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THE ACCURACY ASSESSMENT OF DEVICES USED FOR DISTANCE MEASURING IN DYNAMIC VEHICLE TESTS

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The paper presented deals with the accuracy of three selected devices based on acceleration measurement: accelerometer – XL meter, the global position measurement device by VBox and the constructed 5th wheel, which allows a very accurate measurement of distance along with speed and acceleration of the vehicle. The accuracy of recordings was tested during various driving conditions when all the three measuring devices were attached to the vehicle. Measurements showed that GPS-based measuring devices level off and even surpass accelerometers when used in locations with a good view of the sky. The 5th wheel provided the most representative results, as the difference between average and real standard deviations of the measured distance were 0.78%, 1.38%, 3.48% for the 5th wheel, VBox GPS and XL meter, respectively. The accuracy of the 5th wheel and VBox can be considered very high when taking into account the fact that dynamic actions were monitored. The paper purpose is to point out the significance of measuring device selection in assessing the distance travelled by the vehicle.

Keywords: accelerometer; vehicle tests; 5th wheel; GPS

Current automobiles and other road vehicles are subjected to high requirements in terms of their active driving safety, technical reliability and high efficiency of individual components. In this context, it is necessary to realize that the automobile has been developing for more than a century and its further improvement constantly requires theoretical solutions, especially in dynamic processes of movement (Jablonický et al., 2015; Szabó et al., 2013). When developing cars, the emphasis is put on car safety requirements. These requirements are prescribed by applicable legislation, as well as sales standards (Králik et al., 2016; Burg and Moser, 2014).

The decisive strategy for solving the occurrence of traffic accidents, whether in national or international transport, is to constantly increase the safety of vehicles. Car manufacturers are focusing on two basic ways to solve this issue: improving the vehicle dynamic properties and improving its active and passive safety (Yicong et al., 2020; Chen et al., 2013). To monitor and evaluate these factors, it is necessary to use appropriate measuring devices capable of recording with high accuracy.

This contribution aims to evaluate the accuracy of selected devices commonly used for measuring the various parameters of vehicle dynamic actions. The experiments were focused on the accuracy of recording the vehicle's trajectory. All the three measuring devices were attached to the car – XL meter (accelerometer), VBox (global position measurement) and the 5th wheel. These devices were used to examine the dynamic states of vehicles, as well as to check the vehicle brakes by measuring braking deceleration. Employment of these devices for the purposes of research is popular, e.g., accelerometers were observed by Kohút et al. (2017), Guo et al. (2014), Ondruš and Hockicko (2015), VBOX GPS device was assessed by Ciepka and Janczur (2019) and Toropov et al. (2021), and the 5th wheel was observed by Ivanov et al. (2010).

Material and methods

For the purposes of experiment, a measuring chain of the 5th wheel was constructed. Subsequently, it was verified whether it was functional for assessment of selected dynamic and safety parameters. The 5th wheel system constructed at the Department of Transport and Handling (Faculty of Engineering, Slovak University of Agriculture in Nitra) comprised an auxiliary frame with a gripping mechanism with suction cups, a wheel fork, sensor, transducer and software (Figs 1–2).

Basic parameters of the 5th wheel measuring chain:

- dynamic wheel diameter: 62 cm;
- units of measurement: m;
- display resolution: 0.1 m;
- minimum measured distance: 0.036 m;
- maximum tested speed: 130 km·h^{-1} (1113 Hz);
- minimum speed: 2 km·h^{-1} (17 Hz).

Table 1 shows the evaluation of the verification measurements of the 5th wheel during calibration at a distance of 100 meters. The average distance measured during the experiment was 100.20 meters. The largest difference compared to the reference distance of

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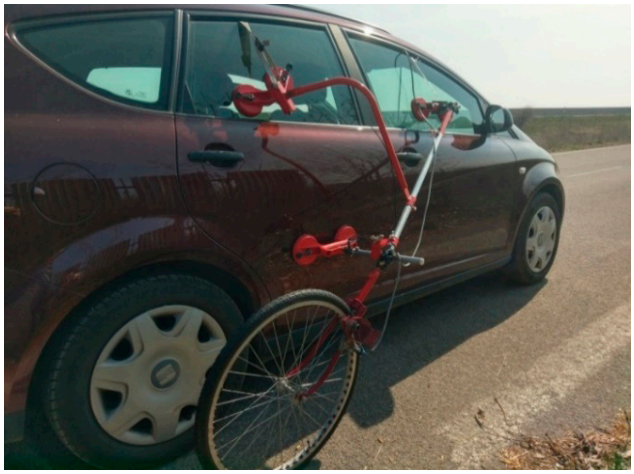


