

The Simulator of Train Position Locator

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Abstract

The European satellite navigation system Galileo is under development and it is expected to be used, together with GPS, for railway safety of life applications such as signalling, train control and the protection of track workers. A key element of this new concept is a GNSS / INS based train position locator. However, the tuning and testing of the locator during its development process is sometimes quite difficult and time consuming, particularly if it is necessary to do it on a locomotive during its real operation on the track. Therefore, it was found to be more efficient if some of these tests and verifications could be performed in laboratory conditions by means of a test bed.

This paper describes the laboratory equipment called, the Simulator of Train Position Locator, based on using exactly the same inertial sensors as employed in the real locator. The simulator is able to simulate functions of the real train locator using the input reference trajectory data generated by Real Time Kinematics (RTK) during a test run on the track. The simulator enables testing of the following modes: 1) position determination during train routing on switches, 2) position determination on track sections with limited GNSS satellite "visibility" (tunnels, track cuttings, etc.), and 3) train positioning under different speed profiles.

A main benefit of the simulator is that it helps to optimize the locator architecture and its parameters with respect to the railway safety requirements. The simulator also enables the simulation of hazardous states, which is obviously impossible to do under normal operational conditions.

Keywords: simulation, simulator, train position locator, GNSS, INS, Kalman filtering, PDAF method.

1 Introduction

It is clear that the Train Position Locator (TPL), for safety related applications, must be properly tested. The TPL must be especially tested in critical situations,



such as wheel slips, sensors faults and errors, reduced GNSS satellite visibility etc.

Nowadays, test platforms consist of a DC electric locomotive and a mobile track robot. The locomotive is mostly used for real track tests and for high-speed tests (<160 km/h). The mobile tract robot is able to provide low speed tests (<12 km/h) and tests with accurate speed profiling. But these platforms are not able to provide all required tests (wheel slips in a given place etc.).

That is the reason we decided to develop the Simulator of the Train Position Locator (Simulator). The simulator provides sensors motion, as if it was on a real locomotive during running on a track. The simulator also enables the simulation of hazardous states, which are obviously impossible to do under normal operational conditions. Last but not least, the simulator helps to improve the time and costs of development.

This paper describes the laboratory equipment mentioned above. In section 2 the architecture of TPL will be described. Next, in section 3, the architecture of the simulator will be described with attention to the principle of simulation of each sensor. In section 4 the results of simulation will be presented, and in section 5 are the conclusions, with attention to simulator significance.

2 The Train Position Locator

The TPL is described in detail at [1] and [2]. Generally, the TPL is a real-time system that calculates position and speed of a train on the track by fusion of data from the GNSS receiver and INS sensors (odometer, accelerometer, gyroscope and microwave Doppler radar). Use of INS sensors can be simply described as follows: odometer, accelerometer and radar are used for the distance travelled calculation and validation. The gyroscope is used for gyro-odometry for routing detection on switches [3].

The positioning, in a track section, is mostly done by the GNSS receiver, where the Signal-In-Space (SIS) is available from minimally three satellites. On 'dark' tracks, where SIS is not available (radio shadow places), the position is calculated by means of data fusion of INS sensors. The Kalman filtering is used for INS data fusion. The Kalman filtering was extended by the PDAF (Probability Data Association Filter) method to achieve better stability and to filter INS data corrupted by sensor faults [4] and [5].

The recent work on the TPL is focused on development of the Autonomous Safety Integrity Monitor of the TPL. Its design results from the user safety requirements that have been specified, and reflects such terms as the position error, the protection level and the horizontal alert limit [6].

3 The simulator

The TPL must be properly tested, especially during running on 'dark' tracks with sensor malfunctions. That is not possible to provide on existing test platforms; therefore, the simulator has been developed.



The simulator should simulate motion of all INS sensors and the receiving of SIS by the GNSS receiver, in the same way as if it was provided on a real locomotive during running on tracks. The simulation must be defined by a speed profile with specified sensors faults – for example: wheel slips, acceleration drifts etc. The simulation of the receiving of SIS should be included too. It will respect predefined requirement as: satellites visibility, receiving conditions, daytime, added noises, elevation mask, signal multipath etc. Some of GNSS receivers provide precise timing by a 1 pulse-per-second (1PPS) signal. It should be included in the simulation too. The simulation of the GNSS message generation and the sensors motion must be precisely synchronized. The simulator should achieve synchronization with an accuracy of 1 millisecond.

