Lateral acceleration of passenger vehicle in roundabouts in term of cargo securing

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Abstract. In today’s modern infrastructure, roundabouts are found in almost every city, which makes them impossible to avoid. Roundabouts with a radius of up to 15 m generate high accelerations even when traveling at average speeds. For this reason, it is essential to analyze the events that occur when passing through such roundabouts. In the research, we have performed a complex analysis of the accelerations on the x, y and z-axis for five passes through five different roundabouts, with a focus on the vehicle dynamics. This helped us to understand how the vehicle behaves when crossing a roundabout, as well as what accelerations and forces are affecting the cargo. Therefore, the paper is comparing data from two sensors that were mounted on various parts of the vehicle. The first sensor was mounted on the dashboard and the second on the roof of the vehicle. What is more, we found that the Y-axis accelerations, which are the most important for the analysis of vehicle dynamics in roundabouts, are not affected by the change in sensor location. In addition, we performed an acceleration calculation based on the data recorded from the sensor and radius, which can serve as a basis for further research.

Key words: acceleration, sensor, vehicle dynamics, cargo securing

1. Introduction

Accidents and damage of cargo occurs on European roads every day, mostly because of the incorrect storage or securing of loads on vehicles. The European Agency for Safety and Health at Work estimates that up to 25% of heavy vehicles accidents are caused by insufficient load securing [1].

Accelerometers based on a micro-mechanical system (MEMS accelerometers) are not new and have been serving different customer needs for many years [2]. With the introduction of MEMS technology, a number of sensor systems have emerged to record phenomena that would require professional technology only a few years ago [3]. Authors developed in [4] system for measuring pavement roughness. Low-cost MEMS accelerometer and global positioning system (GPS) was used for data measurements. They demonstrated that this solution is less expensive than previously known as [5], [6], [7]. MEMS sensors can also be used for saving lives and preventing accidents [8]. Research [9] describes system, that will in case of incident connect to nearest hospital and inform staff. Comparable system was developed [10] but rather than contacting officials, authors focused on early warning system for accidents that will provide location data and data from MEMS sensor. Low-cost navigation applications depend mainly on satellite navigation systems, especially the Global Positioning System (GPS). In [11], [12] authors discovered, that inaccurate coordinates can occur in urban areas or in tunnels. To solve this problem, author of [13] proposed improving the accuracy of the MEMS UMI stochastic model. Other solution was to use initialization of Kalman filtering for sensor parameters and including a body velocity
constraint and improved zero velocity updates [13], [14]. Measurements with GPS device were performed in [15].

In this paper, we will be focusing on vehicle dynamics when passing roundabout, mainly lateral acceleration. Authors of [16], [17] also studied and analysed lateral acceleration of vehicles. In [18], [19], [20] analyse of vehicle breaking was described. This topic is connected to road safety and can also help us to better understand vehicle dynamics. Authors of [21] proposed the methodology of measurement for a vehicle’s centre of gravity, which is important for precisely describing complex vehicle dynamics. Breaking performance and vehicles centre of gravity calculation was also performed in [22]. Research for cargo securing, which can prevent damage to cargo or even road accidents was carried out in [23], [24].

2. Definition of physical phenomena and methodology

Anyone who ever travelled knows, that speed of vehicle is constantly changing. That is why we are using average speed. The average speed is calculated as the ratio of the total distance $s$ and the time $t$ interval in which the movement took place: [25]

$$v = \frac{s}{t}$$

(1)

The unit of speed in the international system of units is determined according to the equation: [25]

$$v = \frac{s}{t} = \frac{m}{s} = m \cdot s^{-1}$$

(2)

When describing traffic phenomena, speed is usually expressed in kilometres per hour (km $\cdot$ h$^{-1}$) [25]. The speed of movement may vary or may be constant. The movement in which the speed of movement changes is called acceleration. Accelerated movement is not only when the magnitude of the speed changes, but also when the direction of the speed changes. Acceleration is introduced as a measure of the change in speed per unit of time. The average (mean) acceleration $\bar{a}$ in the time interval $\Delta t$ is defined as: [25]

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

(3)

If the vehicle is moving with an acceleration of 1 m/s$^2$, this means that every 1 second the speed increases by 1 m/s. Unit of acceleration is m/s$^2$, but unit g is widely used in cargo securing instead, where $1g = 9.81$ m/s$^2$ [26].