Fig. 1 Attachment of the 5th wheel to the test vehicle on the right-side view

100 meters was 100.76 meters, which represents 0.56%. The mean deviation was 0.2%. Using descriptive statistics, basic indicators were calculated, determining a standard deviation of 0.11 and a coefficient of variation of 0.0033. Statistical analysis further showed the necessary number of repetitions of distance measurement to ensure the relevant measurement accuracy at the level of 1%. Just one measurement was proved sufficient to ensure such measurement accuracy.

Rollmeter

A suitable wheel for these purposes appeared to be a digital wheel, the so-called rollmeter. This device is used

Table 1 Accuracy statistical indicators of the 5th wheel at a distance of 100 m

Arithmetic mean (m)	100.202
Standard error (m)	0.061
Median (m)	100.17
Modus (m)	100.52
Estimation of standard deviation (m)	0.33
Standard deviation (m)	0.11
Coefficient of variation (m)	0.0033
Maximum value (m)	100.76
Minimum value (m)	99.76
Determination of the minimum number of measurement repetitions	
Required accuracy Δ (%)	1
Maximum permissible error δ (%)	1
Critical value of normal distribution, t_α – 90%	1.645
Critical value of normal distribution, t_β – 90%	1.282
Required number of repetitions for value normal distribution, t_α	1
Required number of repetitions for value normal distribution, t_β	1
Required number of repetitions for δ/v_k	1

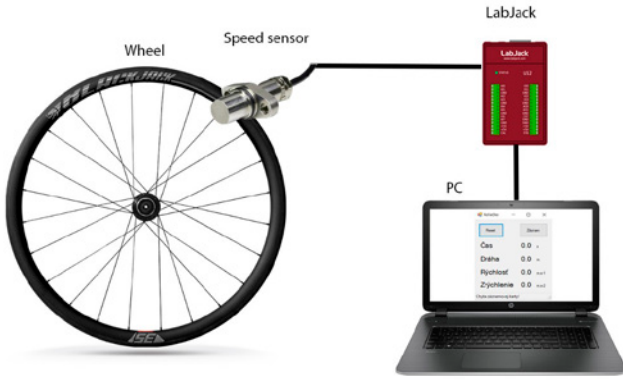


Fig. 2 Diagram of the 5th wheel measuring chain

to measure the ground distance on the road or in the field, its construction is shown in Fig 3. The meter works with a measuring range of 0.1–9999 m with the smallest possible unit of 1 dm. When moving backwards, the device automatically records the opposite rotation of the wheel and counts out the value.



Fig. 3 Rollmeter

XL Meter

The XL meter is a gravimetric accelerometer-based instrument equipped with a digital recorder, from which the precise deceleration and acceleration values can be read after the measurement. The XL meter by Inventure Automotive Electronics (Fig. 4) was attached to the car windshield prior to measurement, adjusted and then fixed so that the initial acceleration values in the X and Y axes are zero. After a test drive, the device was connected to the computer via an RS-232 interface and the results were processed using XL VISION software. After the test, the average braking deceleration was displayed immediately. Moreover, the initial speed, braking time and braking distance were automatically calculated via algorithms



Fig. 4 XL METERTM Pro Alpha device

(Jablonický et al., 2020). Technical information on the XL meter is given in Table 2.

VBOX

The VBox GPS from Racelogic (Fig. 5) was selected for the purposes of continuous measurement of the position and secondary parameters such as time, speed, acceleration and track of the vehicle. This device operates at a frequency of 20 Hz, and communication with a computer or smartphone is done via USB or Bluetooth technology. Other technical parameters are listed in Table 3 (Mahapatra and Maurya, 2018).



Fig. 5 VBOX GPS device

Results and discussion

To verify the recorded distance using all the three devices – the 5th wheel, XL meter and VBox – the vehicle's distances were measured at different speeds. Subsequently, the vehicle's trajectory from start to halt was monitored using a rollmeter, compared with the results from the devices and the measurement deviations were determined.

