**Low-cost Sensor for Seamless Road Quality Monitoring**

ECE 445 Design Document — Spring 2022

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1. **Introduction**

**1.1 Problem**

Today's transportation system has been well developed. People can find the route to a specific destination through navigation, which provides a lot of convenience. The problem is that the road condition is changing all the time, but we can't get the information of real-time road condition, such as whether there are many potholes and whether the road is flat. Because the traditional road monitoring is carried out regularly through special vehicles, it needs a lot of cost. In the blank period of monitoring, if there are serious changes in the road surface somewhere, it may affect the comfort and safety of passing vehicles, and even force vehicles to change the route, which wastes a lot of time. Therefore, we need a lower cost and more efficient seamless pavement monitoring device.

**1.2 Solution**

We propose a device composed of acceleration sensor, GPS and independent power supply, with supporting mobile applications on smart phones. The device can be placed on a bicycle or vehicle and transmit the position information and corresponding sensor data to the server in real time. By filtering, processing and extracting features of sensor data, the application can display intuitive road condition data. As a portable and low-cost monitoring device, we can equip it with a large number of vehicles or public bicycles. In this way, the road condition of the road section can be directly obtained by the vehicles passing through the road section and provided to other users, so that everyone can obtain the real-time road condition and make a reasonable route choice.

**1.3 High-Level Requirements**

• When the measurable range is ± 2g, the sensitivity of the accelerometer should be greater than 10000LSB to ensure the accuracy of data measurement.

• The server needs a high-precision module to eliminate the sensor noise signals caused by the vehicle itself, such as acceleration, deceleration or turning, so as to provide high-precision road conditions.

• The data transmission between monitoring device and server, server and mobile application should be completed within 500 milliseconds to ensure the real-time and effectiveness of road condition data.

1. **Design**

**2.1 Physical Diagram**

图示

描述已自动生成

Figure 1. Device Physical Design

**2.2 Block Diagram**

**图示

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Figure 2. Block Diagram

Figure 2 shows the block diagram for the system we design. It can be divided into 3 main sections: PCB board subsystem, cloud server, and smart phone device. PCB board system is a hardware system installed on the PCB board and controlled by a control module. The board is powered by a 5-V battery. We will use GPS and accelerometer modules to collect data. Data will be firstly sent to control module and then transmitted to cloud server to perform classification by wifi signal. Finally, the location and the label for road quality will be displayed on a smartphone.