The instantaneous acceleration $a$ and steady movement in the circle is caused by a change in the direction of the velocity and is directed to its centre at each point of the trajectory. We call it centripetal acceleration $a_d$. We calculate the magnitude of the centripetal acceleration from the relation: [26]

$$a_d = \frac{v^2}{r}$$

(4)

The vehicle can enter a curve at such a speed that two basic conditions are met, which are lateral skid resistance and rollover resistance. As the vehicle moves in a circular path, it is subjected to the centrifugal force $F_c$ and the mass of the vehicle $G$. The centrifugal force tries to push the vehicle out of the circular path away from the centre of turn [27].

The sensor is a functional element forming the input block of the measuring chain, which is in direct contact with the measured environment [28]. For purpose of measuring vehicle dynamics, we used device that consist of three MEMES sensors. The BOSCH BHA250 is a small, low-power MEMS sensor with an integrated three-axis accelerometer. The BOSCH BMG250 is a three-axial gyroscope consisting of a state-of-the-art lowpower 3-axis gyroscope. The UBX-M8030 high-performance standard precision GNSS chip provides exceptional sensitivity and acquisition times for all GNSS systems.

In the research, one respectively two identical sensors were used to measure vehicle dynamics. We performed two groups of measurements. In first group, two roundabouts (measurements 1, 2) were recorded. To record the data, we used one sensor (A) that was placed in vehicle on dashboard.
roundabouts were recorded within the same conditions. In second group three roundabouts (measurements 3, 4, 5) were recorded. This time we used two sensors, sensor A which was placed in vehicle on dashboard and sensor B which was placed on roof of the vehicle. All three roundabouts were recorded within the same conditions.

In all measurements raw data were recorded. Therefore, it was necessary to evaluate them. The maximum (minimum) average acceleration at 80 ms is applied in relation to the standard STN EN 12642: 2016 [29], which is used in strength tests of superstructures or load securing by dynamic driving tests. For evaluation it was essential to use average time. According to the standard EN 17321:2021 [30], when vehicle dynamic acceleration is tested, the minimum average time should be 300 ms. For the dynamic driving test, the minimum average time should be 1000 ms. Based on the above, all raw data from tests were evaluated at 80 ms, 300 ms and 1000 ms.

To describe physical processes, it is necessary to introduce a unified system that can clearly define the physical quantities. For this purpose, coordinate systems have been introduced. In describing three-dimensional events such as vehicle dynamic, it is best to use cartesian coordinate system, that contains three axes [31]. On axis X is shown horizontal acceleration, on axis Y lateral acceleration and on axis Z vertical acceleration. For simplification, we will be using shortcuts for average times and axis, e.g., $y_{1000}$ which means that data were measured on axis Y and evaluated with time 1000 ms. When two sensors were used, data from sensor A has shortcut $A_y$, while data from sensor B has shortcut $B_y$. In accordance to [25, 26], secured cargo should withstand following acceleration when transported in heavy vehicle: on axis X to the front 0.8 g, to the back 0.5 g; on axis Y 0.5 g and on axis Z 1 g.

For uniformity of data, we selected data at each roundabout from the same area that we called evaluated area (EA). Selected data are starting at value 0.0 g ($y_{1000}$) and are ending at value 0.0 g ($y_{1000}$). That is because at every entrance to roundabout there are positive values of acceleration, while at every roundabout there are negative values of acceleration (positive and negative value means if curve is to the right or to the left). We selected data beginning 0.0 g and ending 0.0 g to ensure, only negative values will be considered in calculations. We can see evaluated areas at figures 1, 2, 3, 4 and 5 between “start” and “end”. This area is also background on graphs in figure 1, 2, 3, 4 and 5. On graphs that are showing axis $Y$, there are highlighted values 0.0 g from start and end of roundabout with red line. These are same places as point start and end in visualization of roundabouts. That means from every roundabout we will only be comparing data where acceleration happened. This guarantees uniformity of data from every roundabout. But it is important to mention, that every passing of roundabout is different, and it is impossible to achieve completely equal passing. In figures 1, 2, 3, 4 and 5, every graph has on axis X number of samples, while 200 samples are 1 second.

