ENEL300-19S2, Group Design and Build Project Report

Adaptive Bike Light

By Group 7

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Abstract

By law [1], bicycle users are required to signal their intentions just as any other road user would. This includes stopping and turning. Having to remove a hand from the controls of the bicycle to perform these signals can reduce effective control and lead to increased stopping distances when braking. Current bicycle lighting solutions available are typically fixed in their function and do not provide any signalling capabilities. This report describes an implementation of an adaptive bicycle light for commuters that responds to acceleration and gyroscopic events to automate the signals required while maintaining complete transparency to the end user.

A prototype based on an AVR microcontroller and through-hole components was designed. The device was assembled on a custom printed circuit board and housed in a 3D printed case. The following key findings are discussed in further detail in the report:

- The 3D printing process yielded unpredictable results in terms of the structural integrity of the case. However, all the components fit well inside the housing and the printed circuit board components sit correctly atop their mounting posts.
- The battery does not output a high enough voltage to power the Arduino at 16 MHz; this is due to selecting a 5.0 V instead of a 3.3 V Arduino system. This can be mitigated by reducing the clock speed to 8 MHz or less.
- The 3D printed mounting system has some limitations: the rear light cannot be tilted for maximum visibility; the mount cannot be moved for easy charging; the mount lacks the strength required to endure bumps and shocks. In future, the mounting system would be redesigned.

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1 Introduction

This report presents the requirements, specification, and design of an adaptive bike light. The bike light is for persons who use a bicycle on roads, cycle ways, and/or shared paths where other users need to be aware of the bicycle and rider’s presence. The primary users will be urban and suburban commuters, however the system is multipurpose and suitable for other users such as children (on both scooters and bikes), mountain bikers, and others.

Cyclists are required, just as any other user, to signal their intentions at all times to other users [1]. For most users the requirement to provide a signal to turn left, right, or brake requires the rider to remove a hand from the handle bar thus reducing the amount control over the bicycle. When slowing or coming to a stop the rider also needs to release the front or rear brake in order to signal, increasing the likelihood of a skid as all braking transfers to one brake set. The alternative is to release both brakes, or not indicate. The adaptive bike light provides a means of signalling other users automatically, without the user needing to remove their hand from the handlebars. In this way, the rider maintains control of the bicycle and visual indications are provided to other road and pathway users.

The bike light adapts to three types of movement or motion change without direct input by the rider: braking, turning left, and turning right.

2 Background and Requirements

To provide a high level of visibility, separate front and rear modules are used. Each module includes case, PCB, accelerometer, microprocessor, rechargeable battery, charger, and yellow LEDs (for turn indication). For general visibility, the front module includes white LEDs and the rear module includes red LEDs. The microprocessor runs a single code base with a hardware jumper on the board to determine if the unit is running as a front or rear module. The accelerometer is continuously monitored by the microprocessor for motion change events. The microprocessor then controls the LEDs in response to motion events. The standard operating mode is to pulse the front (white) and rear (red) LEDs. When braking, the rear red LEDs are lit continuously, while the yellow LEDs are pulsed to indicate turning.

The adaptive bike like has the following requirements.

- Modules shall be self-contained and not require external sensor connections. (No external cables for wheel speed detection, brake lever pull detection or turn indicators.)
- Internal rechargeable battery shall be recharged with a readily available standard charging mechanism.
- Provide a front facing white light [2].
- Front module shall provide a presence indication.
- Front module shall provide a yellow turn indication.
- Provide a rear-facing red light [2].
- Provide a rear facing yellow turn indication.
- Provide a rear facing braking indication.
- Single codebase for front and rear lights.
- Failure of a front module should not cause failure of a rear module and vice versa.
- Modules should be easily fitted to a bicycle to face rearwards or frontwards as required depending on the specific module.
- The modules should provide light for three to five days of average daily commute before requiring recharge.
- The modules shall include a low power mode such that battery life is maximised if no movement has been detected for a pre-set time.
- The system production cost should not exceed $30.00.

3 Specifications and Implementation

The adaptive bike light provides three key functions:

1. Normal mode is flashing front (white) and rear (red) LEDs.
2. A tilt left or tilt right represents turning and will pulse the appropriate side (yellow) LEDs.
3. A forward deceleration event represents braking and the tail LEDs will be lit continuously.

3.1 Specification

3.1.1 Inputs, Outputs and the Microprocessor

Inputs

- Single accelerometer with I^2C output.
- Low supply voltage detection.
- Activity timer.
- Power switch.

