

ECE 445  
SENIOR DESIGN LABORATORY  
FINAL REPORT

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# Gesture Base Turn Signaling System

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# Abstract

This document provides an outline and L<sup>A</sup>T<sub>E</sub>X template for report formatting in Senior Design. This document does not teach you what to include, or how to use LaTeX. Assumes a workable level of LaTeX proficiency.

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# 1 Introduction

## 1.1 Problem Statement

Cyclists, skateboarders, and scooter riders often face challenges in signaling their intentions to drivers, especially in low-light conditions. According to the CDC, 1,000 cyclists die and 130,000 are injured every year on the road in the United States [1]. These numbers don't include other riders sharing the road on things like skateboards and scooters. There are many interventions in place to prevent these accidents, such as fluorescent or retro-reflective clothing, or active lighting on the bicycle (required by law in most states) [1], but the traditional method of using hand signals is not always visible or practical, particularly at night or during adverse weather conditions. This lack of clear communication can lead to dangerous situations on the road, as other motorists may fail to recognize the cyclist's intended maneuvers, or if an accident occurs.

## 1.2 Proposed Solution

To address this issue, we propose the development of a gesture recognition-based turn signaling system for cyclists and scooter riders. This system will utilize IMUs containing 9 degrees of freedom (3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer), integrated into a jacket. Then the data from the sensors will be processed to identify the specific arm gesture made by the rider and activate corresponding LED signals. For example, if the rider extends their arm straight to the left, the left turn signal is activated, or if the rider indicates a stop (arm out and forearm down), then the brake light is activated, and so on. Additionally, the sensors will be able to detect when the rider has had an accident or a crash, and activate a hazard signal on the LEDs.

We propose placing an IMU below the on the left wrist, and another on the waist. The microprocessor will then receive and process the data from the IMU, and determine what kind of movement has been made in real time. Then, depending on the movement, it will output a specific signal to the LEDs to display on the front and back of the wearable.

The final product achieved all 3 high level requirements. The device is able to correctly detect predefined arm gestures (raising right/left arm for turn signals, forearm down for slowing down) with an accuracy of 90%. In addition, the device is able to correctly map the arm gestures into the different indications on the LEDs. The turn signal will be indicated by either the left or right side LED flashing red, while the brake/slow down signal will be indicated by all LEDs turning red. A crash or accident activates the hazard light, indicated by all LEDs flashing red. Lastly, the turn signals, brake lights, and hazard signals were all visible and easily identifiable from a distance of at least 250 feet to ensure that they are clearly visible at both day and night. All of these functionalities ensure that hand gestures are more visible to drivers and other people, thereby increasing the safety of the rider.

### 1.3 Visual Aid

Figure 1 is a mockup of the wearable device that we created. The device will be powered by a battery and will have 2 IMUs to detect the arm gestures. The system will be controlled by an ESP-32 microcontroller that will process the data from the IMUs and send a signal to the LEDs to turn on when the arm gestures are detected.

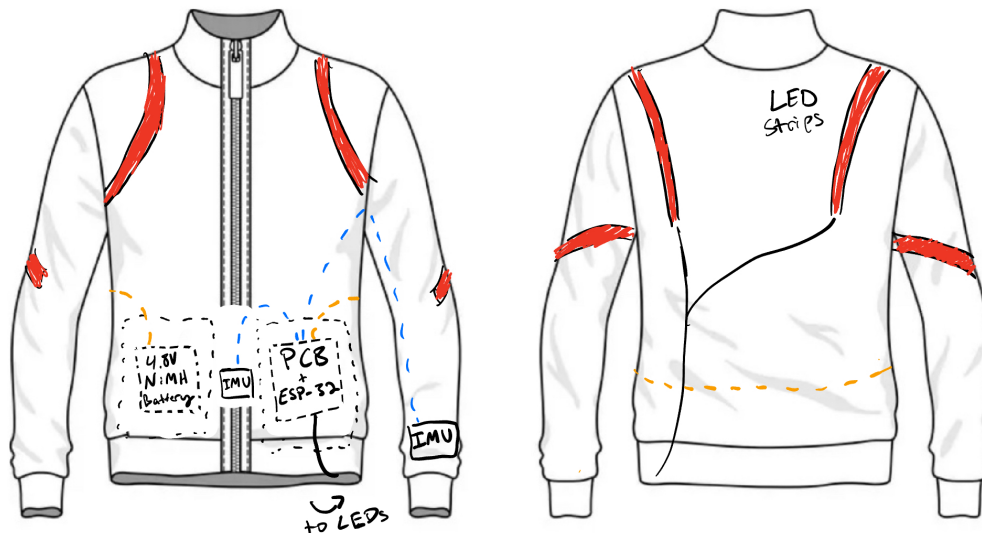


Figure 1: Visual Aid mockup of the wearable [2]