All measurements were performed with passenger vehicle. We wanted to achieve lateral acceleration 0.5 g or more. Because of required acceleration, it will be very dangerous to perform measurements with heavier vehicles. In such a high acceleration, slide or oven turnover can occur.

3. Evaluation of measured acceleration, comparison of sensor position and calculation of lateral acceleration

3.1 Evaluation of measured data

In figure 1 we can see roundabout 1 (R1) with a radius of 12.53 m. We observe two areas where the lateral acceleration was the highest. The first area is located after entering the roundabout at the first sharp turn. There was an acceleration of approximately -0.4 g to -0.45 g ($y_{1000}$). Acceleration between 0.3 g and -0.4 g ($y_{1000}$) was achieved throughout the majority of roundabout. The highest acceleration was recorded at the second area with increased values which was located at the exit of the roundabout, where a maximum value of -0.51 g ($y_{1000}$) was also recorded. This was mainly due to the increase in speed $V$. We can clearly see the increase in value of the lateral acceleration as the speed increases in graphs in figure 1. Overall, the average speed was 24.02 km/h, with the lowest speed of 19.52 km/h recorded at the entrance of R1 and the highest speed of 33.03 km/h recorded at the exit of the R1. Since this was a long-term acceleration, we do not observe significant differences in the values of acceleration between the individual times. As for the accelerations on the X and Z axes, we did not observe any significant values on the X axis, with the highest value being -0.13 g, respectively 0.11 g (x80). On the
Z axis we can see increased values during the whole transit time. These accelerations were caused by the tilt of the vehicle. The accelerations on the Z axis are directly related to the accelerations on the Y axis and also to roll of the vehicle. The highest recorded acceleration value on the Z axis was -0.27 g (z80).

![Figure 1. Analysis of accelerations at R1 with sensor A](image)

