Wireless Sensor Network for Safe Transportation

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Abstract

Since dangerous goods have special physical and chemical properties, they can easily produce explosion, fire, poisoning and other accident due to a traffic collision or hazardous leak under a complex transport condition. Compared with ordinary traffic accidents, accident of dangerous goods transportation has greater risks and subsequent influence. Due to the huge transportation equipment and high freight volumes, once the accident occurred, it will be difficult to deal with the danger in the first place.

Faced with such a grim situation, this paper develops a system to achieve real-time monitoring of dangerous goods transportation based on wireless sensor network (WSN). Combined with different kind of sensors, wireless communication technology and data fusion technology, a real-time monitor system is developed for dangerous good transportation. In addition to real-time monitoring, the system can analyze the state parameters obtained to check whether the vehicle is in a safe condition.

The system has a real-time tracking, monitoring and early warning function which has important significance in curbing accidents and lowering the accident loss as far as possible.

**Keywords** Wireless sensor network, transportation, real-time
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Chapter 1 - Introduction

This thesis presents the system aiming to monitor the vehicles conveyed dangerous goods in real-time. The WSN (wireless sensor network) based system would check if there is leakage of the dangerous goods, strenuous vibration or anything wrong with the vehicle itself. Were these to happen, warning system will notify the driver to stop in time to check and at the same time, the system will also store the data in the terminal for late vehicle diagnostics or accident responsibility confirmation purposes.

1.1 Background

With the rapid development of the economy, a sharp increase in demand for transportation of dangerous goods across the world. Road Safety is a major societal issue. In 2011, more than 30,000 people died on the roads of the European Union, i.e. the equivalent of a medium town. For every death on Europe’s roads there are an estimated 4 permanently disabling injuries such as damage to the brain or spinal cord, 8 serious injuries and 50 minor injuries. [1]

Figure 1-1 Road fatalities in the EU since 2001
Due to the inherently physical and chemical properties of dangerous goods sensitive, chemical reaction occurs, combustion and explosion are easy to occur in case of special transport conditions such as high temperature, vibration, friction, etc.

In October 6, 2012, Hunan China, a serious traffic accident happened, caused by leaks of liquefied petroleum gas tankers. LPG tanker suddenly exploded, which killed three fire officers.

According to statistics, the loss caused by the transport of dangerous goods amounts to 50 billion dollars every year around the world. Once the accident occurs, such as toxic gas leak, explosive, tanker burning and explosion, major accident might be triggered off in case of these accidents, often led to huge casualties, economic losses and environmental pollution.

Therefore, safe transportation of dangerous goods has been a popular issue of global concern. Dangerous goods refer to substances that could do harm to human, other living organisms, environment or property. The classification of dangerous goods follows the “ADR, Agreement, concerning the International Carriage of Dangerous Goods by Roads” of 30th September 1957. [2]

On the macro front, relevant laws and regulations and regulatory agencies are dedicated to the management of dangerous goods transportation company to develop stringent industry standards and certification, provide training for dangerous goods operators, and give them regular review and assessment to test whether all the requirements were met. [3]

Currently, the United States and European countries are active in the establishment of relevant regulatory agencies. For instance, the American Chemical Transportation Safety Board and the National Rescue Center, the two agencies cooperate with each other to provide 24-hour support services.
for the accident emergency personnel, the shipper and the staff to handle
dangerous goods. At the same time the federal law stipulates that emitting
hazardous substances into the environment in excess of certain amount must
be reported to the national rescue center. [4]

But up to now, awareness and management in this area are basic staying at
the management mechanism and accident analysis stage, research for the safe
transportation systems of dangerous goods and related technology should be
further improved, only in this way the dangerous goods transportation
accident can be reduced fundamentally.

For the microscopic technical aspects, ITS (Intelligent Transportation System)
is applied for control.

![Figure 1-2 A vivid description of ITS](image)

Some developed countries have leading technology in terms of dangerous
goods transportation monitoring. Meanwhile, they also have a lot of
experience and research results at the application layer. Such as some projects carried by Japan and the United States mainly include: heavy-duty trucks (vehicle rollover warning and control systems, driver fatigue alert system, electronic brake systems, etc.), special vehicle (lane departure system), and intersection collision avoidance system (turn left route suggestions, warning signals and the lateral spacing suggestion). RAE Company has developed a detection unit for liquefied natural gas, liquefied petroleum gas and other flammable gases; French company THALES developed an equipment to detect the impact acceleration. The development of these technologies provides a strong support for improving Car monitoring capabilities.

1.2 Summary of Contribution

This paper conducts a detailed research on safe transportation of dangerous goods, and finally designed a system based on WSN architecture.

This thesis has following objectives:

(1) To clear and define the research object in the field of safe transportation for dangerous goods. While vehicles running at high speeds, vehicle collision, leakage, hazardous chemical reaction itself and some other factors can lead to accidents. However, due to limitations of space and the lack of sensors, monitoring every detail of the vehicle is unrealistic. So, how to identify the factors which could most likely let to the accident in many predisposing factors and provide efficient real-time monitoring is a prerequisite for the system design.
(2) To do a deep study about WSN technology (wireless sensor networks), sensor data fusion and display, the sensor wiring technology and the wireless sensor communication by WiFi.
(3) To design a monitoring for safe transportation of dangerous goods based on microcontroller unit chip. The system can do real-time monitoring of
the target, if the monitored parameter of the target exceeds the threshold, the alert notification check and record the current driver information. If the accident occurred, the system informs the center to take action immediately.