### 1.4 Block Diagram

As can be seen from the block diagram in figure 2, the device is split into 4 subsystems: Sensors, Control, Power, and LEDs. The power subsystem provides 4.8V to the LEDs through a BJT that gets a signal from the ESP-32. The Control Subsystem and the Sensor Subsystem receive 3.3 volts from the battery through a voltage regulator. The Control Subsystem receives real-time data from the 2 IMUs through I2C, processes the data, then sends a signal to the gate to turn the LEDs on when the IMU data is within a certain range.

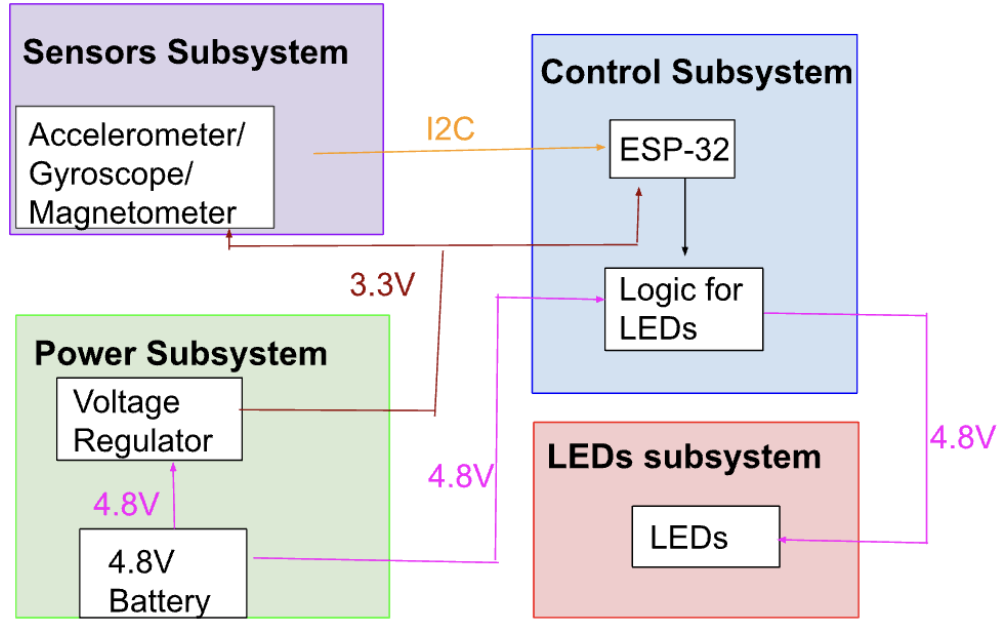


Figure 2: Block Diagram of the system

## 2 Design

### 2.1 Design Procedure

Our design consists of four different subsystems, each with their own functions and requirements. At the center of the system is the control subsystem consisting of the ESP-32 microcontroller along with some simple logic for controlling the LEDs. The goal of this subsystem is to establish communication with the sensors, receive the necessary data from them, determine which hand gesture is being activated, and activate the corresponding LEDs. The main design decisions that we had to make for the control subsystem were software related as the circuit is quite simple. We decided to simplify the algorithm for detecting the gestures due to some time constraints with the PCB order waves along with a problematic ESP-32 DevKit. We originally wanted to devise an algorithm that utilized all three sensors on the IMU, but ultimately decided that it would be too difficult to program, and we found that the magnetometer was all that was necessary to accurately detect the gestures.

The original plan was to use an IMU on each arm, but this approach proved to be difficult in terms of programming. Instead, we used one on the waist, which ensures that one of the IMUs is always stable. Then, we just take the difference in angles between the two IMUs, and set ranges for each hand gesture. We also had to discard our PCBs for our IMUs as we were unsuccessful in soldering the small IMUs onto the board. Therefore we decided to continue with the breakout boards.