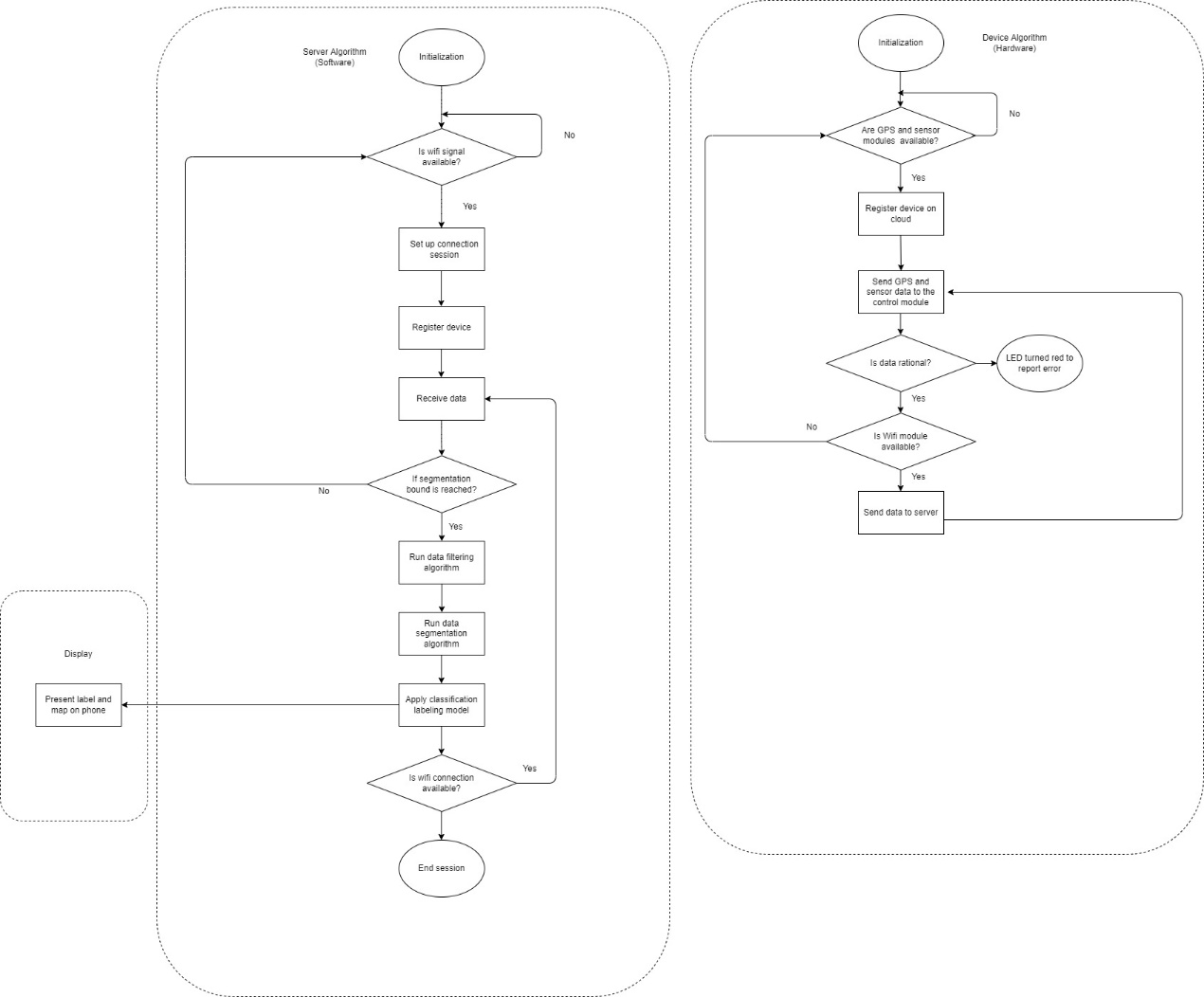
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Figure 3. Flow Chart for Hardware and Software

**2.3 Subsystem in PCB**

**2.2.1 Power Supply Subsystem**

**Description:**

To enable the PCB and the attached components to work, the power supply subsystem is consisted of two 5V Batteries as the power supply and a voltage regulator. The voltage regulator will convert input voltage to voltages 3.3V by the corresponding components.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| The batteries should hold sufficient capability to support the hold system work | We need to check the batteries’ capability to ensure that the available working time of power supply should exceed the time for a vehicle’s test period on a road |
| The power module could support all the voltage supply requirement of the sensor components | With two 5V Batteries and a voltage regulator, the power module could provide voltage of 5V and 3.3 V, which is the voltage requirement of the modules in PCB |
| The set position of power module should be arranged properly | To avoid sliding or poor connection when the vehicle is driving, the power supply subsystem should be fixed well somewhere near the PCB |

Table 1. RV for the Power Supply Subsystem in PCB

**2.2.2 Location Tracking Subsystem**

**Description:**

To fetch the location information of the vehicle, our group is considering setting a GPS module into the PCB. By using a NEO-6M GPS module, we can use the TinyGPS library provided by this module to get varieties of location data we need, such as latitude, longitude and altitude along with time. We can save these data and upload them into the server by WiFi module for further use.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| The GPS module should be capable to do location tracking on the vehicle in real time | During the test, we need to be provided with location data in enough accuracy (at least 95%) to allow us to detect the vehicle’ real-time position on a road. |

Table 2. RV for the Location Tracking Subsystem in PCB

**2.2.3 Road** **Anomalies Detection Subsystem**

**Description:**

In order to detect road anomalies, we decide to use a 6-axis sensor module MPU-6050, including a 3-axis piezoresistive accelerometer and a gyroscope.