1.3 Thesis organization

The above parts give the introduction, background and summary of contribution of the thesis work. Next, the organization of the thesis will be introduced.

In Chapter 2, we will list different kinds of platforms, sensor devices and research methods which are commonly used at present and analyze all the given methods and devices. Then appropriate devices and methods will be selected and the reason why choose them are also explained. For example, we would present all the methods used to measure the acceleration, as well as different accelerometers. Finally I choose one accelerometer and list its advantages.

Chapter 3 mainly describes how we design the system and achieve all the functions. The chapter will demonstrate the operating principle of the selected sensors work, how to integrate these sensors onto WSN platform and how to make the integrated system output proper sensed data.

Chapter 4 summarizes the contributions of the thesis work and sums up all the realized functions by the designed system. This chapter also illustrates what kind of future work can be done related to the thesis work.
Chapter 2 - Fundamental Architecture, Device and Technology

2.1 Introduction to WSN Architecture

The development of wireless sensor networks has experienced two phases: sensor phase, wireless sensor network phase.

The first stage: during the last decade of the Cold War, the US military continuously strengthen the role of wireless sensor network in the war. For example, the cooperative engagement capability (CEC) system is one of the earliest networks centric warfare (NCW) systems used by American navy and remote battlefield fighting sensor system are the most typical applications of wireless sensor networks applied in war. Now with the development of Very Large Scale Integration (VLSI), miniaturization sensors and even micro-sensors have emerged. They play a vital role in the fields of communication, health care, education, business, etc. The WSN technology was voted as one of the 21st century’s most influential technology by Business Week.

Second stage: since the start of the new century, sensor networks have made encouraging progress in ad hoc networks and low power consumption. These technological improvements make it easier for wireless sensor networks to access to all areas of society easier. Among them, in fighting terrorism, medical and aerospace, WSN has demonstrated irreplaceable advantages. Now, wireless sensor networks are widely used in all aspects of society, such as environmental monitoring, automation, health care, and traffic transportation control.
Wireless sensor network (WSN) is a research focus in modern frontier science field which possesses features such as multidisciplinary, cross-domain and knowledge integration. It applies different kinds of technologies, such as sensor, embedded architecture, network technology, wireless communication and distributed processing technology. Through all kinds of integrated sensors collaboration, WSN realize real-time sensing, monitoring, and information collecting about the environment. This information is transmitted wirelessly to the user terminal in multi-hop network, ultimately realizing triple world connection, the computing world, the physical world and the human world.

Basic components of wireless sensor networks include the following four basic elements: sensing unit (with analog-digital conversion module), processing unit, the communication unit and power supply. Different kinds of sensors monitor physical or environmental conditions cooperatively in different locations. Then each node will preliminary process the collected information by processing unit and transmit them to terminals.
Figure 2-2 WSN platform designed by iPack

The above picture is a WSN based platform designed and manufactured by iPack center of KTH in 2012. From the picture we can see the main sensor node and sub sensor node. Besides, this platform also has GPS antenna, PC terminal and remote server.

The figure below shows how the system works and communicates with people. The main node can send data to the server by the GSM module and the user can use the PC terminal to acquire the data from server. Users could also use mobile terminal to read data from WSN platform and send the control information to it by SIM card integrated in the platform.
2.1.1 Introduction to Main Control Chip

This thesis applied Arduino as the control platform. Arduino is an open-source physical computing platform based on a microcontroller board, and a development environment for writing software for the board. It's a tool for making computers that can sense and control more of the physical world than your desktop computer. There are many other microcontroller platforms available for physical computing. Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, and all of them offer similar functionality. All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but it offers some advantages over other systems: Inexpensive, Cross-platform, Clear programming environment, Open source and extensible software. [5]
The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; it can be simply connected to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus. [5]

For the 8-bit ATmega Microcontroller, below are the pin maps and features:

![Pin map of ATmega328 microcontroller](image)

**Figure 2-5 Pin map of ATmega328 microcontroller**
2.2 Methods of measuring acceleration

Some vehicles such as tankers filled with liquids, heavy-duty trailer, etc. because of its high center of mass location, size and quality of the larger and relatively narrow track width and other characteristics, rollover occurs easily. With dangerous goods in these vehicles, body vibration and other factors may have a significant impact on traffic safety. In recent years, with the rapid development of highway transportation, dangerous goods explosions and vehicle rollover accidents are common due to body vibrations. Therefore, it is necessary to do real-time monitoring for the posture of the vehicle (turning inclination, vibration and acceleration).

Vehicle rollover means that vehicle rotating about the longitudinal axis with the angle of 90 ° or more when moving, so that the body comes in contact with the ground. Vehicle rollover is generally divided into two types:

Tripped rollover: lateral slip occurs when running, hit an obstacle on the road side and then "stumble."

