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Design and Development of a Dynamic Impact Detection System for Automotive Safety

Prof. N. R. Pathare
sarvapat@gmail.com
Assistant Professor

Pawan N. Bhople
pawanbhople4@gmail.com

Mayank D. Gadgilwar
gadgilwarmayank8@gmail.com

Sharvari J. Bite
sharvaribite2264@gmail.com

Shubham A. Malwe
shubhammalwe9@gmail.com

Avantika G. Kantode
avantikakantode02@gmail.com

Mechanical Engineering Department, Priyadarshini College of Engineering, Nagpur

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Abstract:

As we see these days, road accidents are increasing day by day, and in many cases the real problem is the delay in getting help on time. Many existing systems try to detect accidents, but most of them depend on a single sensor or simple threshold values, which can lead to false detection or missed events. Because of this, there is a need for a system that can detect accidents more reliably and respond without delay.

In this work, a multi-sensor based accident detection system is developed which considers both sensor data and the behavior of impact inside the vehicle. Multiple MPU6050 sensors are placed at different positions to observe acceleration and motion, while a force sensor is used to detect direct impact. An ultrasonic sensor is also used to provide early warning before collision. The system processes data from all sensors together and checks for sudden changes in acceleration, force variation, and consistency across multiple sensing points before confirming an accident.

Once an accident is detected, the system immediately activates a buzzer, triggers a relay-based cut-off mechanism, and sends an alert message using a GSM module. The system works continuously without manual input and provides a fast response after detection.

The results show that using multiple sensors reduces false alerts and improves detection accuracy compared to single-sensor systems. At the same time, the system remains simple and cost-effective, making it suitable for real-world use, including areas where advanced infrastructure is not available.

Keywords: Accident Detection, Multi-Sensor System, MPU6050, Force Sensor, Ultrasonic Sensor, GSM Module, IoT, Vehicle Safety, Impact Analysis, Emergency Alert System

I. Introduction

As we see these days, road accidents are increasing day by day. There are many reasons behind this, such as over speeding, sudden lane changes, and lack of attention while driving. But even after an accident happens, the biggest issue is the delay in getting help. Ambulances or emergency services often do not reach on time, and this delay leads to serious loss of life.

Because of this, many systems have been developed to detect accidents and send alerts automatically. Most of these systems depend on sensors like accelerometers and GPS modules. They try to identify accidents based on sudden changes in motion and then send location details through GSM. These approaches are useful, but they have some limitations. In many cases, they cannot clearly tell the difference between an actual accident and normal conditions like bumps or sudden braking. This leads to false alerts or missed detection.

Another point that is often ignored is how impact behaves inside a vehicle. When a crash happens, the force does not stay at one point. It travels through the structure, creating vibrations and stress in different areas. Most systems do not consider this behavior. They treat the vehicle as a single unit and depend on data from one location.

To address these issues, this work presents a multi-sensor based accident detection system. Instead of using a single sensing point, multiple MPU6050 sensors are placed at different positions of the vehicle. This helps in observing how the impact spreads across the structure. Along with this, a force sensor is used to detect direct impact, and an ultrasonic sensor is used to identify nearby obstacles before collision.

The system processes data from all sensors together and checks for sudden changes, consistency between sensors, and force variation before confirming an accident. Once detected, it sends an alert message, activates a buzzer, and triggers a cut-off mechanism.

The idea behind this work is simple. Instead of relying on one signal, the system looks at multiple signals and then makes a decision. This improves reliability and reduces false detection, while still keeping the system simple and practical for real-world use.

II. Literature Review

As we all see these days, road accidents are increasing year by year. One thing that keeps coming up in most studies is that the delay in emergency response is a major reason behind loss of life. Because of this, many researchers have worked on systems that can detect accidents automatically and send alerts without depending on people.

Early works such as [9], [13], and [7] focused on simple accident detection using accelerometers and GPS modules. These systems mainly detected sudden changes in motion and then sent location details through GSM. The idea was useful at that time, but the accuracy was limited. These systems could not clearly differentiate between actual accidents and normal conditions like potholes or sudden braking. Since they depended on a single sensor, the chances of false detection were higher.

With time, IoT-based systems started becoming more common. Studies like [2], [6], [11], [12], [15], and [19] used multiple components such as accelerometers, GPS modules, GSM communication, and controllers like Arduino or ESP32. These systems continuously monitored vehicle conditions and sent alerts with location details. The response time improved, and the cost remained affordable. However, most of these systems still relied mainly on threshold values of acceleration. Because of this, they could still generate false alerts in certain situations. Also, they focused more on electronic sensing and did not consider how impact actually behaves inside the vehicle.
To improve accuracy, some researchers started using multi-sensor approaches. Papers like [3], [10], [17], and [18] combined accelerometer and gyroscope data, and in some cases additional validation methods. By comparing data from different sensors, these systems reduced false alarms and improved reliability. For example, using both motion and orientation helped in identifying crash conditions more clearly. Even with this improvement, most systems still treated

the vehicle as a single unit. They did not look into how force and vibration travel through different parts of the vehicle body.