Outputs

- White LEDs for front facing module.
- Red LEDs for rear facing module.
- Yellow LEDs for both modules.

Processor

- Arduino Nano with on board 3.3 and 5.0 volt power regulation.

3.1.2 Detailed Specification

- LEDs light source – Low voltage, comparatively low current.
- Ten 5.0 mm super bright LEDs – Small physical size, high intensity.
- MOSFET switching – Low switching power consumption and support PWM.
- 5x2 LED grid – Reduces number of I/O pins required, minimises number of current limiting resistors and MOSFETs while providing some individual addressability.
- I^2C enabled sensors – Sensor type and model can be changed readily.
- Single PCB for font and rear modules – Lowers cost of manufacture.
- Single code base for both modules - Lower development and maintenance cost of software.
- Jumper - To determine front or rear light operation.
- Accelerometer – Provides detection for acceleration events.
- Arduino Nano – Small physical size, sufficient computation power, existing library support, sufficient I/O pin count, and on board regulator.
- Mounting to support 6mm reusable cable ties.
- Mounting can be attached vertically or horizontally.
- Run time should be 1 hour, twice a day, for 5 days before recharge.

3.2 Hardware Implementation

To reduce the number of I/O pins required on the microprocessor, the LEDs were arranged in a two by five grid. In this way, only five processor output pins were required to control a pair of LEDs. The five by two grid, switching MOSFETs and current limiting resistors are all shown in Figure 1: A 3D render of the printed circuit board.. See appendix 7.1 for the full PCB schematic. Five-millimetre super-bright LEDs were chosen to balance the size, intensity, and current drain requirements.

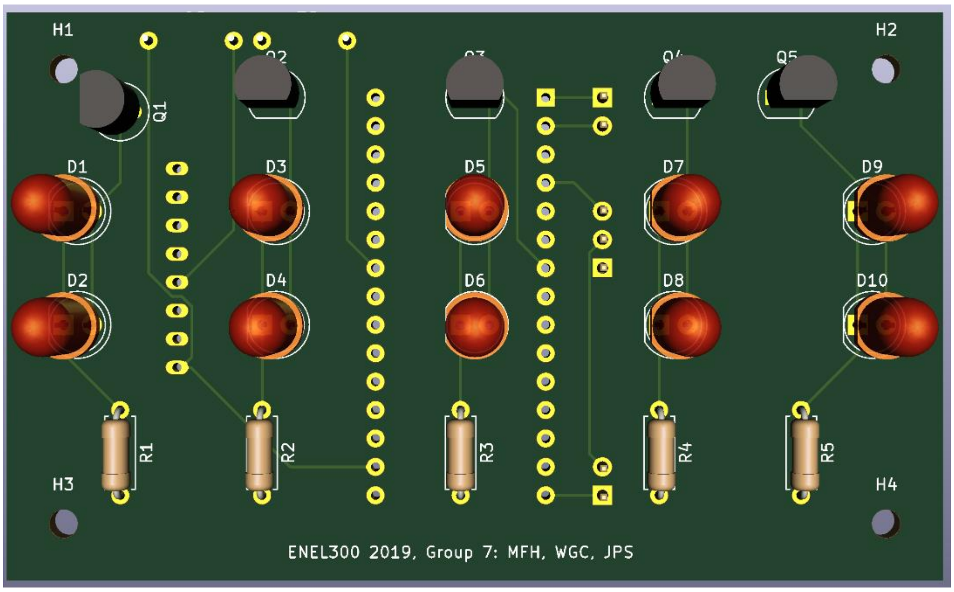


Figure 1: A 3D render of the printed circuit board.

3.2.1 LED Current Limiting

The lighting system uses three different colours of LEDs to provide visual feedback. Each colour has different electrical characteristics. [3] [4] [5]

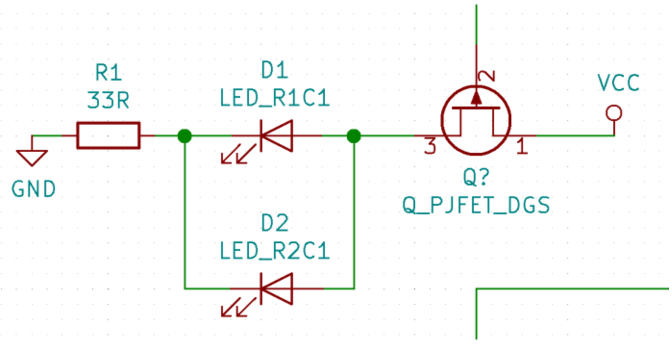


Figure 2: The schematic of the LED driving circuitry. The microcontroller drives the PFET with a low signal.