Curvilinear motion leading to rollover: When the lateral acceleration of the vehicle exceeds the threshold, it will make the vertical reaction force of the inside wheel to zero so that rollover occurs.

Therefore, we need measure the acceleration of the vehicles to monitor its state.

2.2.1 Classification of the accelerometer

There are various types of accelerometers. Each technology has its own opportunities and problems.
**Piezoelectric Accelerometer**, it is a kind of inertial sensors. The operating principle of the piezoelectric accelerometer is to use the piezoelectric effect of certain materials, such as piezoelectric ceramic or quartz crystal.

The piezoelectric effect is that “when external force applied to the crystalline materials with no inversion symmetry, it will change the polarization state of the crystal in addition to deformation, and establish an electric field inside the crystal.” Using mechanical force to polarize the materials is known as piezoelectric effect.

![Piezoelectric Accelerometer](image)

**Figure 2-6 piezoelectric accelerometer**

When vibration occurs, the force applied to the piezoelectric material caused by the mass will change. If the vibration frequency is lower than the natural frequency of the accelerometer, the force of change is proportional to the measured acceleration. The force change on the piezoelectric element can be observed in the change of voltage.

Piezoelectric accelerometer generally have a wide frequency, wide range, small size, light weight, simple and solid structure, almost free from outside interference and generating charge signal without any external power supply, etc. The main drawback is that it cannot measure zero frequency signals.
Piezoresistive accelerometer

Piezoresistive accelerometer is also a kind of inertial sensors. The operating principle of the piezoresistive accelerometer is to use the piezoresistive effect of semiconductors or metal. The piezoresistive effect is a change in the electrical resistivity of certain materials when mechanical force is applied. Compared to the piezoelectric effect, the piezoresistive effect causes a change only in electrical resistance, not in electric potential. [6]

Piezoresistive accelerometers include a mass suspended by a spring and a piezoresistor on a cantilever beam. The schematic of Piezoresistive accelerometer is shown in figure 2-7.

![Piezoresistive accelerometer](image)

Figure 2-7 Piezoresistive accelerometer

Vibration-induced movement of the proof mass deflects the beam, which changes the resistance of the embedded piezoresistor. The electric signal generated from the Piezoresistive patch and the bulk device due to vibration is proportional to the acceleration of the vibrating object. [6]

The advantage of piezoresistive accelerometers is the simplicity of the structure, small size, wide range, simple fabrication process, as well as the simple readout circuitry. However, piezoresistive accelerometers have a relatively high sensitivity to temperature so that it requires temperature
compensation. And compared to capacitive sensors, it has smaller overall sensitivity, so that they need a large proof mass.

**Capacitive accelerometer**

Capacitive accelerometer is a type of pole distance changing capacitive sensor based on the capacitive principle. One of the electrodes is fixed while another electrode is a moving elastic diaphragm. The elastic diaphragm would take place displacement when mechanical strain is applied, which will lead to the capacitance change. This sensor can measure the vibration velocity, acceleration, and calculate the force if necessary.

![Capacitive accelerometer diagram](image)

Figure 2-8 capacitive accelerometers

Its advantage is quite prominent, high sensitivity, zero frequency response, good noise performance, relatively low temperature sensitivity, low-power cost, and simplicity of the structure. These features make them attractive for machine integrations. However, disadvantages are also prominent: The range is limited and itself is a high-impedance source, subsequent circuit needed to improve this.

**2.2.2 Comparison of the accelerometer**

According to the above introduction of the three kinds of accelerometer, each of them has its own advantages and problems. This thesis work needs to select
the most suitable one, so a comparison is done among accelerometers introduced above.

<table>
<thead>
<tr>
<th></th>
<th>Piezoelectric</th>
<th>Piezoresistive</th>
<th>Capacitive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency Range</strong></td>
<td>No zero-frequency response</td>
<td>zero-frequency response</td>
<td>zero-frequency response</td>
</tr>
<tr>
<td><strong>measurement range</strong></td>
<td>Very wide</td>
<td>Relatively wide</td>
<td>Limited but enough</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>Relative high</td>
<td>Relative high</td>
<td>Highest</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>High</td>
<td>Relative high</td>
<td>High</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>Stable enough</td>
<td>Sensitive to temperature</td>
<td>electromagnetic interference</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Relatively small</td>
<td>Not so small but enough</td>
<td>Smallest</td>
</tr>
</tbody>
</table>

Table 2-1 comparison of the accelerometer

As the system should be able to measure both the static and dynamic accelerations, piezoelectric accelerometer is excluded due to its no response to zero-frequency. Compared to capacitive accelerometer, piezoresistive accelerometer has a high sensitivity to temperature. Therefore, the capacitive accelerometer is the best choice. Besides, capacitive accelerometers have high sensitivity, shorter response time and less sensitive to environment factors, such as temperature and humidity. All of these features are quite important and necessary for a system designed for vehicles.

So we choose two accelerometer chips, ADXL335 and ADXL345, both of them are capacitive accelerometers. The main difference between the two
accelerometers is the output signal. ADXL335 is a kind of analog output device while the output signal of ADXL345 is digital. Because out platform has its own AD converter and I2C interface, it supports both digital and analog output. We could integrate both of them onto my platform to test their performance.