Another direction in research involves AI-based systems. Works such as [1], [4], and [5] used models like CNN and object detection techniques to detect accidents and even classify them. These systems achieved good accuracy and could handle more complex scenarios. However, they require higher computation, cameras, and stable connectivity. This makes them less suitable for low-cost vehicles or rural areas where such resources are not always available.

There are also systems focused on preventive safety features. Studies like [14], [20], [21], and [16] include alcohol detection, driver fatigue monitoring, and helmet safety systems. These approaches are useful in reducing the chances of accidents, but they do not focus on what happens after the crash. Their objective is different from impact detection and post-accident response.

From all these studies, one thing becomes clear. Most existing systems focus on detecting accidents using sensor values and sending alerts. Very few consider how impact actually behaves inside the vehicle structure. The role of vibration, stress distribution, and force transmission through different parts of the vehicle is mostly ignored. Also, many systems rely on single-point sensing or centralized detection, which may miss important details about where and how the impact occurred.

Because of this, there is a need for a system that goes beyond basic detection. A system that can observe impact from multiple points, reduce false detection using combined sensor data, and still remain affordable for practical use. The work in this project is based on this idea, where both sensor data and mechanical behavior are considered together to improve accident detection and response.

III. Methodology

As we see these days, accidents happen suddenly and many systems fail to detect them correctly or at the right time. Most existing systems depend on a single sensor or a simple condition, which is not always reliable. Because of this, the system in this work looks at impact from multiple points and also considers how force behaves inside the vehicle.

3.1 System Overview

The system follows a simple flow. First, it senses the condition of the vehicle. Then it checks whether the situation is actually an accident. After that, it takes action.

Sensors continuously collect data. This data is processed in real time to decide whether the event is a normal disturbance or something serious. Once an accident is confirmed, the system sends alerts and activates safety mechanisms without any manual input.

3.2 Sensor Placement and Configuration

Instead of using a single sensor, multiple MPU6050 sensors are placed at different parts of the vehicle such as the front, sides, and rear.

Each sensor measures:

- Acceleration along X, Y, and Z axes
- Orientation and tilt

The reason for using multiple sensors is simple. During a crash, force does not stay at one point. It spreads across the structure. By collecting data from different locations, the system gets a clearer picture of where the impact occurred and how strong it was.

3.3 Impact Behavior and Signal Capture

In real conditions, a crash produces more than just a sudden force. It creates vibrations and stress that travel through the vehicle body.
When an impact occurs:

- Acceleration increases suddenly
- Vibrations move through the chassis
- Different regions experience different stress levels

To capture this properly, sensors are mounted using rubber supports or isolation materials. Thishelps in reducing unwanted noise such as engine vibration or road disturbances. At the same time, actual impact signals are still captured clearly.

3.4 Detection Algorithm

The system uses a step-by-step method to confirm an accident instead of relying on a single condition.

First, total acceleration is calculated using:

EQUATION

Then the system checks:

Whether acceleration crosses a threshold (around 3G to 4G)

Whether the change is sudden compared to previous readings

Whether multiple sensors show similar behavior

In addition to this, a force sensor is used to detect direct impact from the front side. If the force value crosses a set limit, it supports the decision made using MPU data.

This combined approach helps in reducing false detection. Small bumps, braking, or uneven roads do not trigger the system easily.

3.5 Additional Components

Along with the main sensors, a few supporting components are used to complete the system:
Ultrasonic sensor to detect nearby obstacles before collision
Microcontroller (ESP32) to process all sensor data
GSM module to send emergency messages
GPS module to provide location details
Buzzer to alert nearby people

All components are connected in a way that allows continuous monitoring.

Response Mechanism

Once an accident is confirmed, the system reacts immediately.

- A message is sent through the GSM module with location details
- A buzzer is activated to indicate emergency
- A relay-based cut-off system is triggered

The cut-off system helps in reducing further risks such as electrical issues after the crash.

3.6 System Workflow

The system runs continuously without waiting for user input. Data is read, processed, and evaluated in real time.

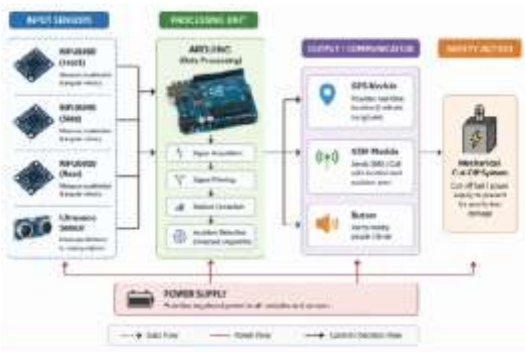
The approach is simple. Detect early, confirm properly, and respond without delay.

