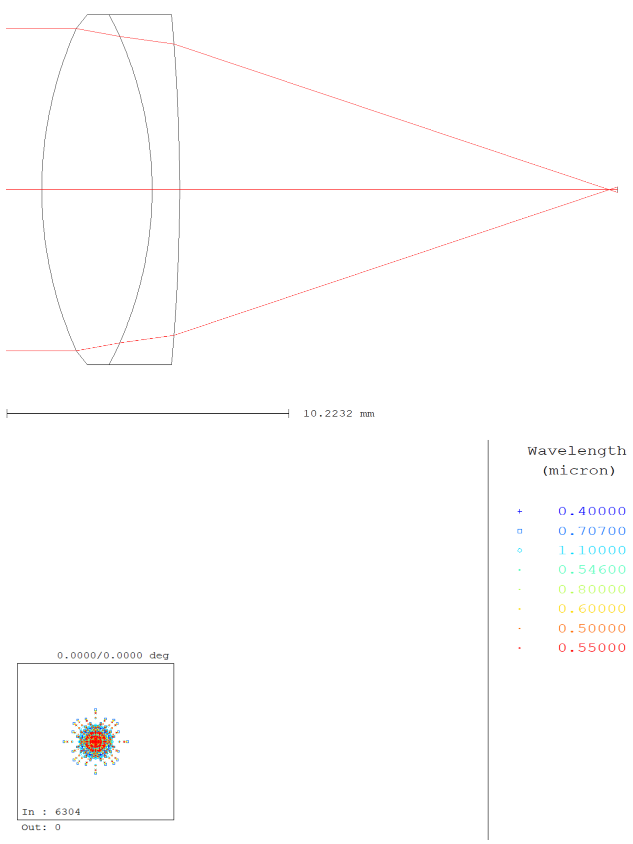


Fig. 4. Achromatic Doublet lens design detailing how the light is being passed through the lens. The bottom half of the image shows how the light is spread as wavelength varies due to chromatic aberration.

The last optical element which is an achromatic doublet ensures that light is focused onto the spot size of the photodetector for diffracted light. By capturing light with the lens this ensures that there is no excess light lost and the efficiency measurement is accurate. The wavelength range of interest for our measurements is determined by the coatings of the optical elements. For this reason, the project is limited to measuring 350-700 nm wavelength values. However, if necessary additional wavelengths could be measured with adjustments to optical parts.

D. Photodetectors

In our project, a photodetector is essential to measuring the wavelengths produced by the light source. As a result, we are using two photodetectors for the grating station. Two photodetectors will measure the wavelengths produced by the light source of our system. The photodetectors can be placed at any desired angle, as long as it is in contact with the grating system. The photodetectors will be able to measure the intensity of the input power and the power of the diffracted signal. We are using the photodetectors to compare these measure values. The photodetectors have relatively large active areas in order to capture the total amount of light in the system. Additionally the photodetectors are viable for 200 - 1100 nm which is useful for a variety of spectroscopy applications.

E. Motorized Rotation Stage

The motorized rotation stage is the platform that will hold the mechanical arm and will be motorized in order to allow for more precise angle adjustments. The accuracy of the motor movements is what will determine the overall effectiveness of this system's design. If the motor is not at the minimum as accurate and time efficient as turning the stage by hand, then there would be no point to using a motorized stage over a manually adjustable one. Through motorized automation, the efficiency data can be collected optimally.

Additionally, multiple orders can be collected using a motor if the user chooses to take interest in higher orders. The use of a motor allows for future proofing in the event that a second motor is added to compare angle of incidence to wavelength values and efficiency. Additionally, the motorized stage allows for broader wavelength ranges of measurement outside of what the current system allows for.

F. Battery/Power Source

For our design as our team discussed, we want to design a power supply that would power an Arduino mega, photodiode, rotation stage motor and LCD display. We come to a point that the wall outlet might not be ideal to power the PCB because we want to move it around, and we want to make sure that our PCB is self-efficient as it is only going to power for a period of time. After deep research, we end up choosing the Tenergy 12 volts battery to power our PCB grating efficiency station. The tenergy 12 volts battery is one of the best portable out there as it is used in many RC devices. The battery is rechargeable, as it comes with a charger to recharge if needed. After choosing the battery, we know that in our PCB, the electronics components require up to 5 volts to operate, and due to voltage fluctuations, we also want to make sure that each has a constant voltage to avoid components failure. To do this, we need to reduce the battery's voltage to meet that requirement. After careful research, we end up using a buck converter that will deregulate the 12 volts battery to 5 volts.