For the power subsystem, we decided that the system should last at least one hour. We determined the current required to power the system to be 1864.2A total, so we needed a

battery that could supply 5V with a capacity larger than 1864mAh, in addition to being rechargeable. The battery we used for the power subsystem was a 3000mAh 4.8V NiMH battery that provided ample voltage and current to power the LEDs. During the Design review, using an LED Driver was recommended to get a constant current to the LEDs. We researched several drivers and found one that fits the requirements. However, we also tested the LEDs without the driver, and the brightness was sufficient. The plan was to add the driver to get slightly brighter LEDs, but the driver only works with a PCB, and we were unable to get the LED drivers to function from the first and third order PCBs. Ultimately we decided to discard the LED driver in order to simplify the PCB and increase the odds of it functioning properly. We decided that a working PCB was more important than a slightly brighter LED.

## 2.2 Design Details

The LM317 datasheet [3] provides us with equation (1) which relates the output voltage to the resistances of  $R_1$  and  $R_2$  when using the schematic in figure 3

$$V_0 = V_{REF} \left( 1 + \frac{R_2}{R_1} \right) + I_{ADJ} \times R_2 \quad [3] \quad (1)$$

Where  $R_1$  and  $R_2$  control the output voltage of the linear voltage regulator, and  $V_{REF}$  and  $I_{ADJ}$  are given to be 1.25V and  $50\mu$  A respectively. Using this equation, we were able to find the resistor values necessary to achieve an output of 3.3V, which are  $R_1 = 314.2\Omega$  and  $R_2 = 512\Omega$ . Note that we also have a linear voltage regulator which outputs 1.8V, which we added with the intent of making our own IMU PCB, but we ended up using a breakout board which takes in 3.3V.

## Power Subsystem

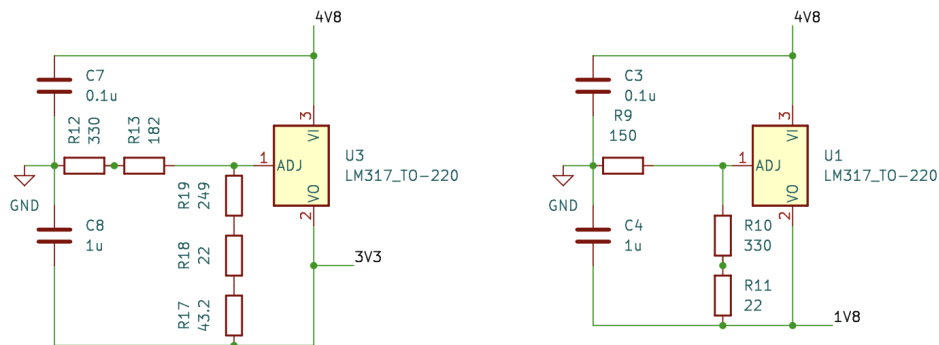


Figure 3: Schematic of the power subsystem

**Control Unit**

The diagram illustrates the connection between an Arduino Uno and an ESP32-S3-WROOM-1 module. The Arduino's ATmega328P microcontroller is connected to the ESP32's pins. Key components include a 10k pull-up resistor on the DTR pin, two 10k pull-down resistors on the RTS pins, and a 100k pull-up resistor on the CHIP\_PU pin. The ESP32's power pins are connected to a 3.3V regulator. The UART pins (TX, RX) are connected to the Arduino's TX and RX pins. The diagram is labeled 'Control Unit' and includes a pin list for the ESP32-S3-WROOM-1 module.

**ESP32-S3-WROOM-1 Pin List:**

- 17 TX
- 16 TX
- 15 GPIO0\_STRAPPING
- 14 GPIO0\_STRAPPING
- 13 GPIO0\_STRAPPING
- 12 GPIO0\_STRAPPING
- 11 GPIO0\_STRAPPING
- 10 GPIO0\_STRAPPING
- 9 GPIO0\_STRAPPING
- 8 GPIO0\_STRAPPING
- 7 GPIO0\_STRAPPING
- 6 GPIO0\_STRAPPING
- 5 GPIO0\_STRAPPING
- 4 GPIO0\_STRAPPING
- 3 GPIO0\_STRAPPING
- 2 GPIO0\_STRAPPING
- 1 GPIO0\_STRAPPING
- 0 GPIO0\_STRAPPING
- 18 TX
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Our LED subsystem in figure 5 was intended to use an LED driver, so we designed a circuit for it which we have on our pcb. Due to time constraints however we did not have enough time to test it and ended up hotwiring the LEDs to bypass the LED driver.