As each bank of LEDs contains two LEDs in parallel (Figure 2), the resistance of the current limiting resistor is calculated using the following formula:

$$R = \frac{V_{cc} - V_{drop}}{2 \times I_{max}}$$

The minimum resistance required to limit the current to recommended levels, along with other relevant characteristics, is given (**Error! Reference source not found.**). V_{CC} is assumed to be between 3.3 and 4.2 volts as this is the typical range of a lithium polymer battery, which directly supplies the twin LEDs via MOSFETs and current limiting resistor. The MOSFET [6] also offers some resistance while operating but it is considered negligible. Actual resistances were chosen from the E24 series of resistors. These have a 1% tolerance and provide greater accuracy than typical 5% tolerance resistors. **Error! Reference source not found.**, **Error! Reference source not found.**, and **Error! Reference source not found.** show the current available to the LEDs as the supply voltage fluctuates.

Given the supply voltage is not regulated and comes directly from the battery module, the resistors were chosen to give the best trade-off between restricting the maximum current to a safe operating value versus varying supply voltages.

Colour	Voltage Drop (V)	Max. Current (mA)	Minimum Resistance (Ω)
White	3.2	30	16.67
Yellow	2.2	30	33.33
Red	2.2	30	33.33

Table 1: Characteristics of the LEDs and current limiting resistors at V_{CC} = 4.2 V.

Colour	Resistor (Ω)	Min. Current (mA)	Max. Current (mA)	Mean Current (mA)
White	22	22.50	22.96	22.73
Yellow	47	21.07	21.49	21.28
Red	47	21.07	21.49	21.28

Table 2: The current characteristics of each LED when VCC = 4.2 V.

Colour	Resistor (Ω)	Min. Current (mA)	Max. Current (mA)	Mean Current (mA)
White	22	11.25	11.48	11.36
Yellow	47	15.80	16.12	15.96
Red	47	15.80	16.12	15.96

Table 3: The current characteristics of each LED when VCC = 3.7 V.

Colour	Resistor (Ω)	Min. Current (mA)	Max. Current (mA)	Mean Current (mA)
White	22	2.25	2.30	2.27
Yellow	47	11.59	11.82	11.70
Red	47	11.59	11.82	11.70

Table 4: The current characteristics of each LED when VCC = 3.3 V.

3.2.2 Current Consumption Calculations

A desired run time of one hour, twice a day for five days before recharging is preferred. This represents 10 hours of use per charge. The current consumption results (Table 2) assumes a 50% PWM duty cycle of the LEDs. It is also assumed that the user indicates for 5% of the time and brakes for 10% of the time.

Table 2: Current consumption breakdown.

Component	**Current Peak (mA)**	**Current Average (mA)**
Arduino and sensor	75	22
Red LED branches	96	55
White LED branches	70	35
Yellow LED branches	64	3
Total	305	115

Converting the above total current average into watt-hours, assuming a 3.7 V nominal battery voltage, yields 425 mWh. For 10 hours of operation, this represents a battery capacity requirement of 4.25 Wh. From these calculations, a 1200 mAh battery was chosen to give 4.44 Wh to meet the specified runtime.

3.2.3 Module Mounting

Reusable cable ties were used to attach the light modules to the bicycle, as they are readily available, easy to use and robust. A common case is required for both front and rear modules, thus a custom mounting was needed to support both horizontal and vertical mounting positions.

Seat tube, handlebar, and head tube diameters were recorded for a hybrid (or commuter) bicycle as follows:

- 18.5 mm and 27.5 mm (seat post suspension tube and actual seat tube respectively).
- 32.5 mm
- 22.3 mm and 25.3 mm (tapered handlebar from outer to inner and stem fixing point).

Based on the above dimensions a diameter of 23 mm was used for the custom mounting. A technical drawing of the case, including mounting is shown in appendix 7.3.

3.2.4 Code for Turn and Braking Indications

Two initial methods were proposed to provide the change of motion outputs:

1. Provide the indication, in response to a motion detection, for a predetermined time
2. Provide the indication, in response to a motion detection, until a corresponding motion cancelling response is detected.