Table 2 Technical parameters of XL meter

PC interface	RS-232, USB
Number of measurements	3–8
Memory for the measurement (200 Hz)	1 × 80 s + 2 × 40 s (5 × 40 s + 3 × 80 s)
Acceleration measurement	
Longitudinal direction (a_x)	
Range	-5.0… +5.0 m·s^{-2} to -20.0… +20.0 m·s^{-2}
Resolution	0.0021 m·s^{-2}
Sampling frequency	25 Hz to 200 Hz
Lateral direction (a_y)	
Range	-5.0… +5.0 m·s^{-2} to -20.0… +20.0 m·s^{-2}
Resolution	0.002 m·s^{-2}
Sampling frequency	200 Hz to 25 Hz

Table 3 Technical parameters of VBOX device

Speed	Acceleration	Position
accuracy: 0.1 km·h^{-1}	accuracy: 0.5%	2D position: ± 5 m 95% CEP*
measuring units: km·h^{-1} or mph	maximum measurement: 4 G	height: 5 m 95% CEP*
data refresh rate: 20 Hz	resolution: 0.01 G	
minimum speed: 0.1 km·h^{-1}		**Rotation**
minimum speed: 0.1 km·h^{-1}		accuracy: ±0.2° s
resolution: 0.01 km·h^{-1}		resolution: 0.01° s

* 95% CEP (Circle of Error Probable) means that the location data belong to a circle with a specified radius 95% of the time

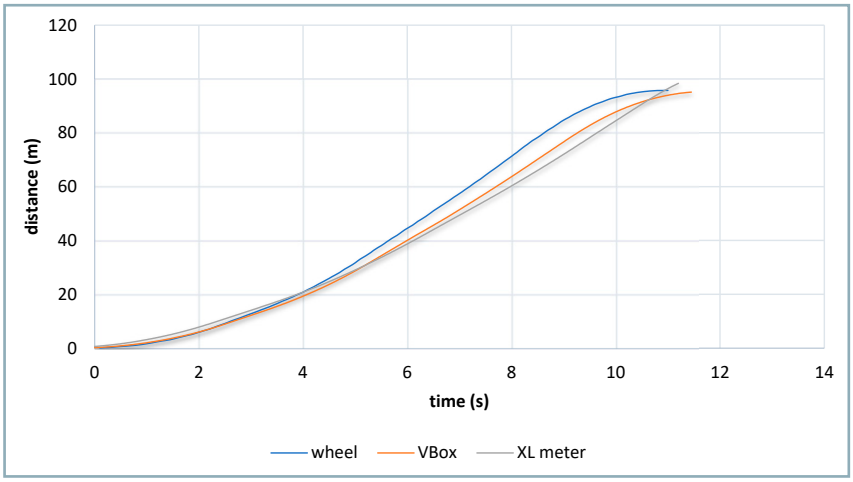


Fig. 6 Comparison of devices at 96 m distance depending on time

Table 4 Differences in measured trajectories by each device at 96 m

Distance 96.0 m	5th wheel	XL meter	VBox
Trajectory (m)	95.79	103.90	94.91
Difference (m)	0.21	7.90	-1.09
Difference (%)	0.22	8.23	1.14

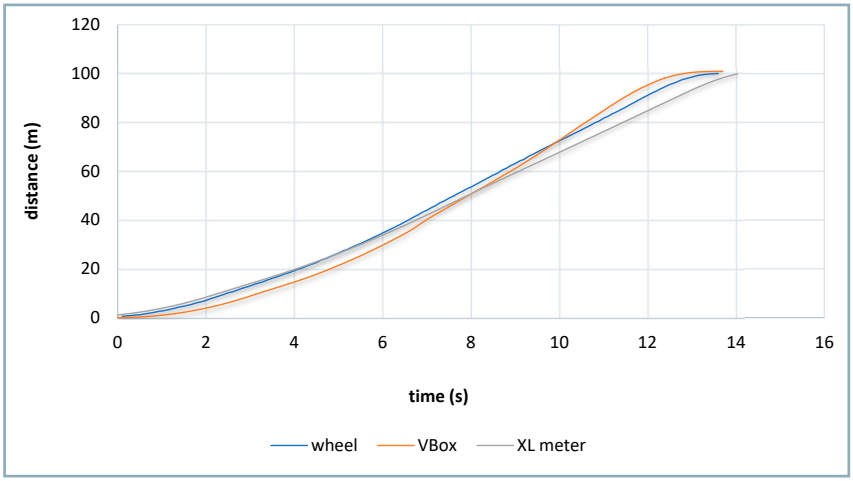


Fig. 7 Comparison of devices at 99.2 m distance depending on time

Table 5 Differences in measured trajectories by each device at 99.2 m

Distance 99.2 m	5th wheel	XL meter	VBox
Trajectory (m)	99.44	99.8	100.96
Difference (m)	0.2	0.36	1.52
Difference (%)	0.20	0.36	1.53