Battery specifications

- Nominal 12 volt and made of features a 2000mAh capacity rating
- 2 amp for two hour of usage and also have 24 wattage
- No memory effect which helps retain its max energy capacity despite recharges and discharge
- This 12 Volt battery NiMH features rapid charging, long life, and can power our electronics for an extended period of time.

G. Buck Converter

A buck converter is used widely in modern electronics devices as it is used to convert higher input voltage to lower output voltage. In addition, the Buck converter we have in our PCB is the LM2973-5 and the last digit denotes its total output voltage, and as we mentioned we want our output voltage to be 5 volts. Many regulators require a heat sink due to the regular being hot after running for a period of time, but for these regulators a heat sink is not needed. Below is the schematic of the LM2973-5 Buck Converter.

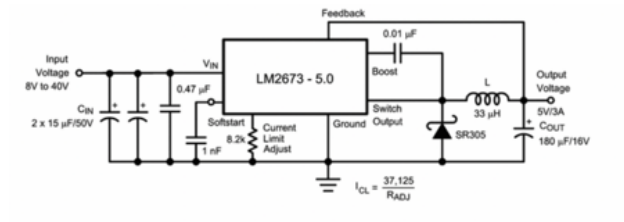


Figure 5: Schematic for LM2973-5 Buck Converter.

The efficiency of the buck converter is shown in the figure below. The graph below displays the efficiency versus output current. As can be seen, the range of the input voltage goes from 8-24 volts, as it will deregulate to 5 volts and with an output current of 2 amps which is ideal for our PCB.

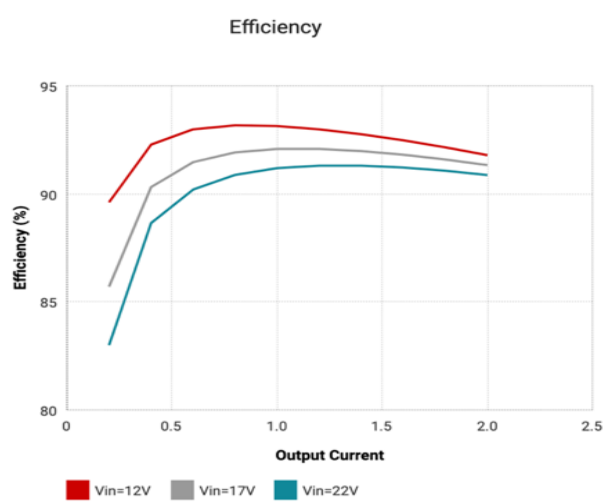


Figure 6: Efficiency Rating of Buck convertor based on Input Voltage .

Table I. Typical performance for the LM2679-5

Efficiency	90%	Steady state efficiency
Frequency	260 KHz	Switching frequency
Duty Cycles	23.3%	Duty Cycles
Mode	CCM	Conduction

		Mode
Vin (Max)	22 volts	Operating point
Vout	5 volts	Output voltage

H. Microcontroller

The Microcontroller, or more specifically the Microchip being used in this project is the ATmega2560-16AU. It was chosen for its wide functionality range as well as its compatibility with Arduino IDE for programming. The chip is able to interface with all of the necessary parts being utilized which is its primary requirement in this project.

There are a total of 86 pins, with 16 of them being Analog pins. The Analog pins will be used to get voltage readings from the photodetectors. The other pins will be used to configure standard I/O controls for the display. The supply voltage will be around 5 V for the microchip to operate in its 0 – 16 MHz clock speed range.

For memory space, there are 256KB of Flash memory, 8KB of SRAM, and 4KB of EEPROM. For the project scope, this amount would be more than enough for what is needed from the Microcontroller.

I. LCD Display

The display in this system will provide the user with both touch screen controls for the grating adjustments as well as an on-board location to view the data output stream in a graphical representation. A 7" Arduino Touch Screen display was chosen for this purpose. This larger screen size was chosen in order to increase the area of possible GUI controls as well as the clarity and quantity of data output to the user. With the Microchip being compatible with Arduino IDE, this board was also chosen to ease the process of interfacing with the hardware and software components. The power requirement for this display is similar to that of the chip with it also being 5 V.

J. CH376S

The CH376S is an Arduino IDE compatible module that will be used in aiding the storage of the collected data. The CH376S will be attached to our microcontroller, and will allow the user to insert a portable USB drive. With this USB drive the microcontroller will be able to transmit and store the analog information from the photodiodes. Since the data collected from the photodiodes is being displayed on the LCD display, the data will also be stored on the USB drive in such a way that when the user opens the drive on their computer they will be able to replicate the graph in excel or any similar program.

III. System Concepts

With all the major parts detailed, it's time to look at how the project should operate as a whole. The block diagram below will show the flow between the major components mentioned in the previous section.