Option 1 has been implemented with the view that simpler code will be easier to maintain, but fine-tuning is required to optimise the indication timings.

3.3 Firmware Implementation

The firmware for the bike light was written using Arduino C++. A modular design was employed to allow different parts of the system to be written and tested independently of one another (Figure 3). To ease the development process, one version of the firmware is used for both front modules and rear modules. The firmware was designed using the Arduino Studio IDE and GitHub was used for version control.

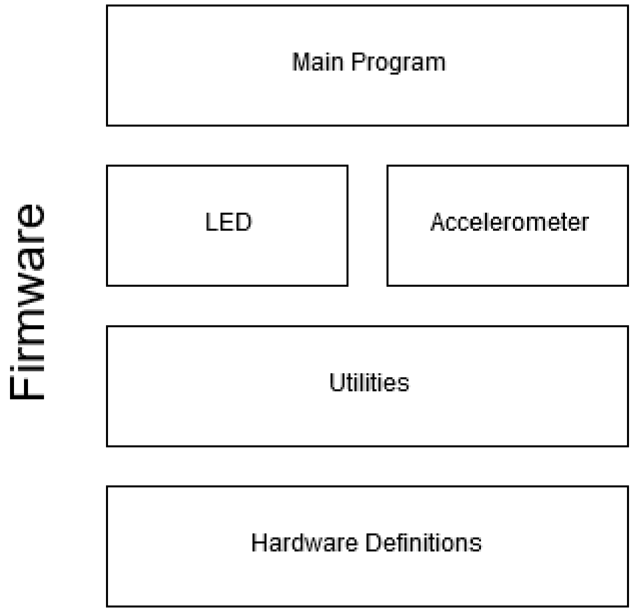


Figure 3: The software system architecture.

3.3.1 Hardware Module

The hardware module simply defines on which pins certain signals are expected. This file is only changed when the actual hardware is also changed. Also included are other useful macros, such as the I^2C address of the accelerometer and the baud rate of the serial connection. No functions appear in this module, only macros.

3.3.2 Utilities Module

The utilities module defines several functions that are useful but perhaps do not fit in any other module. Such functions include checking if the hardware module is wired as a front light or a rear light. This module depends upon the hardware module.

3.3.3 LED Module

The LED module contains functions, macros, and ISRs for dealing with turning the LED lights on and off. The LEDs are abstracted into columns, and the columns are further abstracted into banks. This allows the other modules to call a function that will turn an entire bank on or off. To save power, the LEDs are pulsed at 50 Hz (with a 50% duty cycle) using software PWM that is controlled by a timer ISR. Each bank can contain multiple columns; if more columns are introduced then the firmware must be changed to reflect this. The LED module depends upon the utilities and hardware modules.

3.3.4 Accelerometer Module

The accelerometer module contains useful abstractions for dealing with querying and normalising data received from the hardware accelerometer. This module uses a timer ISR to query the accelerometer at 4 Hz via I^2C. The getter functions can then be used to use this data in the main program. The accelerometer module depends upon the hardware module and the Wire library provided by the Arduino standard library.

3.3.5 Main Module

The main module initialises the other modules and then waits for an event from the accelerometer. This information is then used to enable or disable the LEDs. This is where the "business logic" of the firmware resides. The main module depends on the LED and accelerometer modules.

3.3.6 Testing

The important functions of each module were tested individually in a test module. This allowed us to unit test each module before integrating them into the system. This allowed us to improve our debugging time and to verify the functionality for the modules. The test module depends on the LED, accelerometer, and utilities modules.

4 Analysis and Improvements

4.1 Analysis

Five iterations of 3D printing were required to achieve a suitable prototype case. This was due to lack of strength in the mounting stays and inability to accommodate the USB charging [7] entry and power switch, plus two print failures (over temperature shutdown and filament run out). Further details are captured in section 5.2.1 and a number of these have been implemented in the final prototype case.

During testing, it was discovered that the MOSFET switches were unable to be switched off once conducting. This was due to the use of an N type MOSFET in an arrangement where the load was connected to source (ground) instead of drain (V_{CC}). These had to be swapped to P-channel enhancement-mode MOSFETs to enable the required switching behaviour. Microcontroller code also had to be changed to provide an active low output for LEDs on and active high for LEDs off.

