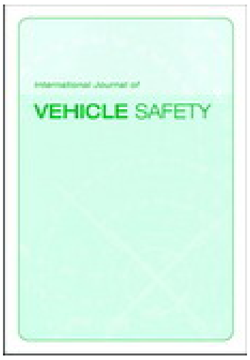

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Accident detection system using laser, multiple sensors and GNSS

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Abstract: Lasers combined with GNSS can be used to create a safer design of automobiles. Laser sensors can detect if an accident has taken place. Combination of both the data can be used to inform fire brigade, ambulance, friends and family in case of accident. This technology can save lives and avoidable injuries. It can be new dimension in automobile safety and is comparable to airbags or seatbelts. Multiple GNSS were used in parallel for more accuracy, network coverage and reliability. Combination of satellite phones and sim card was used to ensure that the message reaches even in the presence of network, software and hardware failures. Multiple sensors such as gyroscope, accelerometer and proximity sensor were used to increase the accuracy of observations. A vehicle can become debris and disintegrate. A vehicle can fall into an underground pit and reach a place where no network connectivity is available.

Keywords: GPS; GLONASS; GALILEO; BeiDou; QZSS; IRNSS; gyroscope; gravity sensor; magnetic field; digital signature.

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1 Introduction

Many times emergency services take a lot of time to reach the spot of accident. It has led to tragic loss of lives and permanent handicapness. The human cost of such tragedies is only increasing. Sometimes accident may happen in remote areas such as forest or desert. It may not even be possible to contact emergency services for any kind of medical help because of no network. In some countries, the roads are of good quality and people drive even at speeds of more than two hundred kilometres per hour. If any collision occurs at this speed then even the vehicle can disintegrate into pieces. This is the identification of second problem. Message should reach even if the device gets completely destroyed. This third problem identified is reliability of the device. In the worst case everything mentioned can go wrong and vehicle may be in area with nil cellular connectivity. Satellite phones and cellular communication were used in parallel.

1.1 Proposed solution

Some of the examples of GNSS (Xiao et al., 2019; Sun, H. and Jafar, 2019; Jha, 2019) are GALILEO (Basile et al., 2019), BeiDou, GLONASS and GPS (Wang et al., 2019; Yang et al., 2017). They have coverage in the entire world. NAVIC (Mishra, D.K. and Mirza, 2018; Ratnam et al., 2018) is regional navigation system by ISRO. Combinations of GNSS (Dabove, P. and Di Pietra, 2019) were used to make the system more reliable. GNSS (Li et al., 2019; Sung-Hyuck et al., 2019; Panda et al., 2019) may not work in mountainous regions or underground. They can track speed, altitude and direction of a vehicle. Another example of satellite navigation systems with regional coverage is QZSS. This technology already existed since 1970's. However, the novel idea could not be implemented because of costly hardware and limitations of software. Even satellite communication was expensive and almost beyond civilian use in 1970's. Hardware of that time was too heavy and consumed too much power to be fitted on a vehicle. Weight and power consumption of the device was kept low to implement the same on automobile.

1.2 Working model of the system

A GNSS (Gruszczynski et al., 2019) based tracker can keep a record of the past activities of vehicle. The past location of vehicle was monitored to make it easier to find the same in case of an accident or collision. The accident may take place in an area of almost negligible network connectivity. The history of past location was stored in the device itself. A central server was created to monitor past location of vehicle. In the worst case, the device may get completely destroyed after the accident. It may even fall into a water body. Satellites may not work properly due to electromagnetic disturbance by sun. Tracking of past locations by server using multiple GNSS (Zekavat and Buehrer, 2019; Yuan et al., 2018; Kuzin, 2018) made it easy to find vehicle after accident even in worst conditions. The device was designed in such a manner as to avoid fake positives. Lasers and laser sensors were installed around the vehicle. More is their number, more is the accuracy. The corners and edges of the vehicle were chosen for more accuracy. Any kind of accident will replace the laser and laser sensors from their position. Even only one of them can be displaced too. It will activate the sensor connected to GNSS. It will automatically send email, sms and automated phone call to concerned receivers depending on the number of sensors displaced. The same has reduced the time for ambulance, fire brigade, friends and family members to reach the spot.