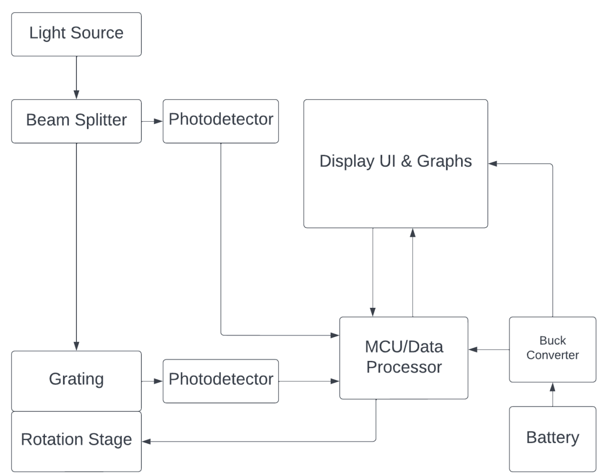


Figure 7: Major Component Block Diagram

The PCB that will hold the microchip as well the display will be powered by the battery, with the voltage being deregulated to 5 V accordingly by the buck converter. The diffraction grating will be measured based on the analog voltage readings coming from the photodetectors. These reading will be acquired after taking these necessary steps:

(1) Set the wavelength of light being sent to the grating.
(2) Input the angle needed for the light to hit the second photodetector (the first photodetector will be placed in a position to collect the light measurement prior to it reaching the grating) after hitting the diffraction grating.
(3) Let the system align the photodetector using the motorized rotation stage to get the appropriate angle to

measure the light at close to its maximum level off the grating.
(4) Using the two analog readings coming from the photodetectors, determine the efficiency of the grating at the respective wavelength.
(5) Output the efficiency readings on a graph as the wavelength of light changes to the display.

IV. Hardware Details

This section will provide a more technical explanation for the parts listed in the System Components section that weren't already mentioned previously. Some parts won't need as much further explanation depending on their role in the project.

A. Light Source

The light source being used is a broadband light source which provides the wavelengths of interest for efficiency measurements. Additionally, there is an attenuator dial to control the amount of incoming light passing through the system. This is potentially useful in the case of a lower efficiency grating which may require more light to result in an accurate reading.

B. Rotation Stage

The motorized rotation stage from Thorlabs uses a DC servo motorized 360° stage with a tapped platform. This allows for continuous rotations when looping past 360° repeatedly. There is also a home limit switch which allows the user to have automated rotation to the precise 0° position, accurate to ±0.2°. The maximum rotation speed of the platform is 25 deg/sec with markings along the dial [1].

To control the rotation stage, there is a Kinesis K-Cube Servo Motor Controller that is also made by Thorlabs. This controller can be used with either Thorlabs own software, or other third party software that have a compatible programming language type in order to create custom programs for the motorized rotation stage. It requires a specific 15 V, 1 A regulated power supply to operate and uses a USB port to interface to computers [2].

C. Universal Serial Bus

The Universal Serial Bus, USB, will be used to transfer the data being output by the project to external devices. The microchip can be used to store data, but not long term or in the capacity that the users of this device would require. With a USB connection, any data being collected by the system can also be transmitted live via the serial terminal.

On the computer/device serving as the place where the data will be sent to, the COM Port designated by the device will be the transfer location for the data stream. With a USB cable, the USB port on the device will be selected as the COM Port. Once the code that will be used as output is configured to be sent through the terminal the baud (transfer) rate, data, stop, and parity bits can be set so that the output can be seen and recorded on the device's serial terminal.

D. SPI Communication

Serial Peripheral Interface, SPI, is a synchronous serial communication that is used for short-distance communication. It is a full duplex protocol, which means communication can take place bidirectionally. It uses a master-slave architecture which means there is one controller (master) that functions as the central device and processes the information and sends signals to the connected device(s) (slave). This protocol is better for higher speed data transfers, but becomes more costly when you want to add more slave devices to the same bus. It should be noted that as more devices are added to the architecture, more select lines will be needed per device.

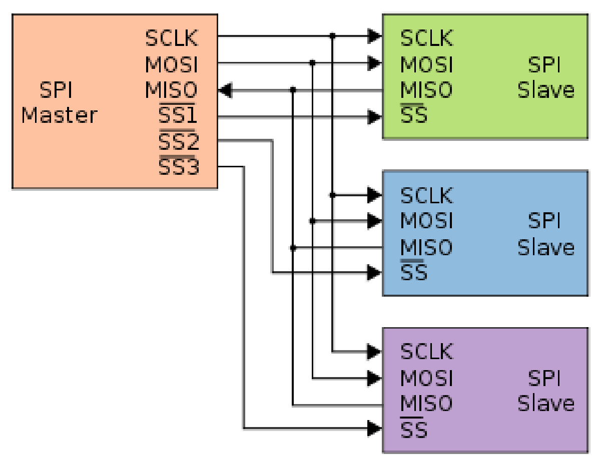


Figure 8. Illustration of SPI Connection between multiple devices. Each additional device requires its own individual SS line.