1. **Accelerometer:**

To measure road quality, the first kind of sensor to be applied is the accelerometer. The sensor can detect real-time acceleration data in 3-D space. Irregular road surface will cause vibration in the acceleration data. To evaluate road condition, we need to find vibrating amplitude and frequency occurring in such signal

Since the initial state of our accelerometer will still have acceleration of g, we need to exclude this factor with initialization. It can be explained by the formula below.

*Gx = (ADCx-offset)/K* (unit:m/s^2)

*ADCx* means sensor output, *Gx* stands for true acceleration, offset denotes output of sensor when Offset acceleration is 0g, and *K* is the scale factor. An anomaly is detected when *Gx* greatly fluctuates.

**(2) Gyroscope:**

While the vehicle is static or in a uniform linear motion, the accelerometer itself serves as an ideal inclinometer. In that the vehicle does not always keep its z-axis upright when swerving, however, a gyroscope should used to normalize signals given by accelerometer. The device detects inclining angles of our measuring board in different directions and uses kalman filter algorithm, which would be applied in our filter module [2]. This process is called reorientation.

Without a need for offset, the values of gyroscope can be more easily calculated.

*R = ADCrate/K* (unit:degree/s)

ADCrate means sensor output, R means angular rate, K stands for scale factor.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| The acceleration data should exclude interference from vehicle swerving or going up and down hills | Reorientation ought to be applied to filter the long wave to exclude such interference |
| The sensitivity of accelerometers and gyroscopes should be appropriate | Choose different measuring range of sensors, and use each time data obtained to label road quality. Compare the accuracy of results to find the best sensitivity. |
| The volume of sensors cannot be too large for PCB board | An integrated chip of sensors is used with its package size 4x4x0.9mm |

Table 3. RV for the Road Anomalies Detection System in PCB

**2.2.4 Control Subsystem**

**Description:**

For better interface with the cloud server, our group is considering using a mini controller to communicate with all the sensor subsystem and the WIFI module. We can use an ATmega328 controller to receive the data from the accelerometer and GPS module and send the data to the backend service using the WiFi module.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| The control module could capture data from the sensors and check if sensor readings are within certain thresholds | If the data is not in rational range, the connected LED would turn into red to indicate a failed status in receiving data |
| The control module should work well with the WIFI module to enable the connection to the cloud server | The control ship should ensure the data transmitted correctly from the sensors to the cloud server by WIFI module with no data missing |
| The control ship mush have enough pins to support all the sensors and module we need | The control ship should have at least 2 pins for power supply, 6 pins for WIFI module, 4+8=12 pins for the sensors. Totally minimum pin number is 20 |

Table 4. RV for the Control Subsystem in PCB

**2.2.5 WIFI Subsystem**

**Description:**

To enable connect with the cloud server, our group consider using ESP8266 microchip to interface with the control subsystem. This module could transmit the data from the microcontroller to the internet server.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| The WIFI module could interface with the microcontroller to allow varieties of data to transmit to the server | 1. The working frequency of this module should be consistent with the frequency of the Mini controller 2. The pins of WIFI module and the pin of microcontroller could be linked properly to allow the WIFI module work properly (Voltage, Groud, Ports for data sent and received etc) |
| The ESP8266 would be programmed to run a HTTP server | we can communicate over the cloud server to the backend service by transmitting the data in the required format |