Measurement at R2 were carried out at the same time as the measurement 1. Both roundabouts also have the same entry and exit points. However, the difference was in the radius, with the first having a radius of 12.53 m and the second 13.66 m. However, we see smaller differences in lateral acceleration, as there are 3 instead of 2 areas with increased values. The first part where accelerations of -0.40 g to -0.45 g (y1000) were achieved occurred earlier than in R1. This was followed by a second part with lower accelerations from -0.3 g to -0.4 g (y1000), followed by increased accelerations of -0.4 g to -0.45 g (y1000) in the third part. In fourth part acceleration decreased to values from -0.3 g to -0.4 g (y1000). The exit, and the maximum values took place in the same place as in the previous case. The driving style of the vehicle affects course of acceleration. Therefore, it is not possible to pass two roundabouts in the same way, even if they are similar. Overall, we see that the average (25.37 km/h), minimum (21.32 km/h) and also maximum (36.04 km/h) speeds were higher than for R1. This was caused not only by the driving style but also by the larger radius of the R2. This is also confirmed by the average lateral acceleration value of -0.38 g (y1000) and the maximum acceleration value of -0.54 g (y1000). Again, we do not observe a difference between the average times. We did not notice any significant values on the X axis. As in the previous case, the Z axis is dependent on the Y axis and on the roll, with the maximum measured acceleration value being -0.50 g (z80) at the exit of the roundabout, where roll the vehicle was very high. The average acceleration on axis Z was -0.11 g, which was the same at all average times.
Measurement of acceleration at R3 with a radius of 11.86 m took place at a different location than R1 and R2 but with similar conditions (temperature, road conditions) and with sensor that had similar position (sensor A). Data from sensor B were only used in comparison of sensors. Overall, the course of the accelerations on the Y axis was slightly different than in previous cases. In figure 3 we can observe a faster beginning of lateral acceleration. After beginning, values reached from -0.4 g to -0.5 g (A\textsubscript{y}1000) during the entire R3. The only exception was before the departure, where we can observe a reduction in accelerations to values just above -0.4 g (A\textsubscript{y}1000). During the departure from R3, we again observe an increase in the values of acceleration, at which we also recorded the maximum value of the lateral acceleration -0.54 g (A\textsubscript{y}1000). The increase in values in this case occurred earlier than in previous roundabouts. This could be due to smaller radius or the driver's driving style. The average value of the acceleration on the Y axis during the roundabout was -0.41 g (A\textsubscript{y}1000). This was a slightly higher value than in previous cases, which is confirmed by the graphs (figure 3), where a significant part of the passage was in the values from -0.4 g to -0.5 g (A\textsubscript{y}1000). We also observe the difference in values of the speed, where at the roundabout 3 we see the entrance at a higher speed (31.81 km/h), which was also the maximum speed. Subsequently, the speed decreased and during the passage reached values between 22.5 km/h and 26 km/h, while the average speed was 25.50 km/h. Before the exit, the speed increased and reached 30 km/h on the way out. On the X axis, we again observe negligible values, which were related to the smoothness of the ride. At Z axis accelerations, we observe a correlation with Y axis accelerations, with the highest value recorded being -0.20 g (A\textsubscript{z}80) and the average value during the pass being 0.05 g at all average times. The difference between the previous roundabouts occurred at the beginning and end of the lateral accelerations, where in R3 we observe a later beginning and an earlier end, so the area of action was smaller.
Measurements at R4 with a radius of 13.82 m took place under the same conditions and at the same location as R3. However, we observe a slightly different course, with the highest value of 0.50 g (A_y1000) being reached in the first sharp turn right after the entrance. Subsequently, during the entire transit period, we see values ranging from -0.4 g to -0.5 g (A_y1000), with one exception. As with R3, the exception occurred before the departure, where there was a slight decrease in speed and also a slight decrease in values that reached slightly above -0.40 g (A_y1000). Although the exit speed increased, there was no increase in lateral acceleration due to the larger radius, with an average acceleration of -0.40 g (A_y1000). The development of speed was almost identical to the R3, with a top speed of 32.61 km/h recorded at entry while the average speed was 26.59 km/h. As in the previous cases, the values on the X axis were negligible. On the Z axis, we see the correlation with the Y axis as in all previous cases. The highest recorded acceleration on the Z axis was -0.25 g (A_z80) while the average acceleration was 0.03 g at all average times. The beginning and end of the action of accelerations on the Y axis in R4 was at similar places as in R3.
Measurement in R5 with a radius of 11.19 m was carried out at the same location and under the same conditions as the R3 and R4, but the trajectory of the passing was different. In figure 5 we see that the whole 360° arc was not made. This is also indicated by the acceleration course, with the driver starting to turn earlier than in previous cases. As a result, the increased values of the lateral accelerations began earlier than in the previous case. Just after entering the arc, we see that the acceleration values reach from -0.4 g to -0.5 g (A_y1000). Subsequently, we observe a difference in the driving trajectory, where the driver drove the vehicle more along the edge of R5. In this section, we also observe the highest values of accelerations, which were in the range from -0.5 to -0.56 g (A_y1000), while the value of -0.56 g (A_y1000) was the highest recorded value. After this action, there was departure from the roundabout, whereas the values of acceleration decreased. The average value of the lateral acceleration was -0.43 g (A_y1000). The course of the speed was similar to the R3 and R4. However, we see the difference in the section where the highest values were achieved. The speed decreased slightly, but due to the small radius and sharper turning, the values of the lateral accelerations increased. The speed at the entrance was 29 km/h, but the highest recorded speed 31.35 km/h was at the exit while the average speed was 25.78 km/h. The values on the X axis were again negligible. On the Z axis, we can see once again correlation with the Y axis accelerations, with the highest value recorded being -0.24 g (B_z80) and the average value being 0.03 g at all average times. From the graph in figure 5 we can see that the maximum value did not occur when passing the roundabout, but when exiting it. In this moment, the values of the lateral acceleration changed direction what caused the vehicle to tilt. Similar action happened at every other roundabout. The beginning of the lateral acceleration at the crossing occurred at a similar place as in R3 and R4. However, the end of the operation was in a different place due to the fact that it was not a passage of the whole arch.
3.2 Comparison of sensors with different positions