The schematic diagram illustrates the LT1618EMS-TRPBF LED driver circuit. The IC is configured with the following components and connections:

- Inductor L1** and **Switch SW1** are connected to the **VIN\_LED1** input.
- Resistors R15 (1k)** and **R25 (1k)** are connected in series between the output and the **VIN\_LED1** input.
- Capacitor C11 (0.01u)** is connected between the output and ground.
- Capacitor C10 (4.7u)** is connected between the **VIN\_LED1** input and ground.
- Capacitor C9 (1u)** is connected between the **ISP1** pin and ground.
- Diode D1** is connected between the **ISP1** pin and the **VIN\_LED1** input.
- Resistor R14 (10k)** is connected between the **FB1** pin and ground.
- Resistor R16 (27.4k)** is connected between the **FB1** pin and the **ISN1** pin.
- Resistor R20 (150)** is connected between the **ISN1** pin and the **ISN** pin.
- Resistor R21 (150)** is connected between the **ISN** pin and the **ISP** pin.
- Resistor R22 (150)** is connected between the **ISP** pin and the **IADJ** pin.
- Resistor R23 (150)** is connected between the **IADJ** pin and the **GND** pin.
- Resistor R24 (R)** is connected between the **GND** pin and the **ISP1** pin.

5



The sensor subsystem in figure 6 consists of the ICM-20948 IMU which we use to detect the hand gestures. This schematic shows the suggested connections [4] for the IMU to communicate via I2C with the ESP32. Unfortunately, we were unable to get the IMU to work with the ESP32, so we had to use the breakout board which has a built-in voltage regulator and I2C communication.