Testing also showed that the system only runs until the battery voltage reaches 3.6 - 3.7 V. The remaining 0.4 - 0.5 V before the battery cuts out is unusable and presents a loss of run time. This is due to the choice of microprocessor whereby a 5.0 V device was specified. A work around was implemented by reducing the clock speed from 16 MHz to 8 MHz to ensure stability and maximum battery capacity utilisation. Changing to a 3.3 V microprocessor would alleviate these issues and give more consistent digital logic behaviour logic across the entire battery voltage range.

4.2 Improvements

In this section, improvements are identified and grouped by category. A number of the case improvements have been implemented in the final prototype.

4.2.1 Case Improvements

- **Clear Focussing Lens**
  The prototype currently uses a thin plastic film to exclude water and dust from the module. This lacks robustness and allows light to “spill” in the general direction to which the module is pointing. A clear focusing plastic, possibly Fresnel, lens is required to provide a weatherproof seal and focus the available light towards the rear.
- **Switch**
  The case does not have an entry or mounting point for the inline power switch. This should be added to the design of the case. Additionally this needs to be weatherproof.
- **USB Charging**
  The prototype does not have an entry or mounting point for USB charging. This should be added to the design of the case. Additionally this needs to be weatherproof.
- **Battery Bay**
  Small mounting ribs should be added on the inside of the case to restrict horizontal movement of the battery pack.
- **Mounting Post Fillets**
  The mounting posts should be filleted to increase their structural integrity where they attach to the case.

4.2.2 Mounting Improvements

- **Quick Release Mechanism**
  The prototype uses reusable cable ties to attach the module to the bicycle. It is desirable to provide a mechanism that allows the module to be easily removed for charging, but is still securely attached when in use.

- **Angled Mounting**
  Since the rear module is directly attached, its alignment follows that of the seat post resulting in down-tilted light output (in most cases). This is undesirable as the light needs to be visible by other road and path users who are positioned above the level of the rear light. This means other users may not see actual light, only reflected light. Thus, the mounting mechanism needs to accommodate non-vertical (and non-horizontal) mounting positions whilst allowing the actual light output to be directed as needed.
- **Strength of Custom Mount**
  The current custom mounting has only nine 3.0 mm by 3.0 mm squares to hold the mount to the case. It is unlikely that this would sustain an impact without shearing.

4.2.3 Circuit Improvements

- **Ambient Light Sensor**
  In bright light, particularly sunlight, the presence LEDs are expected to add little benefit thus can be switched off to save battery life. The turn and brake indications however are mandatory. Adding a light sensor would provide the required input for this feature.
- **Voltage Regulator and/or Constant Current Source/Sink for the LEDs**
  A voltage regulator would provide a constant voltage to the LEDs regardless of battery voltage. Since the battery ranges over 3.0 to 4.2 volts it will need to provide both buck and boost capability.
  Alternatively, a constant current source could be implemented thereby removing the need for current limiting resistors, but the white LEDs would not operate correctly at or below a battery voltage of 3.2 V.
  A further option to consider is using the 3.3-volt regulator on the microprocessor board as the reference input to a series pass transistor configuration for voltage or current regulation to the LED's. In this scenario, the power dissipation of the transistor may be a limitation, as there is a lack of space for heatsinking.
- **Revised Microprocessor Power Supply**
  The system stops working when the battery voltage reaches 3.6 - 3.7 V. This is due to the combination of a lack of supply voltage margin to reliably operate the microcontroller's on-board regulator and the low voltage detection in the microprocessor.
- **Implement Test Points**
  Being able to connect measurement and test devices to different points in the circuit would be extremely useful for debugging
- **Breakout Unused Pins**
  The unused pins on the microprocessor are not accessible, so if additional I/O is required the PCB will need redesign.
- **Increase PCB Mounting Hole Diameter**
  The current PCB design has mounting holes that are 2.54 mm in diameter. This was an issue when the mounting posts (D = 2.00 mm) on the 3D printed case repeatedly broke. In future, the mounting holes should be at least 4.00 mm in diameter to allow the mounting posts to be up to 3.50 mm wide. This would increase the strength of the posts.
- **Update FET Switch Layout**
  The current circuit layout does not reflect the actual physical connections as noted [Sec. 5.1]. Hence, the board layout requires a new layout to reflect this.

4.2.4 Logistical Improvements

- **Ordering Parts Earlier**

Given the required timescales, component lead times affected the build and test timing of the prototype, so in future components should be ordered earlier or from suppliers with more favourable lead times with acceptance of increased cost.