The first distance verification measurement (Fig. 6 and Table 4) was performed at a distance of 96.0 m and at a speed of approx. 30 km·h^{-1}, which represents 8.33 m·s^{-1}. The most accurate and representative result was achieved by the 5th wheel, where the trajectory deviation was only 21 cm, and thus 0.22%. For the accelerometer, this deviation was larger – 8.23%. On the contrary, the VBox achieved satisfactory results with a deviation of 1.13%.

The second distance verification measurement (Fig. 7 and Table 5) was measured while the vehicle was moving at a speed of approx. 50 km·h^{-1} and on 99.2 m long track. The best result was once again recorded by the 5th wheel working with only a small deviation – 0.20%. The result from the XL meter showed a difference of 0.36 m, which is 0.36%. On the other hand, with a deviation of 1.53%, the VBox showed the worst result.

Subsequently, the measurements were conducted at a speed of approx. 50 km·h^{-1} on 109.1 m long trajectory, providing results shown in Fig. 8 and Table 6. During this test, the 5th wheel operated with a deviation of 1.92%, the accelerometer with a deviation of 3.74% and the VBox with 1.27%.

Afterwards, another measurement was conducted at a distance of 167.6 m and at a higher vehicle speed, ranging up to 80 km·h^{-1}. The measurement results are shown in Fig. 9 and Table 7. The 5th wheel achieved the best result in the distance measured accuracy with a deviation of 1.25%. The deviations from the real value of the distance were higher for the XL meter and VBox, which were 3.97% and 2.23%, respectively (Table 7).

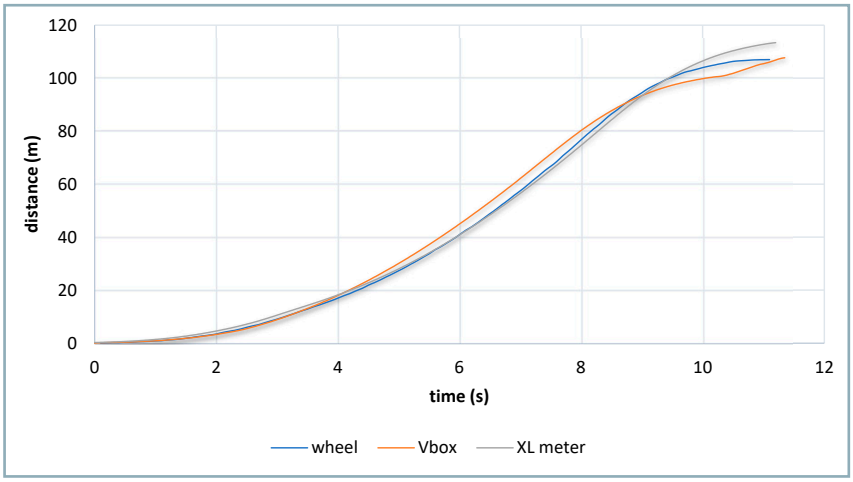


Fig. 8 Comparison of devices at 109.1 m distance depending on time

Table 6 Differences in measured trajectories by each device at 109.1 m

Distance 109.1 m	5th wheel	XL meter	VBox
Trajectory (m)	107.01	113.18	107.71
Difference (m)	-2.09	4.08	1.39
Difference (%)	1.92	3.74	1.27