As mentioned earlier, two sensors denoted as sensor A and B were used in measurements R3, R4 and R5. Sensor A was located on the dashboard and Sensor B on the roof of vehicle. Both sensors were placed in the center of the vehicle. The height difference on the Z axis was 0.6 m and the vertical difference on the X axis was 0.7 m.

Table 1. Results comparisons for sensors A and B from EA

|        | cx80 [g] | cx300 [g] | cx1000 [g] | cy80 [g] | cy300 [g] | cy1000 [g] | cz80 [g] | cz300 [g] | cz1000 [g] | V [km/h] |
|--------|----------|-----------|------------|----------|-----------|------------|----------|-----------|------------|---------|
| R1     |          |           |            |          |           |            |          |           |            |         |
| A      | -0.130   | -0.081    | -0.042     | 0.027    | 0.025     | -0.007     | -0.265   | -0.253    | -0.236     | 19.52   |
| B      | 0.101    | 0.054     | 0.014      | -0.542   | -0.531    | -0.510     | 0.195    | 0.181     | 0.168      | 33.03   |
| R2     |          |           |            |          |           |            |          |           |            |         |
| A      | -0.013   | -0.013    | -0.013     | -0.346   | -0.345    | -0.343     | 0.054    | 0.053     | 0.053      | 24.02   |
| B      | -0.112   | -0.069    | -0.046     | 0.028    | 0.016     | 0.008      | -0.500   | -0.466    | -0.422     | 21.32   |
| R3     |          |           |            |          |           |            |          |           |            |         |
| A      | -0.016   | -0.017    | -0.016     | -0.379   | -0.379    | -0.378     | -0.113   | -0.113    | -0.113     | 25.37   |
| B      | -0.037   | -0.022    | -0.018     | -0.596   | -0.549    | -0.541     | -0.194   | -0.195    | -0.191     | 22.28   |
| R4     |          |           |            |          |           |            |          |           |            |         |
| A      | -0.031   | -0.011    | 0.001      | -0.571   | -0.547    | -0.537     | -0.198   | -0.198    | -0.194     | 22.65   |
| B      | 0.071    | 0.05      | 0.037      | 0.002    | -0.02     | 0.007      | 0.208    | 0.197     | 0.17       | 31.81   |
| R5     |          |           |            |          |           |            |          |           |            |         |
| A      | -0.047   | -0.026    | -0.019     | -0.587   | -0.537    | -0.504     | -0.252   | -0.236    | -0.221     | 21.89   |
| B      | -0.079   | -0.041    | 0.007      | -0.559   | -0.525    | -0.505     | -0.238   | -0.232    | -0.221     | 24.21   |
As we can see in table 1, the differences in the measured values between the sensors were minimal. On axis Y, which values are the most important for evaluation of vehicle dynamics, we observe the difference from the maximum values only 0.009 g on average. On axis X, average difference between maximum values is 0.016 g while slightly larger average differences 0.027 g occurred in the values measured on the axis Z. In table 1 we can also see maximum, minimum and average values from R1 and R2. However, these measurements were performed with only one sensor, so we don’t have data to compare.