- **Proof of Concept Testing**
  Due to time constraints build and test was undertaken directly on the circuit board. Whilst a relatively simple system having the opportunity to implement, test and refine via breadboard would reduce risk.

5 References

[1] New Zealand Transport Agency, “About cycling, Cyclist responsibilities,” 2017 February 2017. [Online]. Available: https://www.nzta.govt.nz/resources/roadcode/cyclist-code/about-cycling/cyclist-responsibilities#hand-signals.

[2] New Zealand Transport Agency, “https://www.nzta.govt.nz/resources/factsheets/01,” 01 December 2016. [Online]. Available: https://www.nzta.govt.nz/assets/resources/factsheets/01/docs/01-cycles.pdf. [Accessed 10 September 2019].

[3] CHINA YOUNG SUN LED TECHNOLOGY CO., LTD., “https://www.sparkfun.com/datasheets/Components/,” 01 August 2017. [Online]. Available: https://www.sparkfun.com/datasheets/Components/YSL-R547W2C-A13.pdf. [Accessed 06 September 2019].

[4] CHINA YOUNG SUN LED TECHNOLOGY CO., LTD., “https://www.sparkfun.com/datasheets/Components/,” 01 August 2017. [Online]. Available: https://www.sparkfun.com/datasheets/Components/YSL-R531R3C-A13.pdf. [Accessed 06 September 2019].

[5] CHINA YOUNG SUN LED TECHNOLOGY CO., LTD., “https://www.sparkfun.com/datasheets/Components/,” 01 August 2017. [Online]. Available: https://www.sparkfun.com/datasheets/Components/YSL-R531Y2C-A13.pdf. [Accessed 06 September 2019].

[6] Diodes Incorporated, “https://www.diodes.com/assets/Datasheets/,” [Online]. Available: https://www.diodes.com/assets/Datasheets/ZVP2106A.pdf. [Accessed 06 September 2019].

[7] Microchip Technology, “Adafruit Micro-Lipo Charger,” 1 November 2005. [Online]. Available: https://cdn-shop.adafruit.com/datasheets/MCP73831.pdf. [Accessed 10 September 2019].