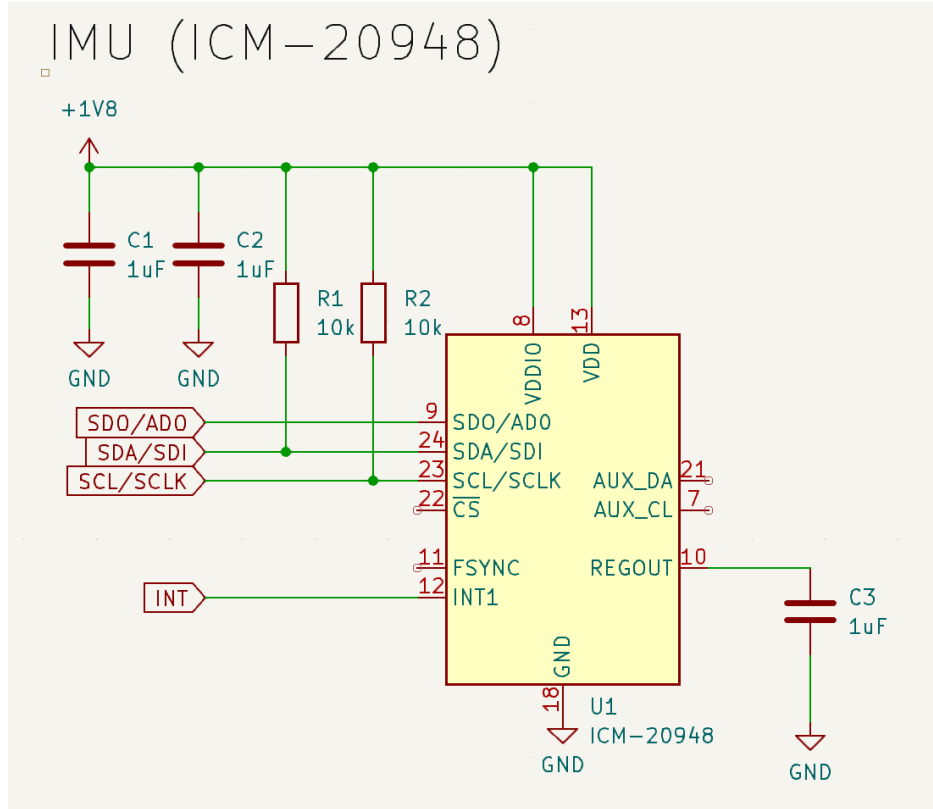


Figure 6: Schematic of the sensor subsystem

In order to power the system, we used a 3000mAh 4.8V NiMH battery from Panasonic [5]. As shown in table 1, our total current draw is 1864.2 mA so our estimated battery life of the system is  $3000 \text{ mAh} / 1864.2 \text{ mA} = 1.61$  hours.

Table 1: Current Draw of System Components

Description	Value
ESP-32 worst case current draw	355 mA
2x ICM-20948 IMU	4.6 mA each = 9.2 mA total
2x LED strip	750 mA each = 1500 mA total
<b>Total current draw</b>	<b>1864.2 mA</b>

## Heat tolerance for battery

- Total Internal Impedance =  $4\text{ m}\Omega \times 4 = 16\text{ m}\Omega$ .
- $I = 2\text{ A}$
- Time = 3600 seconds
- Mass = 0.228 kg for 4 cells
- Specific Heat Capacity:  $900\text{ J/kg}^\circ\text{C}$
- Total Heat Generated =  $I^2 \times R \times \text{time} = 230.4\text{ J}$
- Change in temp =  $\frac{\text{Heat}}{\text{mass} \times \text{specific heat capacity}} = 1.123^\circ\text{C}$

Assuming an ambient temperature of  $25^\circ\text{C}$ , the temperature of the battery will be around  $26.123^\circ\text{C}$  after one hour of operation. This is well within the operating temperature of the battery, so we can conclude that the battery will not overheat during operation.

During testing we found that after powering the system for one hour in an ambient temperature of  $22^\circ\text{C}$ , the battery was  $23.5^\circ\text{C}$ . This confirms our calculations that the battery will not overheat during operation.

## 3 Verification

### 3.1 Control Subsystem

Our control subsystem is used to run computations on input data from the sensor subsystem and output it through the LED subsystem. Because of this our requirements reflect how it interacts with these subsystems.

The first requirement is that it must be able to communicate with LEDs and Sensors through the PCB. We were able to verify this by connecting them to the control unit and seeing that the LEDs turn on when given a signal from the control unit, and that it is able to read data from the IMUs.

Our second requirement is that it must be able to determine the correct turn signals from the IMUs. This was done in software and was easier to verify once the entire system was complete. We verified it by wearing the device and making each gesture 10 times, where we got 92.5% accuracy.

Our third requirement is that it must be able to turn on the LEDs based on the corresponding turn signal. We did this by connecting the LEDs to the Control Unit and seeing that they turn on when given a turn signal.

## 3.2 Power Subsystem

Our Power subsystem had three necessary requirements in order for it to work properly with the rest of the system. The requirements along with how we verified them are listed below.

The first requirement is that it must supply  $3.3\pm0.3\text{V}$  to the IMUs and ESP32. We were able to verify this by using a multimeter to measure the voltage differential between the output of the linear voltage regulator and ground. We placed the red probe on the output pin of the linear voltage regulator and the black probe on the ground of the battery and read that the voltage differential is about 3.36V, meaning that anything connected between the two would receive about 3.36V.

The second requirement is that it must supply  $4.8\pm0.3\text{V}$  to the LEDs. We were able to verify this by using a multimeter to measure the voltage differential across the LEDs. We placed the red probe on the emitter pin of the BJT and the black probe on the ground of the battery. When supplying power from the ESP32 through the base of the BJT, we were able to measure about 5.03V, and the LED between them would turn on. We were able to lower the voltage to 4.8V, but ended up using 5V from the battery because the LEDs are technically rated for 4.8V, not 5V.

The final requirement is that the temperature of the battery should stay below  $50^{\circ}\text{C}$ . We were able to verify this by leaving the entire system running for about half an hour and measuring the temperature of the battery with an infrared thermometer. We read that the temperature remained at  $23.5^{\circ}\text{C}$  which is way below our threshold of  $50^{\circ}\text{C}$ .