Better than judging the maximum values will be to judge the average values. Overall, we will consider the average values for each axis and each time from all three roundabouts. This gives us a total of 27 average values for each sensor. Higher average values were recorded at sensor B for all cases. The largest recorded difference between the average values was 0.035 g at cz300/cz1000 in R5. This difference was mainly due to the fact that the acceleration on the Z axis was directly related to the vehicle’s roll when crossing the R5, with sensor B being positioned higher than A. Looking at the average differences between the axes, on the X axis the difference from all times and roundabouts was 0.007 g, on the Y axis it was 0.002 g and on the Z axis it was 0.032 g. Thus, we can conclude that the sensor position in vertical axis when driving through the roundabout has the greatest effect on the accelerations on the Z axis. However, it should be added that the accelerations on the Z axis when crossing the roundabout are mainly caused by the vehicle roll and not by driving through the bumps. However, a better quantity to accurately determine vehicle tilt is unit roll, which can be recorded by more accurate sensors, but the sensor we used was not able to record this unit. Average speeds on sensor B were 0.503 km/h higher than A. This was mainly due to the accuracy of the GPS coordinates, since the speed is calculated from GPS coordinates, which do not reach the same accuracy as the accelerometer data and thus, cannot be directly compared.

Because accelerations on axis X and axis Z could get positive and negative values, we calculated average accelerations in absolute value (abs), that are shown in table 2. On axis Y we performed calculations only from 0.0 g to 0.0 g that means abs is not necessary. From results we can see, that average difference between sensor A and B on axis X is 0.006 g for 300 and 1000 ms and 0.007 g for 80 ms. On axis Z, average difference is 0.024 g for 80 and 300 ms and 0.025 g for 1000 ms. For values on Axis X we get similar results as in previous case. That also applied for axis Z, but with slightly smaller difference as in previous case. In all case, average acceleration on sensor B had higher values.

### Table 2. Comparisons of average accelerations in absolute value

| Sensor | cx80_abs [g] | cx300_abs [g] | cx1000_abs [g] | cz80_abs [g] | cz300_abs [g] | cz1000_abs [g] |
|--------|--------------|---------------|----------------|--------------|---------------|----------------|
| **R3** |              |               |                |              |               |                |
| A      | 0.021        | 0.020         | 0.019          | 0.072        | 0.072         | 0.068          |
| B      | 0.026        | 0.024         | 0.023          | 0.100        | 0.100         | 0.097          |
| **R4** |              |               |                |              |               |                |
| A      | 0.029        | 0.027         | 0.026          | 0.059        | 0.057         | 0.054          |
| B      | 0.037        | 0.034         | 0.032          | 0.080        | 0.079         | 0.077          |
| **R5** |              |               |                |              |               |                |
| A      | 0.030        | 0.029         | 0.028          | 0.083        | 0.082         | 0.076          |
| B      | 0.038        | 0.036         | 0.035          | 0.105        | 0.104         | 0.099          |
The acceleration on the Y axis, which is the most important for us when monitoring lateral dynamics when passing a roundabout, was almost completely unaffected by the location of the sensor.

3.3 Calculation of lateral acceleration

Due to the fact that roundabouts are circular ride, we decided to calculate the average lateral acceleration using equation (4). The average lateral acceleration for R1 is calculated in equation (5), while the other roundabouts are shown in table 3.

In order to calculate the average lateral acceleration from the centripetal acceleration $a_d$, the average velocity $v$ and the radius of the circle $r$ are needed. The instantaneous velocity was recorded by the sensor. From the instantaneous velocity we then calculated the average velocity. The average velocity was calculated in the region that is located between the "start" and "end" markers in figures 1, 2, 3, 4 and 5. We calculated the radius $r$ using the map data from the route recorded by the GPS device. Thus, the calculation of the average lateral acceleration is as follows:

$$a_d = \frac{v^2}{r} = \frac{6.67^2}{12.53} = 0.36 \text{ g}$$

In table 3 we see the calculation of the average lateral acceleration along with the measured values. The direction of action, i.e. whether it is a positive or negative value, is not relevant in this calculation. Overall, we can conclude that the calculated values agree with the recorded values. The largest deviation is 0.04 g. Taking into account the fact that the vehicle was not driven exactly in a circle, the deviations of the GPS sensor and also the deviations in the speed data, the calculated values can be considered satisfactory.