The GNSS-based receiver with cellular and satellite connectivity is located at centre of the vehicle. It is to ensure that the system works even after the impact of collision. This position is too close to fuel tank. It can leak after accident. That is why engine of automobile was used as a power source. It can only be installed on vehicles with engine immobiliser for safety reasons. It will be mechanically protected by the chassis at the time of collision.

Figure 1 shows laser sensor used to detect any obstruction to laser light at the time of accident. It is mounted at the bonnet of running car as shown in Figure 2. Both laser and sensors will get displaced from their positions at the time of accident. This event will activate the device and messages would be sent.

Figure 1 Circuitry used to connect laser diode and laser sensor

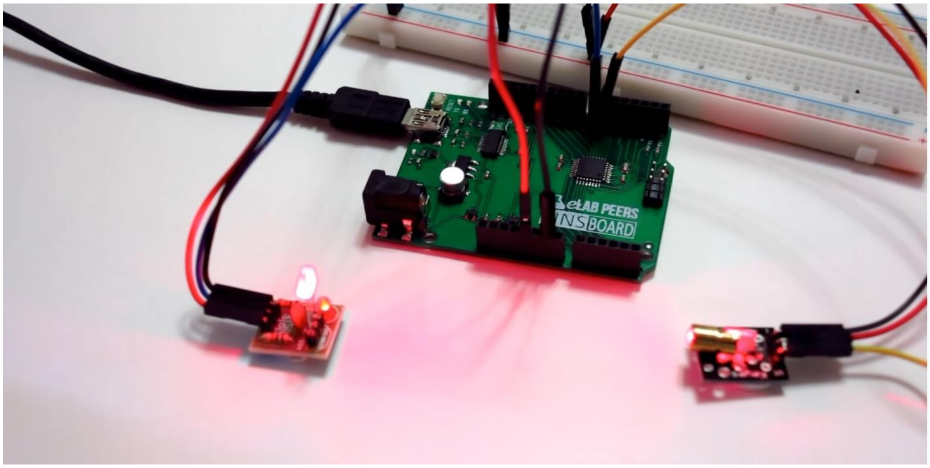

Figure 2 Device mounted on the bonnet of car

Figure 3 shows magnified view of laser LED. It was two millimetres in length. Figure 4 shows block diagram of the invention. Encryption was used to ensure that any kind of modification was not done while data was getting transferred. Digital signature was used to authenticate the vehicle which is sending the message.

Figure 3 Image of laser LED

Figure 4 Block diagram of the system (Xiao et al., 2019)