## 3.3 Sensor Subsystem

Our sensor subsystem consists of two 9 degree-of-freedom IMUs, meaning each one has an accelerometer, gyroscope, and magnetometer. For each IMU, we must verify that the sensor readings are accurate for each of the sensors that we use for gesture recognition.

The first requirement is that the accelerometer must be able to detect acceleration with an accuracy of  $\pm 1\text{m/s}^2$ . In order to verify this we connected each IMU to the ESP32 through the I2C protocol and measured the acceleration due to gravity for each of the three degrees of freedom (x, y, z directions). Then we can check the output on the serial monitor to make sure that the acceleration due to gravity is  $9.8\pm 1\text{m/s}^2$  in the current direction parallel to gravity, and the acceleration readings in the other two directions are  $0\pm 1\text{m/s}^2$ . After conducting this verification, we found that the accelerometers were able to detect the acceleration in all three cartesian directions within  $1\text{m/s}^2$ .

The second requirement is that the magnetometer must be able to detect true north accurately. In order to verify this, we first connect the IMU to the ESP32 through the I2C protocol. Then we measured true north with the compass app on our smartphones and compared it to the direction of the IMU when it read zero degrees on the serial monitor. We did multiple trials for each of the IMUs and found that the magnetometers always

detected north correctly within  $\pm 10^\circ$ . More importantly than being able to detect north, is the measured angles of the two magnetometers need to be accurate relative to each other. In other words, the difference between the magnetometer readings of both IMUs when facing the same direction should be negligible. We verified this by leveling both IMUs so that they faced the same direction and then printed out the difference in magnetometer readings to the serial monitor, and found that the difference was always less than  $5^\circ$ .

There is no verification for the gyroscope as we did not utilize this sensor for the gesture recognition algorithm.

### **3.4 LED Subsystem**

The LEDs must be able to turn on in response to the other subsystems as well as be visible by a distance.

Our first requirement is that the LEDs must be able to turn on and off given a 4.8V input. We verified this by connecting our LEDs directly to our 4.8V battery and verifying that the LEDs turned on.

Our second requirement is that the LEDs must be visible from at least 250 ft away. We verified this by having one person walk 250 ft away with the LEDs while the other 2 filmed that the LEDs are visible.

## 4 Costs & Schedule

### 4.1 Costs

The total cost of parts will be approximately \$234.96 and the expected labor costs are calculated as  $\$40/\text{hrs} * 2.5 * 60\text{hrs} = \$6,000$ . This will be applied to all 3 team members so the total labor cost is  $\$6,000 * 3 = \$18,000$ . This comes out to a total cost of \$18,234.96.

Table 2: Bill of Materials

Description	Manufacturer	Quantity	Price/unit	Total Price	Link
velcro strips	VELCRO Brand	1	19.62	19.62	<a href="#">Link</a>
ESP32	Espressif Systems	1	7.69	7.69	<a href="#">Link</a>
LED strips	Aclorol	2	5.99	11.98	<a href="#">Link</a>
Battery	Panasonic - BSG	1	40.50	40.50	<a href="#">Link</a>
Voltage Regulator	STMicroElectronics	1	6.95	6.95	<a href="#">Link</a>
IMU breakout board	Adafruit	3	18.50	55.50	<a href="#">Link</a>
0.065 Ohm resistors	TFT Corp	4	0.55	2.20	<a href="#">Link</a>
LED Driver	Analog Devices Inc	3	5.70	17.10	<a href="#">Link</a>
1A Diode	onsemi	3	0.50	1.50	<a href="#">Link</a>
Inductors	SAC Inc	3	0.82	2.46	<a href="#">Link</a>
ICM-20948 IMU	TDK InvenSense	10	6.91	69.08	<a href="#">Link</a>
<b>Components Total</b>	N/A	N/A	N/A	234.96	
<b>Labor</b>	N/A	3	40.00	18 000.00	
<b>Total</b>	N/A	N/A	N/A	18 234.96	

## **4.2 Schedule**

# **5 Conclusion**

## **5.1 Accomplishments**

## **5.2 Uncertainties**

## **5.3 Future Work**

## **5.4 Ethics Considerations**

## References

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## Appendix A   Example Appendix

An appendix can go here! Make sure you use the `\label{appendix:a}` above so that you can reference this section in your document.