### 2.3 Methods of measuring alcohol

There are five basic types of equipment that can detect and measure the alcohol in air, namely: fuel cell, semiconductor, infrared, gas chromatographic analysis and colorimetric type. Due to the price, easy-to-use and some other factors, currently the fuel cell type and the semiconductor type are the most widespread used alcohol sensors. These two types could be fashioned into a portable alcohol tester, suitable for field application.

**Semiconductor type**

Semiconductor type use gas-sensitive semiconductor as the sensor, such as SnO2. This type of semiconductor device has gas sensing property. The resistance value of this device would decrease alone with the increase of the certain gas concentration. The semiconductor-type alcohol sensor is designed following this principle.

Figure 2-9 shows the schematic of the semiconductor type alcohol sensor. A-B is the sensor and H is the heater. As the alcohol gas concentration arises, the electric resistance of A-B will decrease. Accordingly, the output voltage which is known as the voltage of the RL would increase. The change of the output voltage is proportional to the change of the alcohol gas strength.
This kind of semiconductor sensor has different gas sensitivity at different operating temperatures. Therefore, the semiconductor-type alcohol tester needs the heating element to take the sensor to a certain temperature, at which the sensor has the highest sensitivity for the alcohol.

**Fuel Cell Alcohol Sensor**

Fuel cell alcohol sensor is also regarded as electrochemical type sensor due to using fuel cell as the gas-sensitive material. The fuel cell is an environmental friendly energy source which is currently being extensively studied by the world. It can convert the combustible gas into electrical energy directly, without producing pollution.
Alcohol sensor is an important research branch of the fuel cell. Fuel cell alcohol sensor use noble material platinum as the electrode, the combustion chamber is filled with special catalysts, which enables the alcohol going into the combustion chamber from outside fully combusted into electrical energy. The electrical energy generates voltage between the two electrodes, and the power is consumed in the external load resistor. This voltage is proportional to the alcohol gas concentration that going into the combustion chamber, which is the operating theory of the fuel cell alcohol sensor.

2.3.1 **Comparison of the alcohol sensor**

Compared with the semiconductor-type sensor, fuel cell alcohol sensor has good stability, high accuracy, and good anti-jamming property. Unfortunately, on one hand it is difficult to manufacture the fuel cell alcohol sensor due to its high precise structure requirements. Currently only a few countries can produce it. And because of the high costs of the materials (dozens of times more expensive than the semiconductor-type alcohol sensor), the price of the fuel cell sensor is quite expensive.
On the other hand, the SnO2 based semiconductor-type alcohol sensor also has high enough sensitivity for the alcohol, rapid response time, long life time, low power consumption and small size. Considering all the factors, we decide to integrate semiconductor-type sensor to my platform.
Chapter 3 - System Design and Test

In this chapter, first we would present the requirements of the system. Then detailed description of each module of the system will be addressed, which contains the working principle of the selected sensors, how we control them by coding and the final output of each module. The last section demonstrates how we achieve the wireless sensing function, including the basic information of the WIFI module and how we integrate it onto the platform.

3.1 System Design Requirements

During the whole design process, we have the following key requirements:
1: Output accurate acceleration data in certain frequency and store them
2: Output alcohol concentration and realize alarm function in case of higher than certain concentration
3: wireless control and wireless data sending and receiving

3.2 Introduction to Acceleration Sensor ADXL335

As stated before, most accelerometers can be classified into two categories: digital and analog. In my work, I introduce both of the digital and analog accelerometers and discuss how to integrate and control them on my platform in detail. We mainly present the specific working theory of these two kinds of acceleration sensors and how to control them in this chapter.

ADXL335 is a kind of analog accelerometer; it outputs the voltage in a predetermined range. Analog-to-Digital circuit should be contained to convert the output into a digital value, and we also need to program to convert the digital value into accurate acceleration value. All the above will be demonstrated in the following chapters.
The ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. [7]

![Functional Block Diagram](image)

**Figure 3-1 ADXL335 functional block diagram**

Its basic working process is: firstly the micro 3-AXIS sensor is used to sense the acceleration, then amplify the collected three-dimensional AC signal and demodulates the signal respectively, amplified the three signals again at the output respectively, finally output the analog voltage proportional to acceleration after filtering.

The output is amplified through a 32 kΩ resistor. Adding a capacitor can set the signal bandwidth of the device, with a range of 0.5 Hz to 1600 Hz for the X and Y axes, and 0.5 Hz to 550 Hz for the Z axis. This filtering circuit improves the resolution of measurement and prevents aliasing.
For sensing the X, Y, and Z axes, the ADXL335 uses a single structure. Therefore, the three axes’ sense directions are highly orthogonal and have little cross-axis sensitivity. Mechanical misalignment of the sensor die to the package is the chief source of cross-axis sensitivity. Mechanical misalignment can, of course, be calibrated out at the system level. [7]

Without introducing temperature compensation circuit, the high performance is built in the ADXL335 by innovative design techniques. Therefore, there is no monotonic behavior or quantization error, and the temperature hysteresis is quite low.