| Roundabout | Radius [m] | Average speed [km/h] | Calculated average lateral acceleration [g] | Measured average lateral acceleration [g] |
|------------|------------|----------------------|-------------------------------------------|----------------------------------------|
| R1         | 12.53      | 24.01                | 0.362                                     | 0.343                                  |
| R2         | 13.66      | 25.38                | 0.371                                     | 0.378                                  |
| R3         | 11.86      | 26.17                | 0.454                                     | 0.412                                  |
| R4         | 13.82      | 27.25                | 0.423                                     | 0.404                                  |
| R5         | 11.19      | 25.96                | 0.474                                     | 0.431                                  |

4. Conclusion

The analysis of the dynamics of a vehicle crossing a roundabout is an important topic. It can help us to prevent accidents in roundabouts such as sliding or even rollover of vehicle. Furthermore, the vehicle dynamics can help us to understand the movement of cargo better, which could help us with its securing. From our analysis, we have found that if the crossing is performed along the same trajectory, the highest accelerations always occur at the same places, namely at the beginning and at the end of the trajectory. We also found that even when the roundabout is passed at normal speed, accelerations greater than 0.5 g can occur on the Y axis at 1000 ms.

Comparing the two sensors, one on the dashboard and the other on the roof of the vehicle, we found that the difference in position mainly affects the accelerations on the Z axis, due to the vehicle's tilt. For the Y axis, which we found to be the most useful in analyzing the dynamics of roundabout crossing, we observed a minimal deviation, which was on average 0.002 g. Thus, we can claim that even if it will not be possible to maintain the same sensor placement height for different measurements, the accelerations on the Y axis will not be affected for passenger vehicle.

Although the calculation of the radius based on the data obtained from the sensor gave us values that are very similar to the measured values, we cannot declare our findings to be completely accurate. To test this theory, it will be necessary to make a larger number of measurements and develop a more sophisticated method of determining the radius to be used for the calculation of lateral accelerations.
However, our calculation can serve as a suggestion for further research. The results of the study are particularly important in terms of vehicle safety [31, 32].