6 Appendices

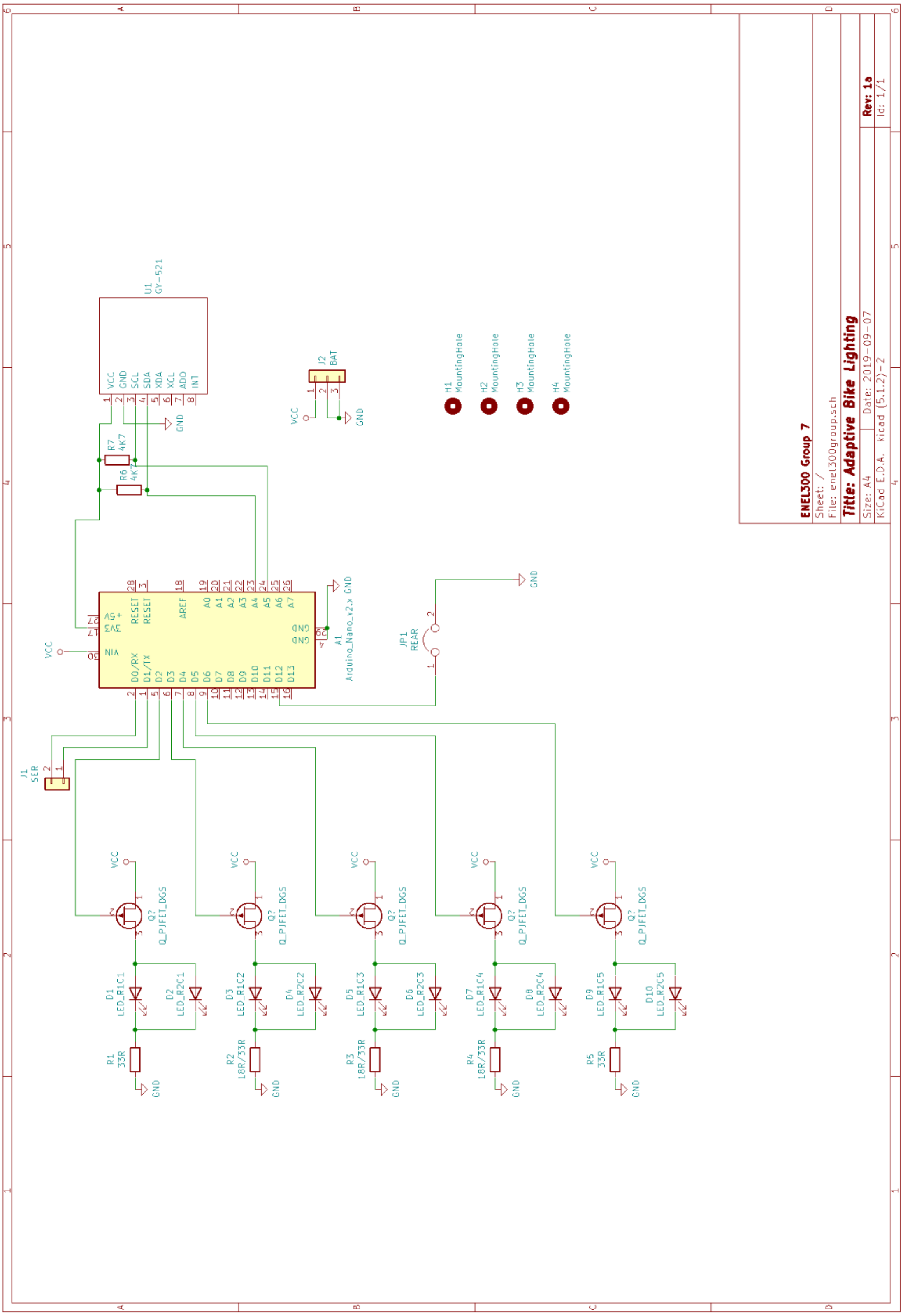
6.1 Bill of Materials

Id	Designator	Package	Quantity	Designation
1	A1	Arduino_Nano	1	Arduino_Nano_v2.x
2	D1	LED_D5.0mm	1	LED_R1C1
3	D2	LED_D5.0mm	1	LED_R2C1
4	D3	LED_D5.0mm	1	LED_R1C2
5	D4	LED_D5.0mm	1	LED_R2C2
6	D5	LED_D5.0mm	1	LED_R1C3
7	D6	LED_D5.0mm	1	LED_R2C3
8	D7	LED_D5.0mm	1	LED_R1C4
9	D8	LED_D5.0mm	1	LED_R2C4
10	D9	LED_D5.0mm	1	LED_R1C5
11	D10	LED_D5.0mm	1	LED_R2C5
12	J1	PinHeader_1x02_P2.54mm_Vertical	1	SER
13	J2	PinHeader_1x03_P2.54mm_Vertical	1	BAT
14	JP1	PinHeader_1x02_P2.54mm_Vertical	1	REAR
15	U1	GY-521	1	GY-521
16	R1,R5	R_Axial_DIN0207_L6.3mm_D2.5mm_P7.62mm_Horizont	2	33R
17	R2,R3,R4	R_Axial_DIN0207_L6.3mm_D2.5mm_P7.62mm_Horizont	3	18R/33R
18	R6,R7	R_Axial_DIN0207_L6.3mm_D2.5mm_P7.62mm_Horizont	2	4K7
19	H1,H2,H3,H4	MountingHole_2.5mm	4	MountingHole
20	Q1,Q2,Q3,Q4,Q5	TO-92	5	Q_PJFET_DGS
21		Battery	1	
22		Battery Charger	1	
23		Printed Circuit Board	1	
24		Power Switch	1	
25		3D Printed Case	1	