**3.2.1 Integration of the ADXL335**

After discussing the features, function blocks and specifications of ADXL335, we need to demonstrate how to integrate this accelerometer onto my platform and how to control it in detail.

The picture below shows the pad employed in my thesis. From the picture we can see that it has five pins, X_output, Y_output, Z_output, GND and VCC. The ADXL335 MEMS accelerometer from Analog Devices is placed in the middle of the pad. As we mention before, the demodulator output is amplified and brought off-chip through the resistor on this pad.
There are three steps to make this device work, solder the wire to pin and connect it with my board, program to convert this analog voltage to gravity amount and calibrate the output, use trigonometry to calculate a true ‘angle’ and display the final output on a graph.

The first step is to connect the accelerometer with the arduino board. Initially, five pins should be soldered to the output of the accelerometer pad. Next we could wire the pins of the pad to the corresponding pins on the board, ‘+’ to VCC on the board, ‘-' to GND on the board, X, Y and Z to three different analog pins on the board. It is because the accelerometer pad outputs a 0V to 3V analog signal of the X, Y, and Z axis.

After connected the pins of the pad to the board, the second step is to program the board to receive and display the analog signal from the accelerometer, as well as convert these analog values to gravity amount correctly.
In the program, we set the analog pins which attached with the accelerometer into input mode and use the analogRead command to convert the input voltage range, 0 to 5 volts, to a digital value between 0 and 1023. This job is done by a circuit inside the board named an analog-to-digital converter. As we discussed before, there are six channels ADC and they have 10 bit resolution.

Actually, the most important part in the step 2 is to calibrate the output of the accelerometer. In other words, convert the digital value which is converted from the voltage output, to the correct gravity value. We would not change the output in this step what we do is to translate the sensor output into certain acceleration in both directions on each axis following a known stable reference force. We use gravity as the calibration reference and determine the sensor output for every axis when it is precisely aligned with the axis of gravitational pull. Below is the axes of acceleration sensitivity.

![Axes of acceleration sensitivity](image)

Figure 3-3 Axes of acceleration sensitivity

I take the Z-axis for an example. The connection between the output of the Z-axis and the orientation of the gravity is described in below figure 3-4.
Firstly, lay the accelerometer on a firm flat table and load the calibration sketch below and open the monitor. It will give the output digital value converted from the voltage value of the pin, which represent 1G force on Z-axis.

```
void loop()
{
  int tenTot = 0;

  for (int i=0; i<readingsPerSample; i++)
    //repeat number of times defined in setup
    {
      zval = analogRead(zPin);  //take single reading
      tenTot = tenTot + zval;   //add up readings
      delay(readingDelay);
      //delay between readings as defined in setup.
    }

  one_G = (tenTot / 10);  
  Serial.print("one_G :");
  Serial.print(one_G);
}
```

It tells that when one G force on the Z-axis, the output digital value is:

one_G : 618
Next we need to determine the zero\_G of the Z-axis. I should make the accelerometer stand on a firm flat surface vertically then the acceleration on the Z-axis should be zero. It is hard to make it vertical to the ground because the accelerometer pad is circle. I achieve it by using a machine in below picture from the laboratory of the Embedded System Department of KTH, shown in figure 3-5.

![Figure 3-5 calibration of the pad](image)

Load the similar sketch as we used to determine the one\_G, we could get the value of the zero\_G of the Z-axis:

\[
\text{zero\_G} : 517
\]

So we can get that 1G range of the Z-axis is:

\[
1G = \text{one\_G} - \text{zero\_G} = 618 - 517 = 101
\]
Now that we could convert the raw output to G’s in the program as follows. Let assume ‘a’ be the acceleration on an axis in Gs and ‘b’ be the actual output we got from the corresponding pin. Then

\[ a = \frac{b-517}{101} \]

All we talked above is about how we convert and calibrate the output of the Z-axis. The similar methods are used to determine the output for X-axis and Y-axis:

\[ X_{out} = \frac{b-504}{112} \]
\[ Y_{out} = \frac{b-507}{112} \]

The third step is to calculate a true ‘angle’ with trigonometry and display the final output on a graph. In the below picture, different colors are used to represent each axis.

We assumed that the vector R is the value measured by the accelerometer. R(x,y,z) are projections of the vector R on each axis. They follow below principle:
\[ R^2 = RX^2 + RY^2 + RZ^2 \]

It is equivalent to the Pythagorean Theorem in three dimensional spaces. In the model, Rx, Ry and Rz are linearly related to the values that the accelerometer will output and you can use them for various calculations. We have already talked about how to convert the digital value into acceleration value. If we just need the inclination of the device to the ground we could only calculate the angle between the vector R and Z axis. If we also want to know the inclination of the other two axes we also could calculate the angle between the gravitation vector and X or Y axes. We go back to the last picture of accelerometer model and add some more notations: [8]

We are interested in the angles between the three axes and the vector R, Axr, Ayre and Azr. We can easily get that:

\[
\cos (Axr) = \frac{Rx}{R} \\
\cos (Ayre) = \frac{Ry}{R} \\
\cos (Azr) = \frac{Rz}{R}
\]

And \( R = \sqrt{Rx^2 + Ry^2 + Rz^2} \)

Now we could get the angels that:
Till now, we have already successfully integrated the ADXL335 onto the platform and programmed it to output accurate acceleration and angles. For the display, graph and wireless control part, we would discuss them in a single part alone. [8]

### 3.3 Introduction and Integration to the Acceleration Sensor ADXL345

ADXL345 is a kind of digital accelerometer; it will give the output by a serial protocol like I2C, SPI or USART. We need to program to read output by serial protocol instead of form ADC modules.

