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VEHICLE NAVIGATION SYSTEMS INVOLVING INERTIAL SENSORS AND ODOMETRY DATA FROM ON-BOARD DIAGNOSTICS IN NON-GPS APPLICATIONS*

Piotr Prusaczyk[1]**,** ***Leszek Baranowski***[2]**,** ***Jarosław Panasiuk***[3]

[1]ORCID: 0000-0002-1347-1202
Faculty of Mechatronics and Aerospace
Military University of Technology in Warsaw
[2]ORCID: 0000-0002-5239-0659
Faculty of Mechatronics and Aerospace
Military University of Technology in Warsaw
[3]ORCID: 0000-0001-8480-1654
Faculty of Mechatronics and Aerospace
Military University of Technology in Warsaw

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Abstract

This paper explores the applicability of on-board diagnostics data for minimizing inertial navigation errors in vehicles. The results of driving tests were presented and discussed. Knowledge of a vehicle's exact initial position and orientation was crucial in the navigation process. Orientation errors at the beginning of navigation contributed to positioning errors. GPS data were not processed by the algorithm during navigation.

Correspondence: Piotr Prusaczyk, Zespół Mechatroniki, Katedra Mechatroniki, Wydział Mechatroniki i Lotnictwa, Wojskowa Akademia Techniczna, ul. gen. Sylwestra Kaliskiego 2, 00-908 Warszawa 46, e-mail: piotr.prusaczyk@wat.edu.pl.

* Research notes (short communications).

Introduction

Knowledge of a vehicle's position and velocity is essential for many applications, in particular in outdoor vehicles. GPS is widely used for accurate and robust localization. Unfortunately, pure GPS localization can be highly inaccurate in urban environments such as tunnels and urban canyons. In specific situations, the GPS signal can be jammed or turned off. For these reasons, there is a high demand for other navigation techniques (PRUSACZYK et al. 2018a). Inertial navigation systems are theoretically optimal because they do not require external signals to estimate an object's movement. Such systems integrate measurements of rotation and acceleration rate to estimate an object's position. However, accelerometers and gyroscopes do not support accurate positioning during prolonged operation due to data drift (TITTERTON, WESTON 2004). In land navigation, wheel encoders that compute odometry are cost-effective and convenient solutions for determining changes in position, especially in wheeled mobile robots (KACZMAREK, et al. 2017). The data acquired by electronic on-board diagnostic (OBD) systems in vehicles can be used for self-localization (MERRIAUX et al. 2014).

The aim of this study was to propose a navigation method based on inertial and odometry data. The XSens inertial measurement unit (IMU) was used to measure acceleration and rotation speed. Odometry data were provided by the OBD system. The experiment was conducted on the assumption that the vehicle's initial position and orientation are known.

The next section of this paper overviews inertial systems. The following section contains a short introduction to OBD systems. Hardware implementation, including the OBD Reader and the XSens Inertial Measurement Unit, is discussed in the subsequent chapter. The experimental design and research methodology are presented in the Materials and Methods section. The results of the navigation experiment performed in a real-world environment are discussed, and the relevant conclusions are formulated in the last sections.

Inertial Navigation System

Inertial navigation systems (INS) are entirely self-contained in a moving object, and they are not dependent on external radio or optical signals. These systems rely on the inertial properties of navigation sensors that are mounted in moving objects. The system processes data from three-dimensional linear accelerometers and three-dimensional inertial angular rate sensors. The system calculates an object's position and changes in orientation over time (Fig. 1). The information about a vehicle's position and orientation at the beginning of navigation is required to determine the vehicle's position and velocity without the use of external data. In modern INS, sensors are attached to the vehicle body, which eliminates the mechanical complexity of platform systems. The use of silicon chips has considerably reduced the size and number of system components, which contributed to a reduction in costs. The MEMS gyroscope is non-rotating device that relies on the Coriolis force acting on a vibrating proof mass to calculate inertial angular rotation. The main disadvantages of MEMS gyroscopes include increasing computing complexity and the need to use sensors capable of measuring higher rates of turn (PRUSACZYK et al. 2018a).

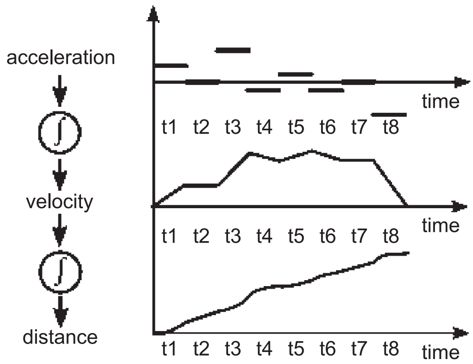

Fig. 1. Integration process

On-Board Diagnostic System

On-Board Diagnostics (OBD) is a term that refers to a computer-based system where an electronic control unit (ECU) collects input data from various sensors to control the actuators and reach the desired performance parameters (Fig. 2).