Table 5. RV for the WIFI Subsystem in PCB

**2.4 Subsystem in server**

**2.3.1** **Filtering Subsystem**

**Description:**

Our model classifies the road to be safe or not according to the abnormal pattern from accelerometer. However, some abnormal pattern can be caused by the acceleration, deceleration, and turning, which is unrelated to road quality. To eliminate the influence caused by these actions, a filter is applied here. According to article written by Basavaraju [3], an 11th-order Butterworth high-pass filter with a cut-off frequency of 2 Hz can be applied to solve this problem.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| Exclude Unrelated Factor:  The abnormal pattern in the signal sequence should not be caused by the activity unrelated to road quality. | We will get the signal from accelerometer when the vehicle does acceleration, deceleration, and turning. Compare the signal sequence before and after applying the filter. |
| Keep Related Factor:  The abnormal pattern caused by the potential road quality problems should not be eliminated. | We will get the signal from accelerometer when the vehicle run on the convex and concave road. Compare the signal sequence before and after applying the filter. |

Table 6. RV for the Filtering Subsystem in Cloud Server

**2.3.2 Segmentation Subsystem**

**Description:**

1. **Split Into Segments:**

We need to report the road segment to have problems or not instead of the whole road, so we need to split the signal sequence into segments. To locate the problem in more precise and convenient condition, we need to make sure every signal segment is corresponding to the road segment with the same length.

1. **Preprocess:**

If all the segmentations will be processed by the Classification Module, it will create great load to system. We need to exclude the segments, which is unlikely to be related to bad road quality with a low-cost method. A threshold of speed and RMS of segment can be applied, according to [3].

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| Keep Same Distance:  Every signal segment should be corresponding to the road segment with the same length. An algorithm that converts the signal from GPS and accelerometer to speed information is necessary. Then the sample rate of accelerometer and speed information will be used to calculate the length of road segment. | We will record the speed and distance of running vehicle. Then use the information from GPS and accelerometer to calculate speed and distance. Verify the accuracy of the algorithm by comparing the recorded value and calculated value. |
| Correct Exclusion:  The preprocess system, which excludes the segments unlikely to be related to bad road quality, should exclude negative sample as much as possible, in the condition that no positive sample will be excluded. | The threshold should make the False negative to be 0. In this situation, test different threshold that has the greatest precision. |
| Limited Time:  The load of Segmentation Module should not be high. In other word, the preprocess algorithm should not be too complex. | We will compare the time cost before and after applying the exclusion algorithm. The time cost should be significantly reduced. |

Table 7. RV for the Segmentation Subsystem in Cloud Server

**2.3.3 Classification Subsystem**

**Description:**

A machine learning based classification nodule is applied to classify the road to be safe or not. For every segment from segmentation Module, the model should classify the segment as accurately as possible. Then it will label the location information from GPS to having problem or not.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| Significant Feature Extraction:  A method of feature extraction should be chosen to make the abnormal pattern can be more easily recognized by model. | We will try different methods of feature extraction to signal from the accelerometer. The abnormal pattern should be obvious from the view of people. |
| Sufficient Training Set:  The training set, which has high quantity and variety should be collected. | We will make sure the number of samples is sufficient. Temperate requirement is 5000 segments with correct label should be collected. In addition, the signal cause from various type of road quality problems should be collected. Temperate requirement is 10 types of road quality problems should be tested. |
| High Accuracy:  The model should have high accuracy. | We will test the accuracy of the model. The high recall is the main target. It should be over 90%. In this situation, precision should be as high as possible. |
| Limited Time:  The model should run in a limited time. | Every segmentation should be processed within 0.1 s. In this situation, a test set with 1000 sample should be processed by model within 100s. |

Table 8. RV for the Classification Subsystem in Cloud Server

**2.3.4 Display Subsystem**

**Description:**

The result reported from classification subsystem is the label and the information recorded from GPS, such as longitude and latitude. These groups of information are not human-readable enough. We will need to display the information in a more readable way.