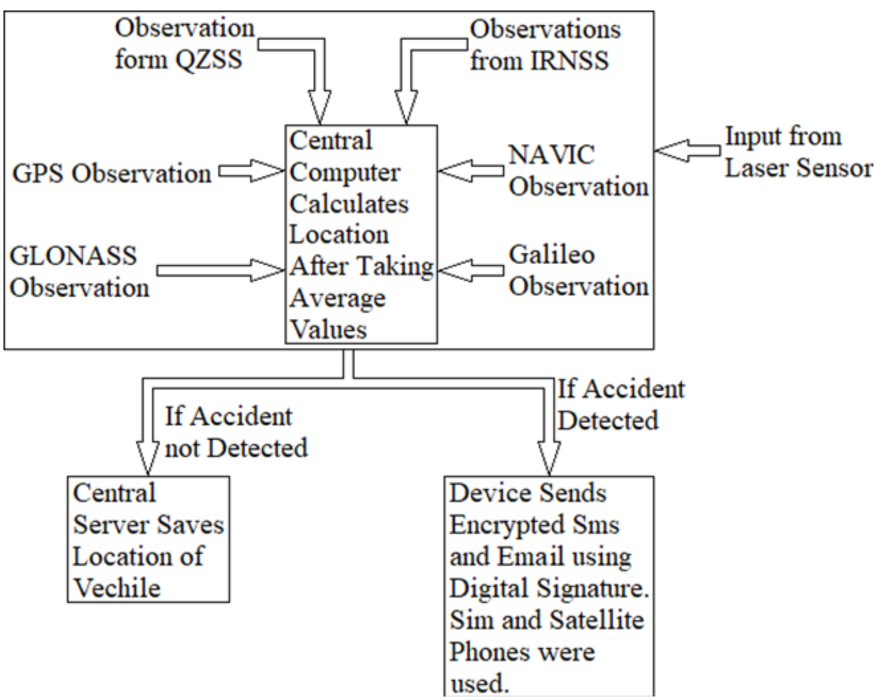

Figure 5 shows device connected to laser and laser sensors fitted at the bottom of the device. Any major accident would break the axle and device would get activated.

Figure 5 Device fitted at the bottom of the vehicle

First the message went to friends and relatives. They decided whether to call emergency services such as ambulance or fire brigade or not. There were reasons for the same. It was done to avoid wasting time of emergency services. The accident may not have happened. The laser sensor mentioned in the design did not get activated. The laser sensor did not get displaced from its position. Everything was going good. The vehicle may be deep underground without any cellular or satellite connectivity. In this situation, only the past location of vehicle was monitored by server. The government owns and controls the server to avoid misuse. Only friends and family knew it through central server. Alarm was not raised by any kind of machine. The central server does know about the past location of vehicle if it was deep underground. Only the network got disconnected. The laser sensor did not raise any alarm. Only this information was sent to friends and family. In any kind of situation, server did not send any message to ambulance and fire brigade to avoid fake positives. The vehicle came back from underground location. Server, friends and family knew it. Emergency services were not aware of anything. Everything was fine.

The same applied to the situation when both the vehicle and device got completely destroyed in the accident. Central server, friends and family knew about last geographical location. Both cellular and satellite communication would get disconnected. Decision to inform ambulance and fire brigade was taken by friends and family. They called the occupants of vehicle after the accident but that did not work. So, emergency services were called manually.

Emergency services were only informed automatically by device if multiple laser sensors across the vehicle were displaced. It was only possible by major accident. Minor accident would displace only one or two laser sensors. Information was limited only to friends and family if at the most three laser sensors got displaced. Multiple laser sensors were placed in the interior of the vehicle but just few millimetres away from edges. They were not placed at the exterior to avoid any mischievous tampering by humans.

2 Already existing systems and their limitations

Already existing systems have the following limitations:

1) They send message when engine is turned off. They also send location of the vehicle. It may even be due to normal operation by driver. So a method was required to distinguish between normal operation and accident.

2) The engine may continue to work even after collision. The occupants including the driver may be unconscious after the accident. An automated system was required to send message after a disaster which destroyed everything.

3) The vehicle can topple with the engine turned on. In the worst case, it may even happen due to the way the car was driven and surface on which it was driven. Laser sensor in the front, rear and sides may not get activated since any collision did not happen in this case. Let us assume that the occupants of the vehicle are unconscious. In this situation, a laser sensor has to be deployed at the roof of the vehicle too.