It was decided to separate development of the simulator into two parts – off-line and on-line (see fig. 1).

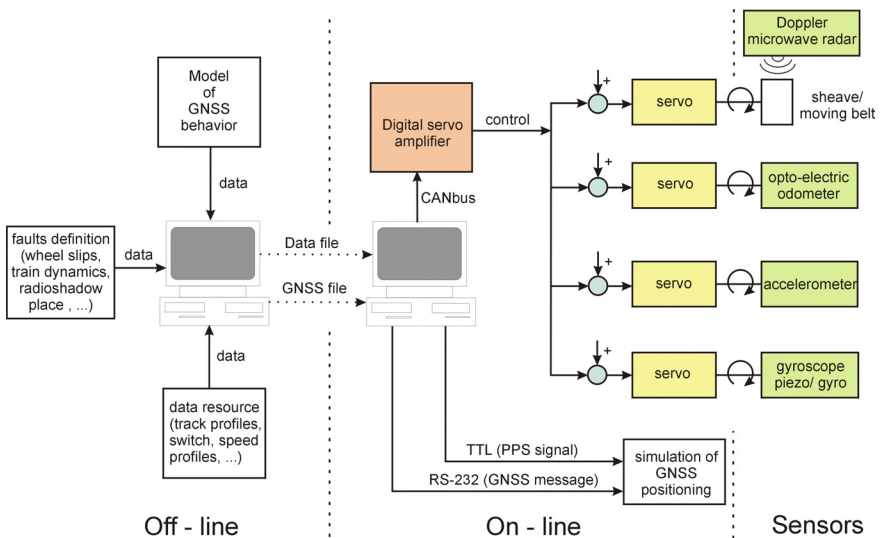


Figure 1: Architecture of the simulator.

3.1 Off-line part

Pre-calculation of the sensors motion is provided in the off-line part. Calibrations of accelerometer and radar servo-sensor systems are added into the pre-calculation. The GNSS message calculation is provided here too. Software tools for the off-line part were programmed in the Matlab. The software can use saved locomotive runs and change it. It enables the adding of sensor faults into specific section of runs - e.g. wheel slips, acceleration fault, different daytime, different satellite visibility etc.

The GNSS message generation is done by the third party software [7]. The Satellite Navigation Toolbox 2.0 for Matlab is used. The Toolbox allows simulating of the satellite constellation (GPS, Glonass and also Galileo in new

version), the propagation environment, the receiver measurements and the data processing of virtually all satellite navigation applications from stand-alone positioning, up through ambiguity resolution for differential carrier-phase applications. The simulation is modified by the daytime, the elevation mask, the satellite constellation, errors (thermal, tropospheric, ionospheric, multipath etc.), pseudorandom codes (P-code, C/A-code), types of measurement (stand-alone, differential or phase-carrier) etc. The results achieved by the GNSS simulation are shown in section 4.3.

3.2 On-line part

The on-line part provides a real simulation (the sensor motion and the GNSS message sending) according to pre-calculated data files and GNSS message files from the off-line part. Sensors motion is provided by the rotation of servo actuators, controlled by the servo amplifier, which is connected with the control computer by CAN-Bus. Maximal rotation of used servos is 3000 min⁻¹. The servo amplifier can be easily extended by other servo-sensor axes. Sensor motion control software was programmed in C++ on DJGPP under DOS environment. It is fully 32bit application.

3.3 Principle of the sensors simulation

An odometer sensor is connected into a servo axle by an axle joint. Rotation of the servo axle is directly transmitted to the odometer axle. Therefore, the maximal theoretical simulated speed of a train on the odometer axle, is about 700 km/h. But, it is reduced due to mechanical limitations of the odometer to approx. 300 km/h.

The simulation of the movement of the gyroscope is more complicated because of gyro sensitivity. It was necessary to include a reducer; the precise planetary reducer (with ratio 1:73) produced by Spinea was used. Rotation of the servo axle is transmitted by the reducer to the rotation of the whole gyroscope.

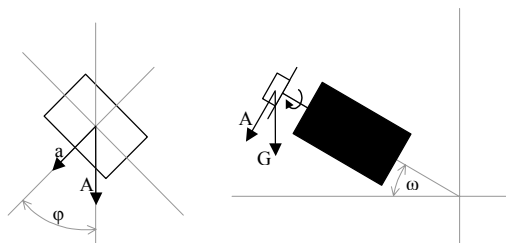


Figure 2: Principle of accelerometer simulation.