The longitude and latitude will be transformed into nodes on the map. The label from classification subsystem will be marked as the color of the nodes. In this situation, people can easily know which road segments is likely to have road quality problems.

|  |  |
| --- | --- |
| **Requirement** | **Verification** |
| The mapping from longitude and latitude to nodes need to be accurate at least 95% | We will get the map of Haining as the map to be marked. Then we will carry our GPS sensor to run along the roads in Haining. We will choose several road segments to test. Get the signal from GPS sensor and use GPS app from phone to mark where we record the signal. Use our display subsystem to see whether the node calculated from signal of GPS sensor match the node we recorded by GPS app from phone. |

Table 9. RV for the Display Subsystem in Smartphone

**2.4 Detailed Modules Introduction in PCB**

**2.4.1 NEO-6M GPS Module**

Our group will use NEO-6M to receive the location information. It will connect to STM32F103C8 to transmit the data. Then it will transmit the data to survey through ESP8266 Wi-Fi module.

**Diagram of NEO-6M:**

手机屏幕的截图

中度可信度描述已自动生成

Figure 4. Diagram of NEO-6M and the pins

**Pins Description of NEO-6M**

|  |  |  |
| --- | --- | --- |
| Pin Number | Pin Name | Verification |
| 1 | GND | Ground (0 V) |
| 2 | TX | Transmit data bit X |
| 3 | RX | Receive data bit X |
| 4 | VCC | Voltage (+3.3 V) |

Table 10. Pin Number, Pin Name and Verification of ESP8266 Module

**Connection between GPS Module and Control Module**

|  |  |
| --- | --- |
| NEO-6M | **STM32** |
| GND | G |
| TX | PA9 |
| RX | PA8 |
| VCC | 3.3V |

Table 11. Pins Connection between NEO-6M and STM32F103C8

**Tolerance:**

|  |  |
| --- | --- |
| Input voltage | 3.3V – 5.5V |
| Dissipation | 50mA (normal mode) 30mA (power saving mode) |
| Work Temperature | -40°C Cto+85°C |
| Storage Temperature | -55°C Cto+100°C |

Table 12. Tolerance analysis of NEO6M Module

**2.4.2 ESP8266 Wi-Fi Module**

Our group will use ESP8266 to connect STM32F103C8 to the internet. We will interface ESP8266 Wi-Fi module with our STM32F103C8 board and send the data to a webpage hosted on ESP8266 webserver. Since STEM32F support varieties of programming IDE(including Arduino IDE which we learned in ECE101), we will use arduino IDE to do the programming work and upload the code to STM32 board.

**Diagram of ESP8266:**

图示

中度可信度描述已自动生成

Figure 5. Diagram of ESP8266 and the pins

**Pins Description of ESP8266**

|  |  |  |
| --- | --- | --- |
| Pin Number | Pin Name | Verification |
| 1 | GND | Ground (0 V) |
| 2 | TXD | Transmit data bit X |
| 3 | GPIO 2 | General-purpose input/output No. 2 |
| 4 | CH\_PD | Chip power-down |
| 5 | GPIO0 | General-purpose input/output No. 0 |
| 6 | RST | Reset |
| 7 | RX | Receive data bit X |
| 8 | VCC | Voltage (+3.3 V) |

Table 13 Pin Number, Pin Name and Verification of ESP8266 Module

**Circuit Diagram and Connections:**

**图片包含 图示

描述已自动生成**

Figure 5. Circuit diagram and connections between ESP8266 and STM32F103C8

**Connection between** **WIFI Module and Control Module**

|  |  |
| --- | --- |
| **ESP8266** | **STM32** |
| VCC | 3.3V |
| GND | G |
| CH\_PD | 3.3V |
| TX | PA3 |
| RX | PA2 |

Table 14. Pins Connection between ESP8266 and STM32F103C8

**Ports and Tolerant**

|  |  |  |
| --- | --- | --- |
| **Serial Port** | **Pins** | **Tolerant** |
| Serial1 (TX1,RX1) | PA9,PA10 PB6,PB7 | 5V |
| Serial2 (TX2,RX2) | PA2,PA3 | 3.3V |
| Serial3 (TX3,RX3) | PB10,PB11 | 5V |