In SPI communication, the clock signal on the microcontroller synchronizes the output of data bits to the connected device. Each time the clock cycles, a bit is transferred meaning that the transfer speed is based on the frequency of the clock being used. This communication protocol can only be initiated by the master device as it is in control of the clock signal. Both devices sharing the same clock signal is also what makes them synchronous.

By modifying the clock polarity and the clock phase, the time for when the bits are output and when they are being sampled can be defined. The clock polarity can let the master device select whether the output/sample bits will be on the rising edge or the falling edge of the clock cycle. The clock phase is set to determine if output/sampling will occur on the first or second edge, whether it be a rising or falling edge. The slave device that the outgoing signals are being sent to is set using the SS line. The MOSI and MISO are the lines used to send and receive bits between the two devices, usually starting with the most significant bit being sent first if the MOSI is being used. If the MISO line is used, then the least significant bit is typically sent first.

V. Software Details

The software for this system will be in control of the major hardware elements of this project. Both the input and output will be shown and controlled by the system's display, but there will also be a need to store the data externally. The methods for these features will be explained in this section. A simplified graphic of the software flow will be shown below to outline the steps that will be taken.

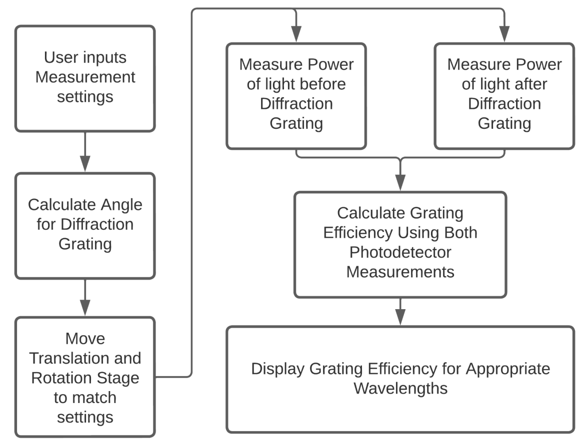


Fig. 9. System Software Processes Flowchart

Before any meaningful data is collected, the motor will first need to be adjusted to the correct angle in order for the diffracted light to hit the photodetector at its maximum intensity. Once the angle is set, the data will need to be collected on the microcontroller and displayed as an efficiency rating for its associated wavelength to the display while also being transferred via a USB connection to an external location so it can be saved for later usage.

A. Microcontroller Programming

As previously mentioned in the System Components section, the Microchip is compatible with Arduino IDE which is a free software program compatible with multiple microcontroller technologies. Inside the software, there are two sections to add code to.

One section is called *void setup()*, which is where the variables for each pin's functionality will be initialized. The photoresistors will be the input and display will be set with its initial background color and layout. The baud rate for serial terminal transmission will also be set here.

The next major section will be the *void loop()*. This is the section where any live runtime measurements will be collected and then transferred to both the display and serial terminal. For the photodetectors, their analog signal is what will be collected, as their intensity level is measured using the voltage being measured across their circuit. A delay will then be set to determine how often the measurements should be collected by the microcontroller. While these measurements are being collected, the graph will be plotting the value of the efficiency between the photodetector that is placed before the diffraction grating for the wavelength currently being used.

B. Transferring Serial Terminal Data

With the code having already been written and burned to the memory on the Microcontroller, the program will run as long as the board is receiving power. Using this, a tool in Microsoft Excel called data streamer can be used to get the data being sent to the serial terminal and put it directly into an Excel spreadsheet by using a USB cable connection. With the data being transferred into excel, it can be set up within the spreadsheet to output the same graphics being displayed on the display for later use, as saving the data onto the microcontroller itself isn’t an option.

VII. Conclusion

This project allowed the group to understand the process by which a project is drafted and built into a real working system. There were a variety of problems that arose concerning project design, parts availability, team communication among other issues. The issues mentioned were able to be overcome and result in a successful working project. The responsibilities and workload were evenly distributed among members to result in an efficient and optimal work environment for the group. In the engineering profession it is vital to work in a group and meet deadlines. Additionally, communication in meeting those deadlines is essential in ensuring that the project is finished by the designated end time.

References

[1] *Motorized Precision Rotation Stage With DC Servo Motor*. www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=4134. October 2022

[2] *Kinesis® K-Cube™ Brushed DC Servo Motor Controller*. www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=2419. October 2022