The functional block diagram of the ADXL345 is shown in figure 3-8. Both the ADXL335 and ADXL345 have a 3-axis capacitive sensors and the work principal of the sensors is similar. However, ADXL345 has some unique modules, such as integrated ADC, digital filter, FIFO and serial I/O.

![Figure 3-8 ADXL345 function block](image)
Compared with ADXL335, we also need three steps to integrate the ADXL345 onto the Arduino board and make it work.

The first step is almost the same; a row of pins to be soldered to the output of the ADXL345 pad. Next we just need to plug the pad into a bread board and wire the board with the Arduino platform. For power and ground, ADXL345 has the same pin VCC and GND as the ADXL335. For the output, instead of outputting three acceleration related voltage for each axis as ADXL335 do, ADXL345 can convert the sensor value to digital value by its own integrated ADC and send accurate acceleration to the FIFO. So we don’t need to convert and calibrate the value as what we do to ADXL335. What we need to do is to access the FIFO and read the acceleration value in it to display them.

Below is the picture of the ADXL345 pad used in the thesis. From the picture we can see that it has pins of GND, VCC, CS, INT1, INT2, SDO, SDA and SCL. CS is the chip selection pin. INT is the interrupt output. SDO is short for serial data output. SDA is data transfer bus and SCL is serial communication clock line used for synchronization and is controlled by the master.

Figure 3-9 ADXL345 pad used in this thesis
The second step is to program the accelerometer to output the accurate acceleration. Wire library should be used to achieve I2C communication. On the Arduino board, A4 and A5 pin support TWI (Two—wire Serial Interface) communication by wire library. TWI stands for two wire interface, which was invented by Philips. Below graph below shows how it works:

The data transmission of TWI is done in asynchronous. TWI uses two wires for communication between master and slave ICs. The two bidirectional open drain lines named SDA and SCL with pull up resistors are used for data transfer between devices. From the picture we can find that it has one master device that control the whole process and other slave devices respond to the queries of master. The ACK (acknowledgement) signal is sent/received from both the sides after every transfer and hence reduces the error. [9]

In my thesis work, SDA and SLC on the accelerometer should be connected to the A4 and A5 pins on the board respectively. Then we could start to program the board to get the accurate value.
Firstly, include the wire library and initialize the essential registers. The last six registers on the above picture (0x32-0x37) are all 8-bits and store the output data (twos complement) for each axis. However, when we output the acceleration data, the resolution is 10-bit. We need two registers for the each data of each axis, for example register_ox32 and register_ox33 each for the least significant byte and most significant byte of the data for X-axis.

After initializing the register, we need to write to and read from the register to get the acceleration data. Below is the sketch:

```cpp
#include <Wire.h>
#define Register_ID 0
#define Register_2D 0x2D
#define Register_X0 0x32
#define Register_X1 0x33
#define Register_Y0 0x34
#define Register_Y1 0x35
#define Register_Z0 0x36
#define Register_Z1 0x37

Wire.beginTransmission(ADXAddress);
Wire.write(Register_X0);
Wire.write(Register_X1);
Wire.endTransmission();
Wire.requestFrom(ADXAddress, 2);
if (Wire.available()<=2)
{
  X0 = Wire.read();
  X1 = Wire.read();
  X1=X1<<8;
  X_out=X0+X1;
}
```

From the above sketch, we can see that when we get the most significant byte of the data, we need to left shift 8 bits and add the least significant byte to it.
Only in this way can we get the intact 10-bit data. The above is just taking the X-axis for an example. We can get the data from Y-axis and Z-axis in the similar way.

Till now, we succeed in programming to control ADXL345, a kind of sensor with digital output, by I2C. The third step is to display the results. Some instructions like ‘serial.print’ can be used to display the data by serial monitor. For the wireless control and wireless send/receive data, I would talk about it in an individual part later.

3.4 Introduction and Integration of Alcohol sensor

The work mechanism of gas sensors is as follow: when semiconductor gas sensor contact with the measured gas, resulting in changes in semiconductor properties, then the concentration of gas can be detected by detecting the changed electrical performance caused by changed semiconductor properties.

In actual measurement, the gas sensor can be used to convert the composition or concentration of the target gas to the change of the resistance, voltage or current, and display on the terminal equipment through the corresponding measuring circuit.

Its sensing device is a gas-sensitive resistor, which is a kind of sintered semiconductor mixed with metal oxide (such as SnO2, ZnO, or Fe2O3, etc.) powder, a small amount of catalyst and additives by a certain ratio.