Table 15. Ports and Tolerant of STM32F103C8

**2.4.3 MPU-6050 Sensor Module**

The acceleration sensor module collects acceleration signal data in 3 directions to provide data for evaluating road quality. The acceleration sensor is connected with the power supply module to obtain power. And it is connected with the control module to transmit the collected data. The model of our acceleration sensor is MPU-6050, which not only includes 3-axis acceleration sensor, but also integrates 3-axis gyroscope and can communicates with MCU through IIC interface.

**Diagram of MPU-6050:**

**图形用户界面, 应用程序

描述已自动生成**

Figure 6. Circuit diagram and detailed design of the MPU-6050 Module

**Pin Out and Signal Description:**

|  |  |  |
| --- | --- | --- |
| Pin Number | Pin Name | Pin Description |
| 1 | CLKIN | Optional external reference clock input. Connect to GND if unused. |
| 6 | AUX\_DA | I2C master serial data, for connecting to external sensors |
| 7 | AUX\_CL | I2C master serial clock, for connecting to external sensors |
| 8 | VLOGIC | Digital I/O supply voltage |
| 9 | AD0 | I2C Slave Address LSB (AD0) |
| 10 | REGOUT | Regulator filter capacitor connection |
| 11 | FSYNC | Frame synchronization digital input. Connect to GND if unused. |
| 12 | INT | Interrupt digital output (totem pole or open-drain) |
| 13 | VDD | Power supply voltage and Digital I/O supply voltage |
| 18 | GND | Power supply ground |
| 19,21 | RESV | Reserved. Do not connect. |
| 20 | CPOUT | Charge pump capacitor connection |
| 22 | RESV | Reserved. Do not connect. |
| 23 | SCL | I2C serial clock (SCL) |
| 24 | SDA | I2C serial data (SDA) |
| 2,3,4,5,14,  15,16,17 | NC | Not internally connected. May be used for PCB trace routing. |

Table 17. Pin Number, Pin Name and Verification of MPU-6050 module

**Connection between GPS Module and Control Module**

|  |  |
| --- | --- |
| **MPU6050** | **STM32** |
| GND | G |
| VCC | 3.3V |
| SCL | PB8 |
| SDL | PB9 |

Table 18. Pins Connection between MPU6050 and STM32F103C8

**3.Cost Analysis & Schedule**

**3.1 Cost Analysis**

**3.1.1** **Hardware Component Cost Analysis**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Description | Cost per unit | Number | Others |
| MPU6050 | Sensors Module | ￥13 | 1 | N/A |
| ESP8266 | Wi-Fi Module | ￥28 | 1 | N/A |
| NEO-6M | GPS Module | ￥42 | 1 | N/A |
| Stm32F103C8T6 | Control Module | ￥11.3 | 1 | N/A |
| 18650 Battery | 5V | ￥45.9 | 2 | N/A |
| Resistor | N/A | ￥0.02 | 10 | N/A |
| Capacitor | N/A | ￥0.03 | 10 | N/A |

Table 19. Hardware Component Cost

**3.1.2** **Mechanical Component Cost Analysis**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Device | Description | Cost per unit | Rent Hour | Total Cost |
| Rent Bicycle | Tested Vehicle | ￥2/hour | 30 | ￥60 |

Table 20. Mechanical Component Cost

**3.1.3 Labor Component Cost Analysis**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Hourly Wage | Total Hour | Total Cost | Other |
| Yuhang Chen | ￥90 | 120 | ￥10800 | N/A |
| Yichen Li | ￥90 | 120 | ￥10800 | N/A |
| Jingyao Dai | ￥90 | 120 | ￥10800 | N/A |
| Yihang Yang | ￥90 | 120 | ￥10800 | N/A |