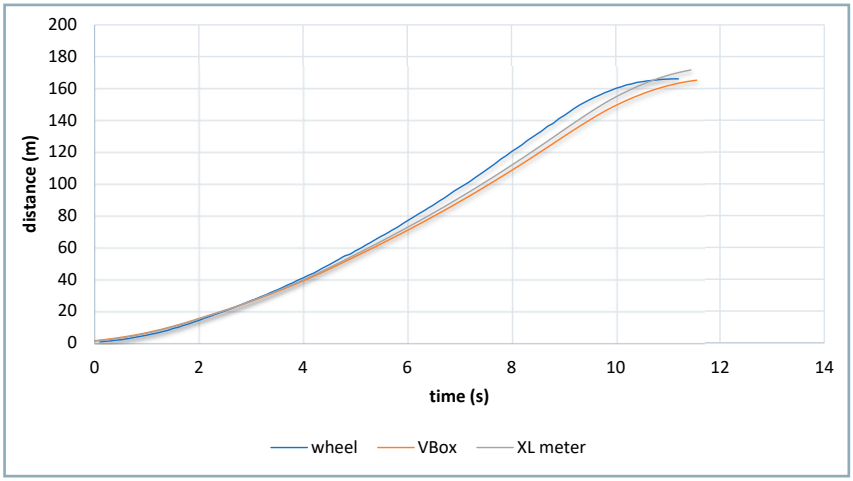


Fig. 9 Comparison of the distance 167.6 m depending on time

Table 7 Differences in measured trajectories by each device at 167.6 m

Distance 167.6 m	5th wheel	XL meter	VBox
Trajectory (m)	165.47	174.25	163.86
Difference (m)	-2.13	6.65	-3.74
Difference (%)	1.27	3.97	2.23

Lastly, the experimental measurements were conducted at a distance of 273.1 m, vehicle speed up to 100 km·h^{-1} and a rapid deceleration (Fig. 10 and Table 8).

All the three measuring devices worked with high precision, with the largest standard deviation showed by the XL meter – 1.12%.

Accordingly, Table 9 summarizes all distance measurements, as well as the average deviation values of individual measurements, standard deviation and the coefficient of variation.

The results of particular measurements together with their statistical evaluation showed that the most appropriate and accurate device for the purposes of measuring the distance is the contact device – the 5th wheel in this case with an average deviation of 0.78%, which is a very good result in dynamic measurement. The second most accurate result was shown by VBox with a deviation of 1.38%. The least accurate device appeared to be the XL meter accelerometer with an average deviation of 3.48%. This is because the device primarily measures vehicle's acceleration and the distance travelled is a calculated parameter that can be affected by various external effects.

In their experiments, Ivanov et al. (2017) and Baena et al. (2019) used the 5th wheel to accurately determine the speed of vehicle on various surfaces, such as snow, where the circumferential speed of the drive wheels is assumed to differ from the real speed of the vehicle.

In these cases, the 5th wheel can measure the actual speed of vehicle regardless of whether the driven wheels are slipping or not. As stated by Pegasem Messtechnik GmbH – producer of a similar measuring device – the 5th wheel is used for highly accurate measurements of speed, distance and acceleration or deceleration, which is independent from the speed of wheels (Gardulski, 2011). A 5th wheel equivalent can also be used to measure the distance, where the speed sensor is mounted directly on the wheel of the vehicle being measured. Such a device also produces accurate results and can be utilized in specific tests, in which the wheel slip assessment represents one

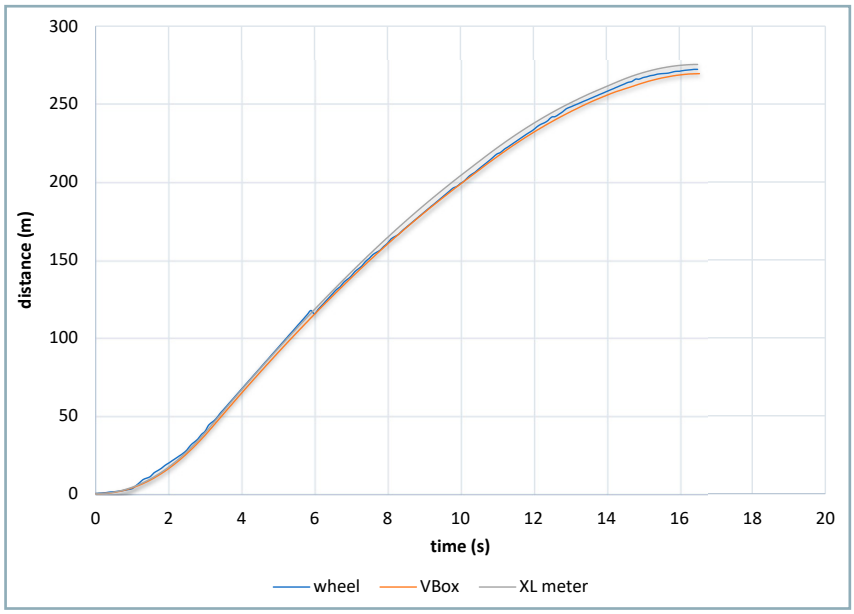


Fig. 10 Comparison of the distance 273.1 m depending on time

Table 8 Differences in measured trajectories by each device at 273.1 m

273.1 m	5th wheel	XL meter	VBox
Trajectory (m)	272.3	276.16	271.1
Difference (m)	-0.8	3.06	2.0
Difference (%)	0.29	1.12	0.73

of the desired results (Moinar and Shahgholi, 2019).