Gas-sensitive resistor sensors are often used in two types of experiments, the reducing gas component measurement and the gas concentration measurement, such as oil vapor, alcohol vapor, methane, ethane, gas, natural gas, hydrogen and other gases detection. Gas-sensitive resistor is a sensitive semiconductor device, and resistive semiconductor gas sensor is made due to the physical characteristics of the gas-sensitive resistor.
When it absorbs different gases, reduction reaction can occur, and then heat is released, so that the temperature of device will increase. The resistance will change due to the changed temperature, so that the gas composition and concentration can be transformed into electric signal. After amplification processing circuit, output the analog voltage proportional to composition or concentration of the target gas.

This thesis would use MQ-3 as the gas sensor of the system. Below is the circuit diagram of the alcohol sensor MQ-3:

MQ-3 alcohol sensor has high sensitivity and fast response for alcohol vapor. Moreover, compared with other types of sensors its drive circuit is simple and with high stability. Therefore, MQ-3 alcohol sensor commonly used in the detection of alcohol, and it can also be used to test other gas if needed.

Sensitive metal oxide material of MQ-3 is SnO2, which has lower conductivity in clean air. When exposed to the alcohol gas, the sensor’s conductivity changes with the gas concentration changing. The change of conductivity can
be converted to corresponding output signal of gas concentration. MQ-3 gas can be resistant to the interference of gasoline, smoke and vapor. It is with low cost and suitable for various applications of detecting alcohol at different concentration. [10]

In my work, three steps are required to make the alcohol sensor work well. The first also is wiring the alcohol sensor to the board. We can simplify this step by introducing the ‘gas sensor breakout board’. The MQ-3 has 6 symmetrical pins, three in each side. We could connect the MQ-3 sensor with the breakout board and insert the breakout board into the Arduino board. Below is the picture of the breakout board with alcohol sensor connected with.

![Breakout board with alcohol sensor](image)

Figure 3-12 breakout board with the alcohol sensor

Then both the A1 and H1 pins should be connected with the 5V pin on the board, GND to the GND pin on the board and A2 to two different pins, one is GND pin through a 4.7K resistor and other pin is an analog input pin on the board.

The second step is program to control the alcohol sensor. The main process is similar to what we did with the analog accelerometer ADXL335, which is programming to read values from the analog input pins to get the digital value converted from the integrated ADC on board.
The calibration of the alcohol sensor is quite complicated. Because when you want to map the output digital value to the concentration of the alcohol, you need to know the accurate concentration of the environment that the alcohol sensor located in. There are too many other factors affecting the concentration of the alcohol, because it is alcohol vapor and it is in the evaporation at anytime. Without certain professional machine, it is difficult to build an environment with stable concentration of alcohol to let you get stable output value. At present we can get the concentration of the alcohol with the help from the below picture given by the sensor manufacturer.

![Figure 3-13 output of the MQ-3](image)

The concentration (in ppm) of the alcohol is on the horizontal axis. For example, when the concentration of the alcohol gas is about 300 ppm the output voltage should be around 4V. Therefore, once we got the voltage value we could convert it into concentration by looking up this picture. Although this method may not be so accurate, it is also useful when applied to achieve safe transportation. We usually aim to realize alarm function instead of giving accurate concentration on devices for safe transportation.
The third step is to achieve wireless control and display in different format. We will explain how we achieve the wireless control in next part in detail.

3.5 Wireless control and remote display in graph

‘Arduino WiFi Shield’ is used in this thesis to make the board to connect the internet so that we could realize remote control the board and wireless displaying the results. It could be quite convenient if we could check the status of the environment where the board is located anytime and anywhere.

The Arduino board could access to the internet by the Wifi shield with 802.11 wireless specifications (WiFi). The WiFi shield is based on the HDG204-WiFi 802.11b/g System in Package. The 32-bit microcontroller AT32UC3 is applied on the WiFi shield to provide a network (IP) stack capable of both TCP and UDP. The WiFi shield connects to an Arduino board using long wire-wrap headers which extend through the shield. The WiFi Shield can connect to wireless networks which operate according to the 802.11b and 802.11g specifications. We need to introduce the WiFi library into the program to make the platform connected to the internet with the shield. [11]

For the wireless output and wireless checking the status, I proposed two different methods in this thesis. The first one is relatively simple, called IP checking. The other method connects the Arduino board with the Xively to realize web service access.

Firstly, we would talk about how to implement the IP checking. Three steps are used to realize it. The WiFi shield has its IP address. The first step is to connect the board to the internet. The second step is to build a HTML page using corresponding functions of client. The third step is to open the browser and type the IP address of the shield into URL field. Then we could check the status of our board.
Below is the sketch used to connect the board to the internet:

```c
#include <SPI.h>
#include <WiFi.h>

char ssid[] = "Chao";
char pass[] = "12345678";
int status = WL_IDLE_STATUS;

void setup() {
  //Initialize serial and wait for port to open:
  Serial.begin(9600);

  // check for the presence of the shield:
  if (WiFi.status() == WL_NO_SHIELD) {
    Serial.println("WiFi shield not present");
    // don't continue:
    while (true);
  }

  // attempt to connect to Wifi network:
  while (status != WL_CONNECTED) {
    Serial.print("Attempting to connect to WPA SSID: ");
    Serial.println(ssid);
    // Connect to WPA/WPA2 network:
    status = WiFi.begin(ssid, pass);

    // wait 10 seconds for connection:
    delay(10000);
  }

  Serial.println("Connected!");
}
```

Specify the name and password of the network you want the board to connect with. After connected successfully, the sketch below can be used to print the information and condition of the network status of the board attached to.
It will give the SSID of the current network, as well as the BSSID (MAC address), the RSSSI (signal strength of the connection) and the encryption type.