Table 21. Labor Component Cost

**3.1.4 Software Component Cost Analysis**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Description | Cost per Unit | Number | Others |
| Server Rent | Vlutr | $5 | 1 | Per month |

Table 22. Software Component Cost

**3.2** **Schedule**

|  |  |  |
| --- | --- | --- |
| Date | Content | Member |
| 3/21-4/3 | Sensor testing | Zhengwei Dai |
| Server design | Yuhang Chen |
| Methods of feature extraction selection | Yihang Yang |
| Classification model selection | Yichen Li |
| Design Document and Design Review | Team |
| 4/4-4/10 | Connection between sensor and microcontroller | Zhengwei Dai |
| WIFI module building | Yuhang Chen |
| Design filtering and segmentation subsystem | Yihang Yang |
| Data input design | Yichen Li |
| Microcontroller Programming | Team |
| 4/11-4/17 | Detailed PCB design | Zhengwei Dai |
| Establishing connection between PCB and server | Yuhang Chen |
| Result presentation design | Yihang Yang |
| Model implementation design | Yichen Li |
| 4/18-4/24 | PCB building | Zhengwei Dai |
| Plan for data set collection and labeling | Yuhang Chen |
| Filtering and Segmentation subsystem implementation on server | Yihang Yang |
| Model implementation design on server | Yichen Li |
| 4/25-5/1 | PCB debugging | Zhengwei Dai |
| Data set collection and labelling | Yuhang Chen |
| Yihang Yang |
| Yichen Li |
| 5/2-5/8 | PCB debugging | Zhengwei Dai |
| Server maintenance | Yuhang Chen |
| Filtering and Segmentation subsystem assessment | Yihang Yang |
| Classification model assessment | Yichen Li |
| 5/9-5/15 | PCB debugging | Zhengwei Dai |
| Server maintenance | Yuhang Chen |
| Classification subsystem optimization and debugging | Yihang Yang |
| Yichen Li |
| 5/16-5/22 | Final testing and debugging  Prepare for presentation | Zhengwei Dai |
| Yuhang Chen |
| Yihang Yang |
| Yichen Li |

Table 23. Schedule for the project

**4.Ethics and Safety**

**4.1 Ethics**

In the development and use of our project, we must avoid violating ethical breaches. Since our device has GPS positioning function and position is a kind of personal privacy, we must comply with 7.8 IEEE Code of Ethics Section1.1 [6] and ACM Code of Ethics 1.6 [7] to strictly protect the privacy of users, collect only the minimum amount of necessary personal information, prevent accidental data leakage, and timely disclose factors that may endanger the public or the environment.

Moreover, because our data will help users determine the driving route, we must comply with ACM code of ethics 2.9 to establish a safe system to avoid problems caused by system vulnerabilities or unexpected data tampering. The wrong route may affect driving comfort and even safety. We should conduct due diligence and provide appropriate guidance and remedial measures in case of problems.

**4.2 Safety**

Our equipment has some potential safety problems that must be solved in the development process. Our device uses lithium batteries to provide electricity. According to “Safe Practice for Lead Acid and Lithium Batteries” Section III, because lithium battery can provide high current, if it continues to work at high temperature, the battery may be ignited, resulting explosion or fire. Therefore, in the process of using the battery, we must strictly abide by the specifications of the battery, which ask us to operate at an appropriate voltage and temperature, and always pay attention to the temperature of the battery to reduce the risk of personal injury or property loss caused by overheating.

Since our device is fixed on the vehicle, the firmness between the device and vehicle is a safety issue that we must consider. If the sudden acceleration or deceleration will cause the device to fly out, it may injure users or pedestrians and lead to a threat to health. Therefore, we will design a fixed support with reasonable structure and materials to fix the equipment. And we will test the firmness of the equipment under different speeds and accelerations to ensure the safety during use.

**5.Reference**

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