Already existing systems are not able to work in areas of low network connectivity. A double hardware, software and network were required to ensure that message reached emergency services in any condition after the accident. The designs given in Madrid (n.d.), Khaliq et al. (2017), Mann Ki Baat (2022), Goud and Padmaja (2012), Thakur et al. (2018) multiple limitations and are out-dated. Most of them are theoretical and may not work on one situation or other. Table 1 shows experimental data from device when it was kept at rest. Real-life implementation of an accident could not be done. Moreover, observations from gyroscope, accelerometer, rotations sensor and proximity sensor were taken into consideration. Observations were taken at latitude of 30.6825150° and longitude of 76.8559639°. Experiments were done at 5:18:14 am. At the time of rest the accelerometer showed acceleration of 0.1 along *X*-axis, –0.1 along *Y*-axis and 9.9 along *Z*-axis in m/s^2. Device when kept in the sun showed 18625 Lux. However, light sensor can show different results at the time of accident. Virtual proximity sensor showed 5 centimetres. But proximity sensor can give different observations during and after accident. Magnetic sensor on device showed 147.7 µT at rest. This too can change after accident. Electrical equipment during accident can short circuit or may cease to function. It may continue to function as normal after accident. Surely extra magnetism will be produced for few seconds of crash. Compass when kept at rest and pointed to 1.7° to North. It can vary abnormally and extremely rapidly at the time of accident. Magnetic field along *X*-axis was +6 µT, along *Y*-axis was –42 µT and –88 µT along *Z*-axis. This will show abnormal observation at the time of accident. Orientation of the device at rest was at 67.77° on *X*-axis, 0.75812 on *Y*-Axis and –3.268 on *Z*-axis. It may suddenly change if vehicle collides. Gyroscope showed 0.00061 rad/s on *X*-, *Y*- and *Z*-axis. Even a minor collision will disturb the observations. Device was rotated in 3D by an angle of few degrees. Observations of gravity sensor changed to –0.96807 m/s^2 on *X*-axis, 8.19519 m/s^2 on *Y*-axis and 5.29424 on *Z*-axis. Corresponding rotation vector in 3D was 0.46251 in *X*-axis, –0.12592 in *Y*-axis and 0.12960 in *Z*-axis. Noise level was 44d B. It will increase will sudden and loud sound of collision. Vehicle can be in air after accident for fraction of seconds. It can fall down from hill or bridge too. Altitude was 291 metres. Altitude sensor will show sudden changes during and after the accident.

Table 1 Experimental data from device when kept at rest

GNSS	*CF*	*C/No*	*Flags*	*Elev*	*Azim*
GPS	L1	31.0	EU	33.9$_0$	303.3$_0$
GPS	L1	34.7	EU	39.8$_0$	110.9$_0$
GPS	L1	31.3	EU	27.3$_0$	259.5$_0$
GPS	L1	36.8	EU	61$_0$	356$_0$
GPS	L1	19.6	EU	10.6$_0$	126.4$_0$
GPS	L1	20.2	E	27$_0$	314.8$_0$
GPS	L1	41.1	EU	70$_0$	186.4$_0$
GPS	L1	32.3	EU	47.7$_0$	36.5$_0$
GLONSS	L1	31.4	E	37.9$_0$	332.5$_0$
GLONSS	L1	43.0	EU	43.1$_0$	157$_0$
GLONSS	L1	20.9	E	16.1$_0$	219.6$_0$
GLONSS	L1	28.5	EU	27.9$_0$	277.2$_0$
GALILEO	E1	37.0	E	41.2$_0$	111.2$_0$
GALILEO	E1	38.1	EU	59.6$_0$	356.4$_0$
GALILEO	E1	31.6	EU	26.8$_0$	291.5$_0$
GALILEO	E1	33.8	EU	39.6$_0$	253.5$_0$
BeiDou	B1	37.3	EU	38.2$_0$	128.4$_0$
BeiDou	B1	36.7	E	30.2$_0$	119.6$_0$
BeiDou	B1	33.6	EU	59.1$_0$	21.5$_0$
BeiDou	B1	21.0	E	25.5$_0$	147.4$_0$
BeiDou	B1	28.5	E	23.8$_0$	173.5$_0$
BeiDou	B1	24.3	E	45.1$_0$	43.2$_0$
BeiDou	B1	35.8	EU	52.6$_0$	333.1$_0$
BeiDou	B1	15.8	E	35.5$_0$	53.2$_0$
BeiDou	B1	20.8	E	15$_0$	265.5$_0$
BeiDou	B1	26.6	EU	10$_0$	214.7$_0$
BeiDou	B1	41.4	E	62.2$_0$	134.8$_0$