Then we could program another similar sketch to obtain the information of the WiFi shield, for example the IP address which we would use to visit the platform later. Below is the sketch for displaying information about the WiFi shield.
By uploading the above two sketches and open the monitor we could get the output below which contains the basic information about the current network and the WiFi shield.

```
Attempting to connect to WPA SSID: Chao
You're connected to the network SSID: Chao
BSSID: B6:1C:C4:82:A4:17
signal strength (RSSI):-20
Encryption Type:4

IP Address: 172.20.10.5
172.20.10.5
MAC address: 7B:04:F:2:95:08
```

The second step is to build a HTML page to show the output. We need to let our board output the status of the sensors on it when some clients access to the board. The below command is used to check if there is an incoming connection.

```
WiFiClient client = server.available();
```

If there is an incoming client, a HTML page should be created by printing functions of the clients.

```
client.println("HTTP/1.1 200 OK");
client.println("Content-Type: text/html");
client.println("Connection: close");
client.println();
client.println("<!DOCTYPE HTML>");
client.println("<html>");
client.println("<meta http-equiv="refresh" content="5"/>");
```

Then we could check the status of the sensors and use ‘client.print’ to display all the information we want to know on the page. And finally, we finish the page and stop the connection with:
After finished both the first two steps, we could implement the third step to check the status using IP address of the WiFi shield. Open the browser and type the IP address of the shield into the URL field. Then the final display could be achieved whenever and wherever users want.

Now, we begin to demonstrate the second method to connect the Arduino board with the Xively to realize web service access. This method will be more advanced and intuitive. It will not only give the final sensor values but also draw a graph for every output.

Xively is a division of LogMeln Inc (LOGM) which is a global company providing essential remote services. Xively is a platform as a service for the Internet of Things. It makes it easy for the interconnection of data, device and people. Its cloud services provide data archiving and directory services through the Xively API. In my thesis, two steps are needed to combine the Arduino board with Xively to realize remote check and display by web.

The first step is to connect the board with Xively platform which includes programming with Xively library and SPI library, definition of channel and data stream and Xively client creation.

Below is the very simplified sketch used to create the connection between the Arduino board and the Xively:

```cpp
client.println("<br />");
client.println("</html>");
client.stop();
Serial.println("client disconnected");
```
A few part of the code has been shown above. When we upload and open the serial monitor, the output will be as below:
We can get the ‘alcohol value’ which is in voltage and can be converted into concentration of the alcohol vapor. ‘Read Xout value’ represents the acceleration value of the X-axis and the unit is ‘g’.

When we use the ‘feed URL’ to access the Xively platform by browser, we could get the results in figure 3-15:
Actually, I get the above from my mobile phone browser. So you can check the status of WSN based system whenever and wherever you want. It will show the alcohol concentration and acceleration value on the screen when you access to the platform. For every output, the graph will be shown when you touch the tag.

Therefore, we meet all the requirements we present at the beginning of the thesis work.
Chapter 4 Conclusion and Future Work

4.1 Conclusion
This thesis completes the WSN based real-time monitoring system for safe transportation. To complete the system, the main work of the thesis has been done as follows:

Study about the status of transportation for dangerous goods and approaches on safe transportation to get the design requirements for the system to design. Conduct a detailed research on different kind of sensors and platforms to get the most suitable device for our WSN based system. Two kinds of accelerometers and alcohol gas sensor are selected to be integrated into our system. Among them we have both analog sensor and digital sensor. Therefore, a platform which can handle both digital and analog signal is built up successfully in my thesis work. If necessary, any other sensor can be integrated into the system easily. Finally, we achieve remote check which means you can access the system by internet whenever and wherever we want.

4.2 Future Work
The monitoring system proposed in the thesis for safe transportation is a kind of system based on wireless sensor network, WiFi communication technology and microcomputer control theory. Depth study is required from the underlying hardware connection and circuit design to software design and process. On the basis of the proposed system, I summarize the following potential improvements:

For the hardware part, as more kinds of sensors will be integrated into the system, the low-power design is becoming more important. Our system is powered by the vehicle battery, and power consumption needs to be reduced in the future design. The main methods are to use low-power electronic
components and optimize the system architecture, such as design sleep mode feature to ensure that the system will not work until it is necessary.

For the software part, develop corresponding software applications for smartphones. In this thesis, when you want to check the output data, you need to open a browser on matter on a computer or mobile phone. In the future, an application can be developed to make the monitoring process easier.
References


[3] Rodney E. Slater, U.S. Department of Transportation, the Changing Face of Transportation, Chapter 3-Safety


[9] I2C Interface or TWI (Two Wire Interface), http://www.engineersgarage.com/tutorials/twi-i2c-interface