The movement acceleration has been measured on the locomotive. But, it is not possible to simulate accelerated movement of the whole accelerometer. Therefore, the measuring of the gravity fraction was used. The principle of accelerometer simulation is depicted on fig. 2. The measured acceleration a is given by rotation ϕ of the servo axle. Range of measurement $\pm A$ is given by

elevation ω of the whole accelerometer-servo system. The reducer (1:46) was used in order to reduce a vibration of the servo.

The simulation of the movement of the microwave Doppler radar is still under development. Two principles are discussed. Firstly, the measuring of tangential velocity of a rotating cylinder, and secondly, the measuring of velocity of a moving belt. The first principle was realized, but there exist a problem with non-linearity of measurement. The second principle is currently prepared, but theoretically it should bring better results.

The GNSS message is sent through RS-232 serial port. The PPS signal is also simulated. It is provided by TTL pulse with respect to predefined delays. All sensors simulations are synchronized with this PPS signal, and it is used as main synchronization of the simulator.

4 Experiments and results

The simulator is usable for the running locomotive simulation, if measured data has identical behavior in the simulator as in the locomotive. For comparing both situations, relevant mathematic methods must be established. If a sufficient number of sufficiently long measurements with accurate reference values exists, it is possible to use this data for the assignment of statistical properties of these measurements. These properties must be identical or almost identical. The difference between measured data and accurate reference can be used for comparing in that way.

Firstly, noises of data obtained from sensor in the locomotive and in the simulator must be mutually independent. (Naturally, assumption of usability of the given sensor is independency of measured noise at the measured values). It is determined with the help of the standard deviation of correlation function of both noises. The value of this standard deviation must be lower then one divided square root from number of measurements.

The second condition is more significant. The probability density of noises from the locomotive and also from the simulator must be identical or almost identical.

4.1 Tests of the simulator

The example of such distributions obtained from gyroscope data is shown in fig. 3. Comparing these distributions shows that the probability density of measurement noise in the locomotive is very similar to the noise in the simulation. These functions have peaks distributed in the spectrum with constant distance. This distance is caused by resolution of used measuring PC card.

The opto-electric odometer is employed on the locomotive. It provides 400 pulses per turn. A fork clutch is used as a standard odometer-servo axle joint. It causes axles eccentricity. If the clutch is in the long run it can cause slight grinding of the clutch. Fig. 4 shows the effect of eccentricity and clutch deformation. There are depicted approximately two and half turns of the odometer.



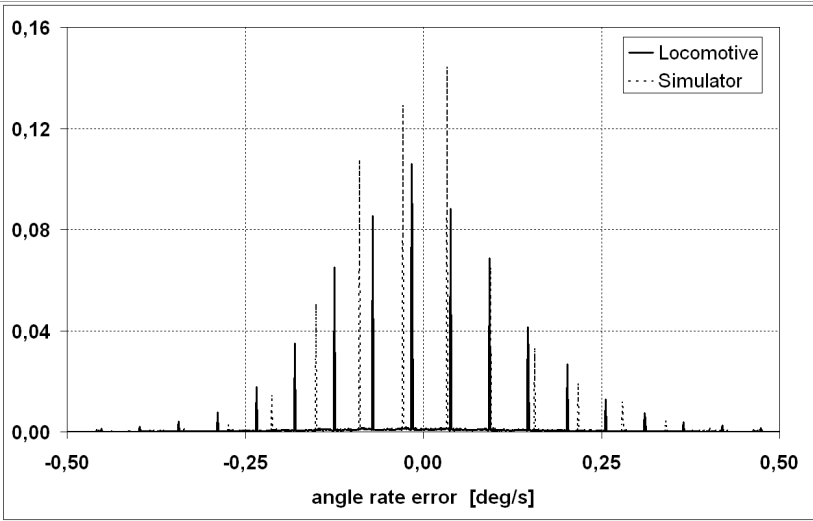


Figure 3: The probability density of gyroscope data obtained from the locomotive and from the simulator.