3.7 Summary of Approach

This method combines:

- Multiple sensing points across the vehicle
- Basic idea of how impact travels through structure
- Simple decision logic based on real conditions
- Immediate alert and response system

Because of this, the system performs better than single-sensor setups while still keeping the cost low and practical for real use.



IV. Results and Discussion

As we tested the system in different conditions, one thing became clear. A single sensor is never enough. Sometimes it reacts too quickly, sometimes it misses the actual situation. Because of this, using multiple sensors gave much better results.

4.1 System Output Behavior

The system was tested under normal driving conditions and sudden impact situations. During normal movement, the sensor readings stayed within a safe range. Small vibrations, road bumps, and braking did not trigger any false alerts.

When an obstacle was placed close to the vehicle, the ultrasonic sensor detected it correctly. The buzzer started giving warning signals when the distance was less than 30 cm.This helped in identifying nearby objects before collision.

4.2 Accident Detection Results

To test accident conditions, sudden force and impact were applied to the system.

When impact occurred:

- Acceleration values increased suddenly
- The calculated total acceleration crossed the threshold range (around 3G to 4G)
- The force sensor showed a sharp rise in value

At the same time, multiple MPU sensors showed similar changes. This made the detection more reliable.

If only one sensor showed variation, the system did not immediately trigger an accident. This reduced false alerts caused by small disturbances.

4.3 Multi-Sensor Performance

Using more than one MPU sensor helped in identifying where the impact was stronger.

For example:

- If front sensor values were higher, the impact was detected at the front
- If side sensors showed variation, side impact was identified

This gave a better idea of how the force moved through the structure. It was not just detection, but also basic interpretation of impact location.

4.4 Response After Detection

Once an accident was confirmed, the system reacted immediately.

- The relay was turned off to simulate engine cut-off
- The buzzer was activated continuously
- The GSM module sent an alert message

The message was received within a few seconds in most cases. This shows that the system can inform emergency contacts without delay.

4.5 False Detection Analysis

One of the main goals was to reduce false detection.

During testing:

- Speed breakers did not trigger the system
- Normal braking did not trigger the system
- Minor vibrations were ignored

This happened because the system checks multiple conditions instead of relying on a single value.

4.6 Overall Performance

The system worked as expected in both normal and impact conditions. Detection was faster and more reliable compared to single-sensor methods.

It was observed that combining acceleration data with force sensing improved accuracy. The system was able to differentiate between real accidents and normal disturbances in most cases.

4.7 Key Observations

- Multi-point sensing improves detection reliability
- Force sensor adds confirmation to impact detection
- Ultrasonic sensor helps in early warning
- Automatic response reduces delay after accident

Parameter	Single-sensor system	Proposed multi-sensor system
False positives	High (bumps/braking)	Low
Detection reliability	Moderate	High
Impact location info	No	Yes
Response time	<5 sec	<5 sec

The idea is simple. Instead of trusting one signal, the system listens to multiple signals and then makes a decision. That is what makes the difference.

V. Conclusion

As we see these days, accidents are increasing and the biggest problem is not always the accident itself, but the delay in response after it happens. Many systems try to solve this, but most of them depend on a single sensor or a simple condition, which is not always reliable.In this work, a different approach is taken. Instead of depending on one sensor, multiple sensors are used at different positions. This helps in observing how the impact actually spreads through the vehicle. Along with that, a force sensor is used to confirm the impact, which makes the detection more dependable.

During testing, the system was able to detect accident conditions correctly while ignoring normal disturbances like bumps and braking. The use of multiple sensors helped in reducing false alerts. At the same time, the system was able to respond quickly by sending alerts and activating safety mechanisms.

Another important point is that the system remains simple and affordable. It does not depend on heavy computation or complex models. Because of this, it can be used in real conditions, even in areas where advanced infrastructure is not available.

In the end, the idea is straightforward. Instead of reacting to just one signal, the system looks at multiple signals and then decides. This small change makes a big difference in reliability and response.

VI. Future Scope

As we worked on this system, one thing became clear. There is still a lot that can be improved and explored further. The current system gives a strong base, but it can be taken ahead in many ways.

One possible improvement is adding GPS tracking. Right now, the system sends an alert message, but adding exact location details will make it more useful in real situations. It will help emergency services reach faster without confusion.

Another direction is improving how the system studies impact. At present, it gives a basic idea of where the force is stronger. In future, more sensors can be added to get a clearer picture of how impact spreads across the vehicle body. This can also help in studying accident severity.

The system can also be connected to a mobile application. A simple interface can show live sensor data, system status, and alerts. It can also include visual representation of the vehicle, which makes it easier to understand what is happening in real time.

There is also scope to improve decision making. Right now, the system uses fixed threshold values. In future, learning-based methods can be used so that the system adjusts based on different driving conditions. This can further reduce false detection.

Another useful addition can be integration with emergency services. Instead of just sending a message to a phone number, the system can directly notify nearby hospitals or emergency networks.

The idea is simple. The system already works well, but with a few additions, it can become more accurate, more informative, and more useful in real-world situations.

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