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References
[1]  Gnap J, Jagelčák J, Marienka P, Frančák M and Kostrzewski, M 2021 Application of mems sensors for evaluation of the dynamics for cargo securing on road vehicles Sensors 21
[2]  Nourelidine A, Karamat T.B, Eberts and El-shafie, A 2009 performance enhancement of mems-based ins/gps integration for low-cost navigation applications IEEE Transactions on Vehicular Technology 58 1077–1096
[3]  Rivas J, Wunderlich R and Heinen, S.J 2012. A mems acceleration sensor for traffic condition detection PRIME 2012; 8th Conf. on Ph.D. Research in Microelectronics and Electronics (Aachen) 321–324
[4]  Mirtabar Z, Golro A, Mahmoudzadeh A and Barazandeh F 2022 Development of a crowdsourcing-based system for computing the international roughness index Int. J. Pavement Eng. 23 489–498
[5]  Chen K, Lu M, Fan X, Wei M and Wu J 2011 Road condition monitoring using on-board three-axis accelerometer and gps sensor Proc. of the 6th Int. ICST Conf. on Communications and Networking in China (Harbin) 1032–1037
[6]  Du Y, Liu C, Wu D and Li S 2016 Application of vehicle mounted accelerometers to measure pavement roughness Int. J. Distrib. Sens. Networks 2016
[7]  Anitha R, Deepak M and Snehash, T Road quality and condition detection using gps and a raspberry pi Int. J. Innov. Res. Creat. Technol. 1 527–529
[8]  Mikusova M 2017 Crash avoidance systems and collision safety devices for vehicle occupants MATEC Web of Conf. (Trstena) 107
[9]  Parmar P and Sapkal A.M 2017 Real time detection and reporting of vehicle collision Proceedings of the 2017 Int. Conf. on Trends in Elect. and Informatics (Tirunelveli) 1029–1034
[10] Mantoro T, Suryasa I.N, Moedjiono S and Nugroho M.R 2016 automatic early warning for vehicles accidents based on user location Adv. Sci. Lett. 22 3065–3070
[11] Cossaboom M, Georgy J, Karamat T.B and Noureldeen A 2012. Augmented kalman filter and map matching for 3d riss/gps integration for land vehicles Int. J. Nav. Obser.
[12] Meiling W, Guoqiang F, Huachao Y, Yafeng L, Yi Y and Xuan X 2017 A loosely coupled mems-sins/gnss integrated system for land vehicle navigation in urban areas Proceedings of the 2017 IEEE Int. Conf. on Vehicular Elect. and Safety (Vienna) 103–108
[13] Allan D 1966 Statistics of atomic frequency standards Proceedings of the IEEE 54 221–230
[14] Li X, Xu Q, Li B and Song X 2016 A Highly reliable and cost-efficient multi-sensor system for land vehicle positioning Sensors 16
[15] Mikusova M, Abduazarov J, Zákovska J and Jagelcak J 2020 Designing of parking spaces on parking taking into account the parameters of design vehicles Computation 8
[16] Visar B, Odhisea K and Doçi I 2017 The influence of the lateral acceleration on vehicle velocity moving on curved road Int. J. Civil Eng. Tech. 8 414–420
[17] Xu J, Yang K, Shao Y and Lu G 2015 An Experimental study on lateral acceleration of cars in different environments in sichuan, southwest china Discrete Dynamics in Nature and Society 2015
[18] Ondruš J and Hockicko P 2015 Braking deceleration measurement using the video analysis of motions by Sw tracker Transport and Telecommunication journal 16 127–137
[19] Ondruš J, Vrábel J and Kolla E 2018 The influence of the vehicle weight on the selected vehicle braking characteristics Transport Means-Proceedings of the International Conference (Trakai) 384–390
[20] Ondruš J and Kolla E 2017 practical use of the braking attributes measurements results MATEC Web of Conferences (Ceske Budejovice) 134
[21] Skrúcaný T, Synák F, Semanová S, Ondruš J and Rievaj V 2018 Detection of road vehicle’s centre of gravity Proc. of the 11th Int. Scientific and Technical Conference on Automotive Safety (Častá) 1–7
[22] Vlkovský M, Šmerek M and Michálek J 2017 Cargo securing during transport depending on the type of a road IOP Conf. Ser.: Materials Science and Engineering 2017 (Prague) 245
[23] Vlkovský M., Neubauer J, Mališek J and Michálek J 2021 Improvement of road safety through appropriate cargo securing using outliers Sustainability 13 1–16
[24] Vlkovský M, Ivanuša T, Neumann V, Foltin P and Vlachová H 2017 Optimizing cargo security during transport using data-loggers J. Transp. Secur. 10 63–71
[25] Hockicko P 2015 Fyzikálna videoanalýza reálnych dejov (Physical video analysis of real events) (Žilina: EDIS) p 195
[26] Gonda J 1966 Dynamika pre inžinierov (Dynamics for engineers) (Bratislava: Vydavateľstvo SAV) p 454
[27] Rievaj V 2013 Automobil a jeho dynamika (Automobile and its dynamics) (Žilina: EDIS) p 224
[28] Ripka P 2011 Senzory a převodníky (Sensors and transmitters) (Praha: České vysoké učení technické) p 136
[29] EN 12642:2016 Securing of cargo on road vehicles - Body structure of commercial vehicles - Minimum requirements
[30] EN 17321:2021 Intermodal loading units and commercial vehicles - Transport stability of packages - Minimum requirements and tests
[31] Jurecki RS, Jaskiewicz M, Zuska A 2013 The variety of the behaviour of drivers at risk accident situations 35 (107) 38-46
[32] Jurecki RS, Stanczyk TL 2018 Analyzing driver response times for pedestrian intrusions in crash-imminent situations, Proc. of the 11th Int. Scientific and Technical Conference on Automotive Safety (Častá) 1–7