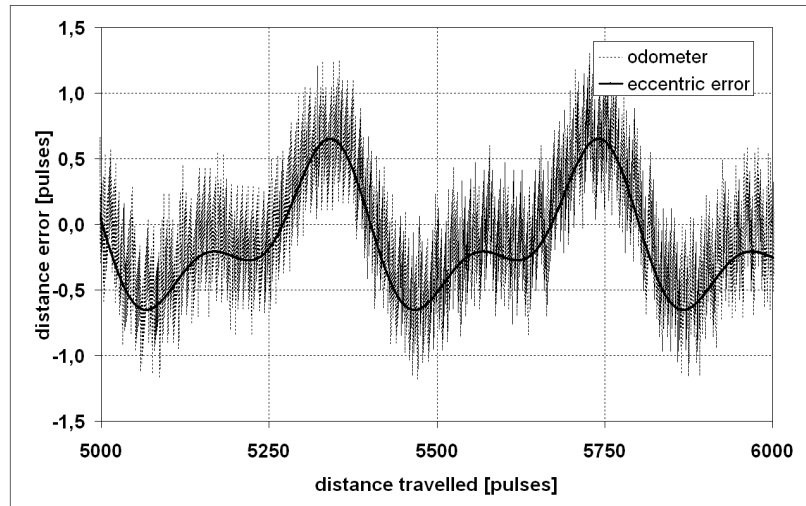


Figure 4: Eccentricity and deformation effects of the fork clutch.

Eccentricity and deformation are mostly constant during the measurement. Therefore they can be easily removed from the data. Residual noise has the distribution function very close to the normal distribution, as is clear from fig. 5. The standard deviation of this distribution is about 0.334 of an odometer pulse. It represents a position error of about 3 mm.



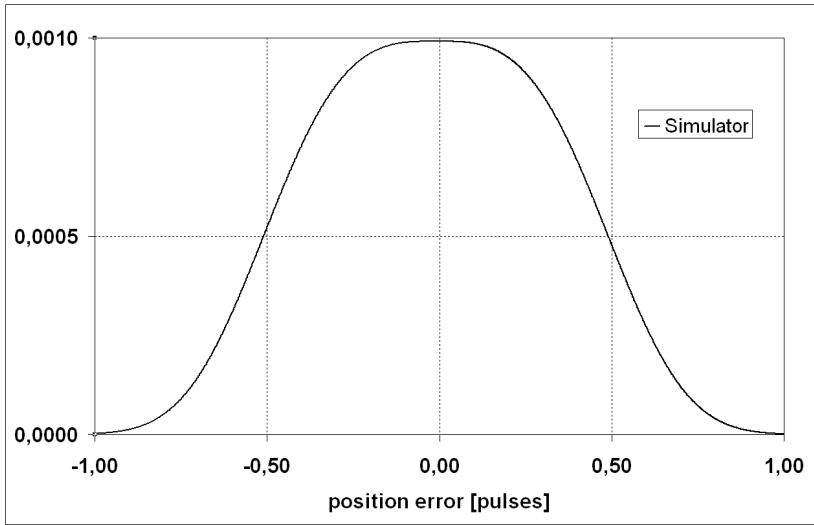


Figure 5: The probability density of odometer data in the simulation.

4.2 Tests of the PDAF method

The following simulations were done for testing of the PDAF method and for testing of behavior of the simulator too. The PDAF method is part of the TPL, as was mentioned above.

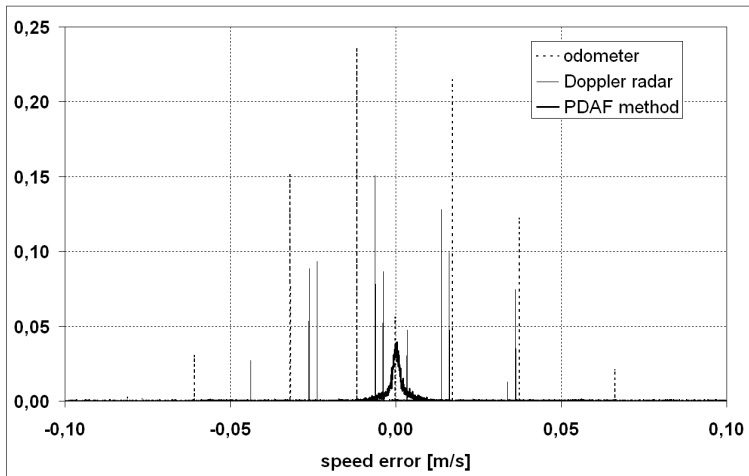


Figure 6: The probability density of speed data.