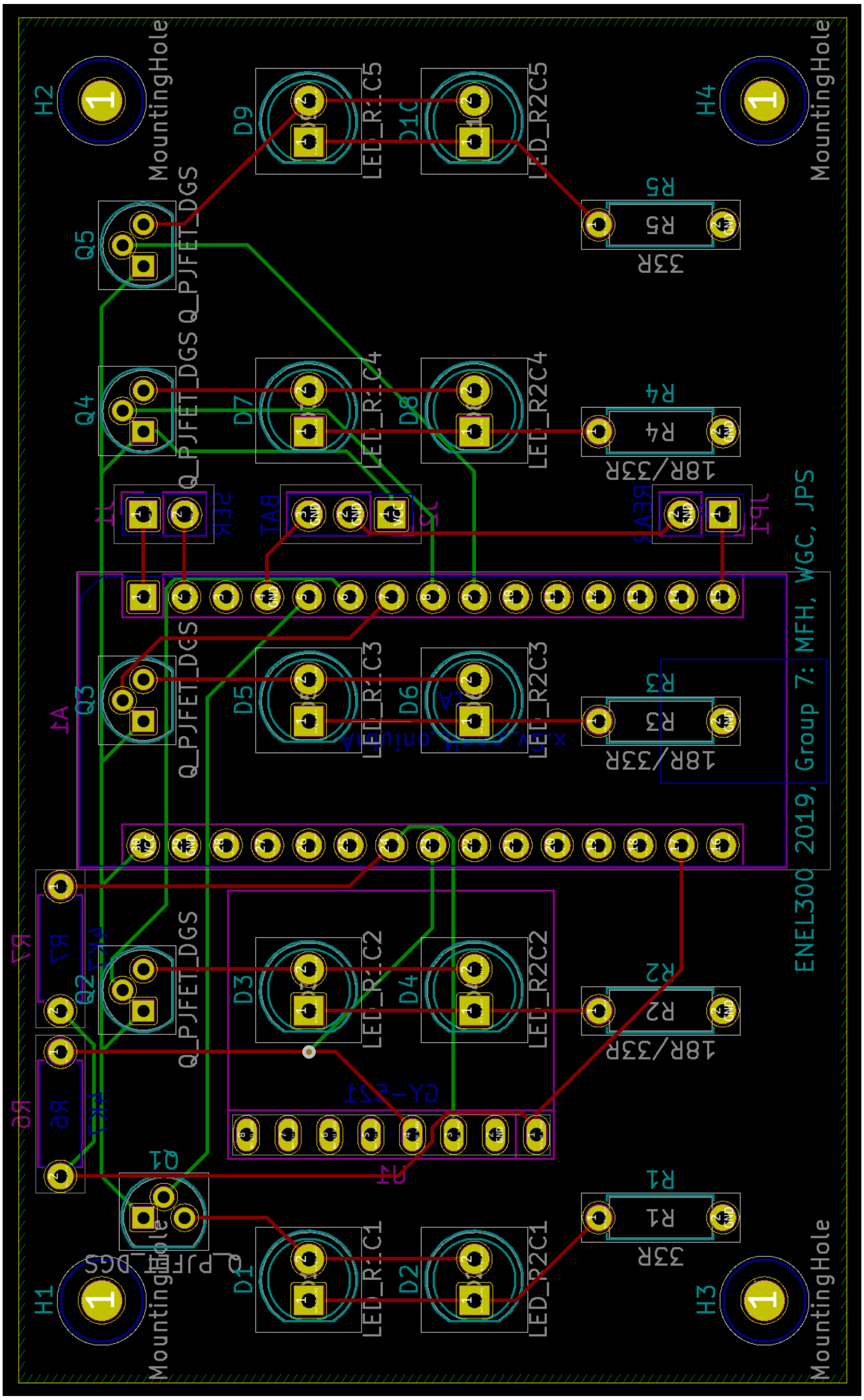
6.2 Price List

Description	Part Code	Supplier	Quantity	Price	Subtotal
Microcontroller	Arduino Nano	AliExpress	2	$1.16	$2.32
Red Superbright LED	R531R3C-A13	AliExpress	6	$0.08	$0.48
Yellow Superbright LED	R531Y2C-A13	AliExpress	8	$0.08	$0.64
White Superbright LED	R547W2C-A13	AliExpress	6	$0.08	$0.48
Accelerometer	GY-521	AliExpress	2	$0.90	$1.80
Battery	803040	AliExpress	2	$4.33	$8.66
Inline switch		JayCar	2	$0.45	$0.90
Charger board	1304 / MCP73831	AliExpress	2	$2.15	$4.30
Case	ABS Filament	UC CAE 3D Printer	2	$1.45	$2.90
Resistor		UC Store	10	$0.02	$0.20
MOSFET	ZVP2106A	UC Store	10	$0.53	$5.30
Cable		UC Store	2	$0.10	$0.20
Header Pins		UC Store	2	$0.10	$0.20
Jumpers		UC Store	2	$0.01	$0.02
Solder		UC Store	2	$0.10	$0.20
Reusable Cable Tie			4	$0.05	$0.20
Total					$28.80

6.3 PCB Schematic



6.4 PCB Layout Drawing



6.5 Technical Drawing of Case