Many authors try to use accelerometers for such driving tests, however, based on the findings presented, certain devices show higher accuracy when measuring the distance (Kolla et al., 2020). It is thus necessary to consider which specific units are going to be measured prior to measuring itself. If the driving test comprises the braking system assessment and direct measurement of the braking deceleration, the best solution is to use an accelerometer, which is frequently employed in forensic engineering (Marienka et al., 2020). If the desired result includes capturing the position of the vehicle, GPS-based devices will be more appropriate.

The disadvantage of GPS measurement devices lies in their dependence on the signal quality and location. In urban environment with densely built-up areas or in places with any obstacles between the vehicle and sky, the number of satellites connected to the equipment decreases, resulting thus in decreased accuracy of the scanned position (Schmiidt, 2015; González et al., 2020; Guochang, 2010). If the result desired is the driven distance itself, it is necessary to opt for devices such as the 5th wheel, Corsys Correvit, etc. Moreover, another aspect of measurements is the time length, in which the XL meter is limited to tens of seconds (40 or 80 seconds). It is more advantageous and convenient to use a GPS-based device to measure longer periods. All in all, the most accurate results are provided by devices that measure primarily a particular unit.

Conclusion

For the purposes of measurement of dynamic parameters of vehicles, several measuring devices can be utilized, the most common being devices working on the principles of GPS and accelerometer. Employment of GPS with a high frequency of data entry shows an increasing trend. On the contrary, although the accelerometers still play an irreplaceable role in measuring decelerations, the experiment presented showed a higher inaccuracy of these devices.

For scientific purposes of examining the accuracy of measuring devices used to assess the dynamic parameters of vehicles, the 5th wheel was designed, which is a device attached to the tested vehicle. The wheel transforms signals into digital form processed by a proposed program evaluating and displaying the current distance, driving time, speed, and acceleration. Based on the calibration and verification measurements, it was confirmed that this type of measuring device shows the best results with the highest

Table 9 Average deviations of measured distances

Measurement (distance) (m)	5th wheel		XL meter		VBox	
	(m)	(%)	(m)	(%)	(m)	(%)
96	0.21	0.22	7.90	8.23	-1.09	1.14
99.2	0.2	0.2	0.36	0.36	1.52	1.53
109.1	2.09	1.92	4.08	3.74	1.39	1.27
167.6	2.14	1.27	6.65	3.97	-3.75	2.23
273.1	0.8	0.29	3.06	1.12	2.0	0.73
Median	1.08	0.78	4.52	3.48	1.95	1.38
Standard deviation	–	0.78	–	3.09	–	0.56
Coefficient of variation	–	0.10	–	0.89	–	0.40

accuracy. At the same time, it served as a gauge for other measurements.

Comparative measurements were performed during the experiment, in which all the three devices were placed on the vehicle at the same time. Five driving tests were performed in total, when the vehicle drove at speeds of approx. 30 km·h^{-1}, 50 km·h^{-1} with a sharper acceleration, 50 km·h^{-1} with slow acceleration, 70 km·h^{-1} and 100 km·h^{-1}, during which the vehicle passed various distances. The track was accurately measured with a rollmeter after each test, recorded and then compared with the results from all the three devices.

The 5th wheel showed high measurement accuracy and its average deviation during five measurements was 0.78%. The second most accurate was the system working to determine the absolute global position VBox with an average deviation of 1.38%, which is also considered a highly satisfactory result. The lowest accuracy was showed by the XL meter with an average deviation of 3.48%, which achieved the best results at full acceleration to a speed of 100 km·h^{-1} and subsequent rapid braking to a stop – it worked with an average deviation of 1.12%. It is thus obvious that the accelerometer is affected by influences from the road, its instability, the lateral and longitudinal roll angle of the vehicle, etc.

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