Results of one of simulations are shown in fig. 6. The odometer and radar were simulated. Speed data was fused by means of the PDAF method. The results (odometer, radar and PDAF speeds) were compared with reference speed. The running with a simple speed profile was performed - acceleration from zero to 80 km/h, next deceleration to 50 km/h and finish deceleration back to 0 km/h (duration of the whole running period was about 20 minutes).

Peaks of measured data correspond to pulse output of odometer and also radar. The graph shows high efficiency of the PDAF method.

Fig. 7 depicts results from the acceleration simulation. Peaks of measured data are caused by the resolution of used measuring PC card. The distribution of simulated acceleration and fused acceleration by means of the PDAF versus reference acceleration is presented here. The center of distribution is shifted due to the bias of accelerometer.

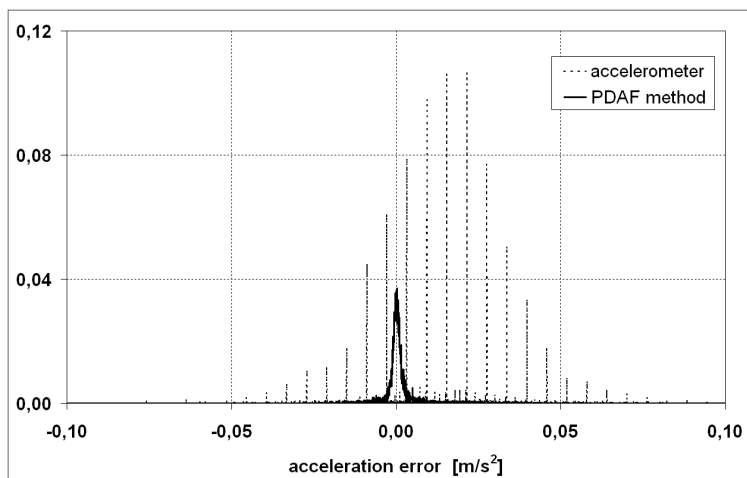


Figure 7: The probability density of acceleration data.

4.3 Test of the GNSS simulation

The simulator allows simulation of the GNSS position by means of the GNSS messages generation. Data in fig. 8 was generated on the same track, at the same speed profile as the simulation in section 4.2, when only daytime and the elevation mask were changed. The position error (95% of time) of the differential GNSS simulated position versus the reference trajectory is presented here. The elevation mask should be chosen from 5 to 20 degrees as it is verified by real measurement. The simulation produces the same result.

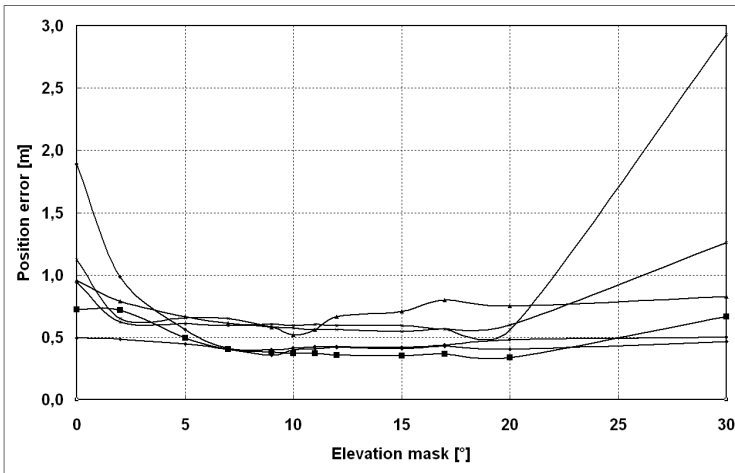


Figure 8: The position error of simulated GNSS position.

5 Conclusion

This paper describes the conception of the simulator of the Train Position Locator. It is clear that this laboratory equipment is necessity for development of the TPL for safety of life applications. It improves costs and time of development. Many experiments can be performed only on this simulator because many of them are not able to be tested in the real environment.

The evidence of the high efficiency of the PDAF method is shown. As is clear from the presented simulation results, it can significantly reduce position error and, therefore, it can improve usability of the TPL.

The simulator is still under development, especially the principle of the microwave Doppler radar simulation. But as it was presented in experiments and in its measured results, it is fully functional. Maximal simulated speed is now limited to 100km/h, but improvement up to 160 km/h are investigated. The open architecture of the simulator is also of a big benefit, because the simulation can be easily extended by other sensors.

Acknowledgement

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