Figure 6 shows sample observations taken from accelerator sensor in *X*-, *Y*- and *Z*-axis. Experiments were done at standby. Any kind of abrupt change in acceleration can mean an accident. It was immediately communicated to the server. Figure 7 shows observations from rotation sensor in terms of roll, pitch and yaw. Figure 8 shows recordings from magnetic sensor in *X*-, *Y*- and *Z*-axis. All these recordings would change suddenly in case of an accident. Figure 9 shows rotation speed in radians per second in *X*-, *Y*- and *Z*-axis. An Accident would show too high and abnormal rotation speeds. Figure 10 shows a sample of observations from gravity sensor. Though the normal gravity is at 9.8 m/s^2, observations from sensor are expected to show abnormal results. All these sensors were tested in absence of accident. A real-accident would show abnormal recordings in all of them.

Figure 6 Observations taken from acceleration sensor in *X*-, *Y*- and *Z*-axis

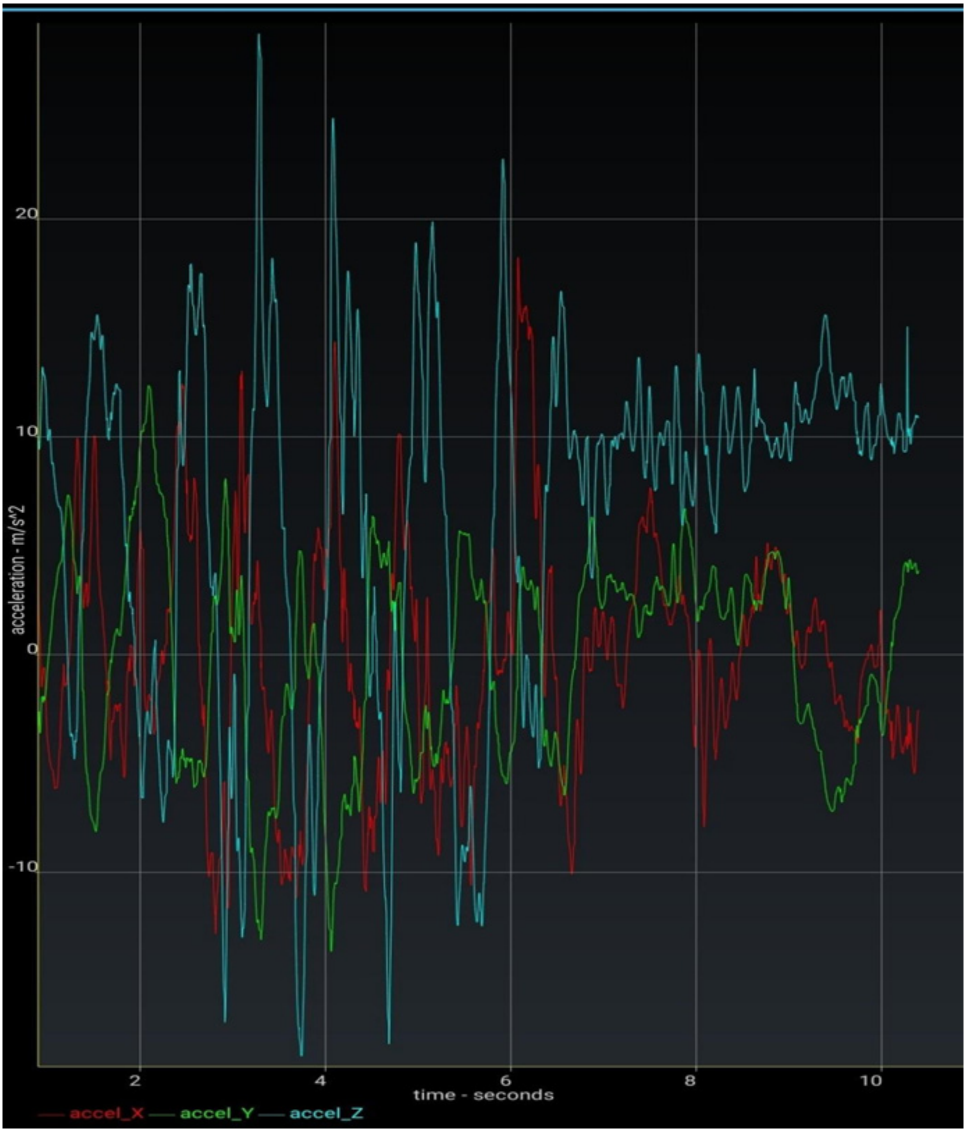

Figure 7 Observations from rotation sensor in *X*-, *Y*- and *Z*-axis

Figure 8 Magnetic field in *X*-, *Y*- and *Z*-axis

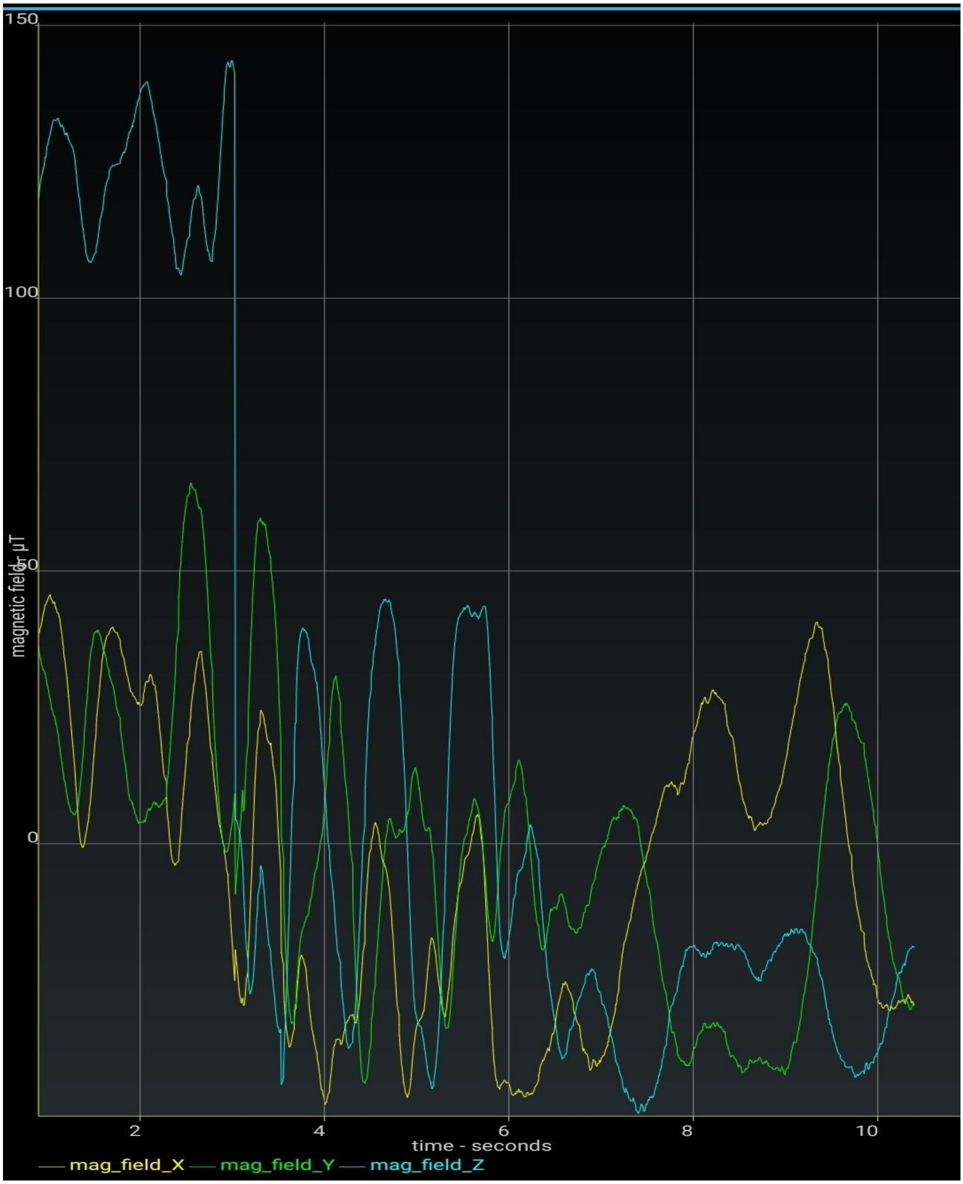

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Figure 9 Rotation speed in radians per second along *X*-, *Y*- and *Z*-axis

