**Low-cost sensor for seamless road quality monitoring**

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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. But the problem is that the road condition is changing all the time, but we can't get the information of real-time road condition. Because the traditional road monitoring is carried out regularly through special vehicles, and 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**

• The battery of the device needs to have a large capacity to provide enough power to operate normally for long-time driving.

• 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

描述已自动生成**

**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.

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| **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

**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.

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| **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

**2.2.3 Road Anomalies Detection Subsystem**

**Description:**

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. What we need is the acceleration in vertical direction or z-axis, and greater vibration amplitude and frequency occurring in such signal denotes worse road condition for vehicles.

According to Newton's second law: A (acceleration) =F (force) /M(mass) . We can obtain the acceleration of a given mass by measuring the force F with piezoresistors. The essence of the acceleration sensor is to cause the deformation of sensitive components inside the sensor through the force, and the corresponding acceleration signal can be obtained by measuring its deformation and converting it into voltage output with the relevant circuit. Our accelerometer will consist of a movable mass, some reed that connect and constrain the mass to balance the force F, and electrodes to convert force to electric signals.

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.

1. **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 [1]. 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.

1. **Magnetometer**

Magnetometer is an optional sensor that could be applied so as to exclude interference in horizontal directions or x-y plane. It is obvious that gyroscope data variation caused by taking turns will not contribute to our detection for road condition. But if the vehicle wobbles due to potholes on the road surface, the changes of gyroscope then become meaningful. Magnetometer can monitor changes in the horizontal direction based on mistors whose value will change according to its relative direction to geomagnetic field. Since nowadays 6-axes sensor modules that combine two kinds of sensors (accelerometer and gyroscope) are more prevalent and convenient, the application of magnetometer can be tedious and fallible to some extent. Also, GPS system can provide similar information alternatively. Therefore, the magnetometer is optional and not necessary.

**Requirement:**

1. **Interference Immunity**

We consider two types of interferences: environmental and kinematical.

One of the factors that count for the accuracy of accelerometers most is temperature. Capacity accelerometers are more immune to temperature changes, thus becoming a better choice. Meanwhile, the application of gyroscope and filter algorithm lowers the error of vehicle motion as far as possible kinematically.

1. **Low cost**

We consider cost of sensors and further how sensor usage contributes to cost of our whole project.

6-axis sensors in China is relatively cheap. For example, MPU-6050 that contains a 3-axis capacity accelerometer and a 3-axis gyroscope is sold for no more than 100 yuan. More budget though an extra magnetometer requires, it can raise overall accuracy of our detection, thus available to be attached to transportations of lower cost, such as electromobiles and bicycles. Therefore, the cost requirement can be achieved.

1. **Appropriate sensitivity**

High sensitivity does not necessarily mean high accuracy of final results, since it might record too many undesired signals.

The sensitivity of capacity accelerometer lies between piezoelectric accelerometer and servo accelerometer. Due to lower sensitivity, piezoelectric accelerometer can hardly monitor continuous variation of acceleration. Worse still, all three-axis acceleration data were close to 0 g when the vehicle was in temporary freefall while entering or exiting the potholes, but in that case a piezoelectric accelerometer will be out of function [2]. by contrast, the sensitivity of servo accelerometer can be too high to come to an effective result. In conclusion, the capacity accelerometer widely used in mobile phones is also optimal in terms of sensitivity consideration.

1. **Space Limit**

Undoubtedly, the volume of sensors cannot be too large for our vehicle.

We would like to limit the size of 6-axis sensors, so that it occupies less space. MPU-6050, for instance, is a rational option. It has super mini package size, which is 4x4x0.9mm, about the same size of any used chip on the PCB board.

**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 a ATmega328 controller to receive the data from the accelerometer and GPS module and

send the data to the backend service using the WiFi module.

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| **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 3 RV for the Control Subsystem

**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.

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| **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 4 RV for the WIFI Subsystem

**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 [4], an 11th-order Butterworth high-pass filter with a cut-off frequency of 2 Hz can be applied to solve this problem.

**Requirement:**

1. **Exclude Unrelated Factor**

The abnormal pattern in the signal sequence should not cause 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.

1. **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.

**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 [5].

**Requirement:**

1. **Keep Same Distance:**

Every signal segment should be corresponding to the road segment with the same length. An algorithm 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.

1. **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

1. **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 apply exclusion algorithm. The time cost should be significantly reduced.

**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:**

1. **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 accelerometer. The abnormal pattern should be obvious from the view of people.

1. **Sufficient Training Set:**

The training set, which has high quantity and variety should be collected. 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.

1. **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.

1. **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.

**3.Ethics and Safety**

**3.1 Ethics**

In the development and use of our project, we must avoid violating the ethical breaches in the project. 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. And we should conduct due diligence and provide appropriate guidance and remedial measures in case of problems

**3.2 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, result in 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.

**Reference**

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