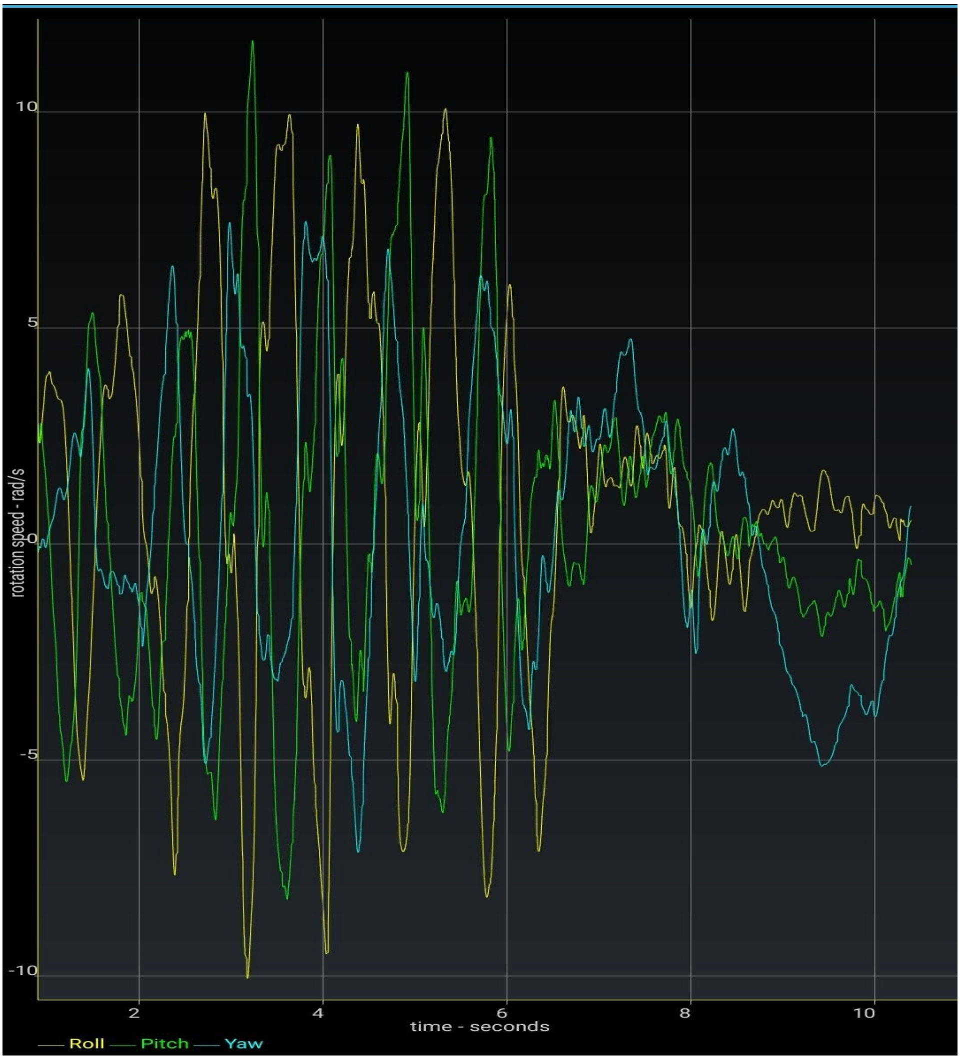

Figure 10 Recordings from gravity sensor

3 Advantages of proposed system

1) The main focus was on ease of implementation. Cost, weight and power consumption were kept low.
2) Reliability was improved. It was done by having multiple global navigation satellite systems to work together. Combination of sim and satellite phones were used for more reliability after collision.

3) Accuracy rate of alarm was improved. Fake positives and fake negatives were reduced.

4) Already existing systems did not have authentication in the form of digital signature. Public key cryptography was used so that only the authorised government officials can decrypt the information.

Real implementation can have multiple challenges. The collision can happen from any side. It can be mixture of multiple collisions too. The vehicle can even topple after multiple collisions. In this situation emergency services were informed depending on the severity of the accident. Even a minor accident on the street can displace laser sensor. Displacement of three laser sensors can only take place by a severe accident. More is the number of sensors, more is the accuracy.

The complete information was sent to central server. It determined the severity of collision. The vehicle may continue to move after a minor collision. The driver can change the gears or apply brakes even if the vehicle was stationary after the accident. The server comes to a conclusion that collision was minor and can be ignored. If the front laser sensors got completely displaced then server comes to know that a major accident had taken place. Keeping record of complete controls can unnecessarily slow down the network. So information of only speed was transmitted to server. If the speed has dropped to zero suddenly and more than three laser sensors got displaced then it needs attention.

In case of multiple collisions, laser sensors got displaced one after other. It may appear to be an ignorable case to server but only for fraction of second. The more sensors got deployed, more was the accuracy. But it also increased the cost. However a balance between accuracy and cost had to be maintained. That is why friends and relatives were always informed. Emergency services were only informed in addition to it on two cases. First, everything got destroyed in accident. It would disconnect both sim and satellite communication. This is different from underground situation. Vehicle may come back from underground location after say ten minutes or something. The central server can distinguish between two situations. If the vehicle did not return from underground situation in ten minutes then server would automatically inform emergency services. Second, the vehicle got damaged, multiple laser sensors were displaced. The vehicle stopped moving.

If the vehicle was in motion after the collision was detected then only the friends and family were informed by the server. They were informed even if a single sensor got displaced. Unnecessary pings can only slow the network. Ping would be sent if both sim and satellite communication got disconnected. In any case, the server would be aware of either the current or past location of vehicle.

Let us assume that the collision did not take place. The vehicle fell down from mountain. It rolled for some time before both vehicle and device got destroyed. Multiple laser sensors would get displaced one after other. Server knows the last geographical location and time at which multiple sensors got displaced. Since the time was different for different sensors, the server would assume it to be an accident. But actually it fell from mountain. The reality would be discovered after the arrival of rescue team. The vehicle would roll for hundreds of metres. Anything can happen after that. Fire can break out. The vehicle can get disintegrated to pieces. In the worst case, the last location saved by server may not match. If the same happens at night, then rescue team may get misguided. They may reach hundreds of metres away from the actual site if everything went wrong. However, the vehicle would only downhill after the fall, not up. In this situation, the laser sensors of entire vehicle would get displaced.

Since engine was used as power source, the device would immediately stop working if the vehicle fell into river. Server discovered that both sim and satellite communication got disconnected. Server sent a ping request. The reply was not received. The river water can take the vehicle away for many kilometres. The server did keep history of past location. But the rescue team got misguided. They reached the wrong location. Since debris was not found, they must have realised that vehicle had floated with the river. It is just an added advantage. The device was basically designed to detect accidents and inform emergency services if required.

It collision occurred between vehicles then server would get same geographical location for two or more vehicles. If vehicle fell down from mountain after collision, then observations from laser sensors and GNSS would be different.

4 Conclusion

Multiple sensors can be installed at different edges and sides to increase accuracy. It can also be connected to black box in automobiles in future work. Less cost and weight are advantages of this technology. It also makes it easy to implement it on large scale. This technology may not work underground or in tunnels because of some limitations of radio waves. This problem was bypassed to some extent by using central server. The aim was to focus on reliability of the device. It also makes forensic investigation by police easy. Many lives can be saved by this idea. Moreover, IRNSS and QZSS will be converted into global satellite navigation systems in future. The device is not limited to a specific place or altitude. It can work anywhere and anytime.

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