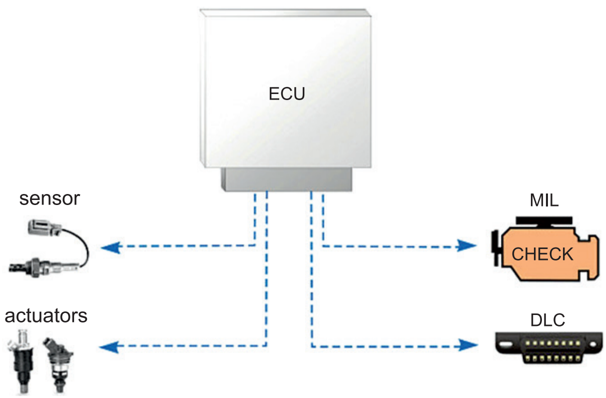

Fig. 2. Diagram of an OBD system

The “Check Engine” light, also known as the Malfunction Indicator Light (MIL), is an early warning of a vehicle malfunction. A modern vehicle can process hundreds of parameters accessed via a Data Link Connector (DLC) which interfaces a scan tool with a vehicle’s control module.

The first version of the OBD system standard was introduced in 1985. The OBD system was implemented to improve in-use emissions compliance by alerting the vehicle operator when a malfunction exist, and to aid automobile repair technicians in identifying and repairing malfunctioning circuits in the emissions control system (GAURI et al. 2017).

Materials and Methods

OBD Reader

In the present experiment, the OBD Reader was used to gather information from the OBD system. The OBD Reader was designed by the authors to export data frames from a vehicle’s subsystems such as the Engine Control Unit (ECU) and the Automatic Brake System (ABS). Data frames are converted and sent to a PC via a USB port (Fig. 3). Data are converted by an 8-bit microprocessor and a K-line interface chip (PRUSACZYK et al. 2018b).

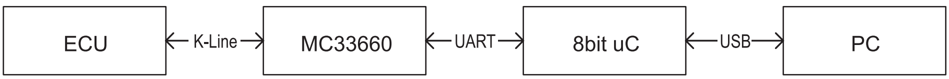

Fig. 3. OBD Reader model

XSens Inertial Measurement Unit

In this experiment, the XSens MTI-G30 Inertial Measurement Unit (IMU) was used to measure linear accelerations and rotational speeds acting on the object (Fig. 4).

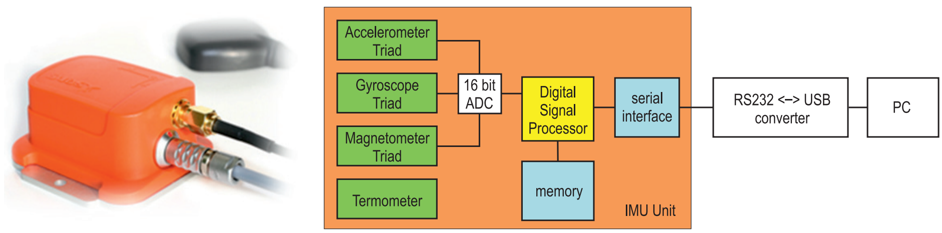

Fig. 4. XSens IMU (*a*), diagram of the test stand (*b*)
Source: based on XSens, www.xsens.com.

Hardware Integration

The XSens IMU and the OBD Reader communicated via a USB interface (Fig. 5). Both devices were controlled by a PC (PRUSACZYK et al. 2018b).

Fig. 5. Hardware connection diagram

Experimental Design

The performance of the inertial navigation system was analysed in an experiment conducted in a real-world environment. The test route was developed based on digital map data and the below parameters:
– Test distance – around 2,000 meters,
– Several reorientation points.

The experimental data were acquired with dedicated communication software and processed in the MATLAB environment. GPS data were collected as real position data during the experiment for the purpose of verification and comparison.

Results

The experiment was performed in city traffic. The following characteristics of the generated route were extracted (Fig. 6):
– Final reorientation of the vehicle – above 360°,
– Several reorientation points (multiple turns),
– Test distance – 2,030 meters.

The vehicle's orientation relative to three axes is presented in Figure 7. The right-most diagram shows the heading of the vehicle. Several changes in the vehicle's heading can be observed when turning at a junction.

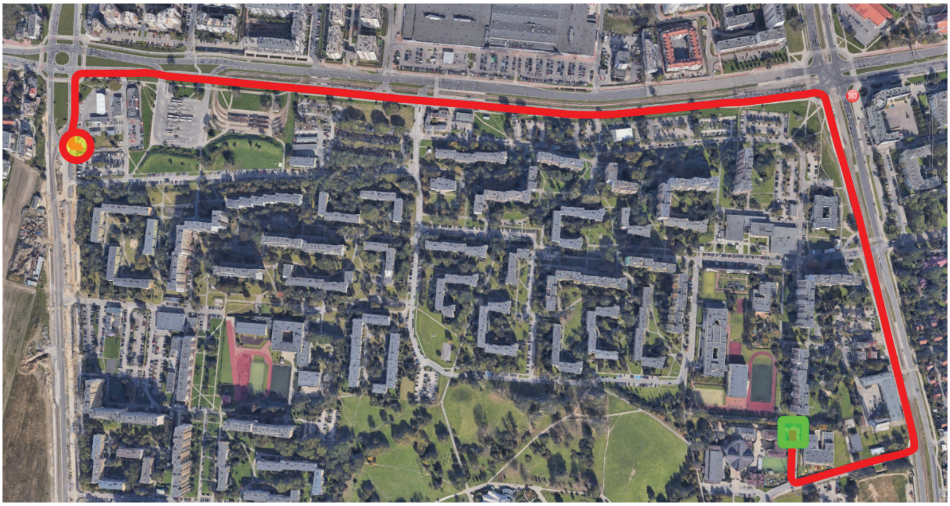

Fig. 6. Experimental path

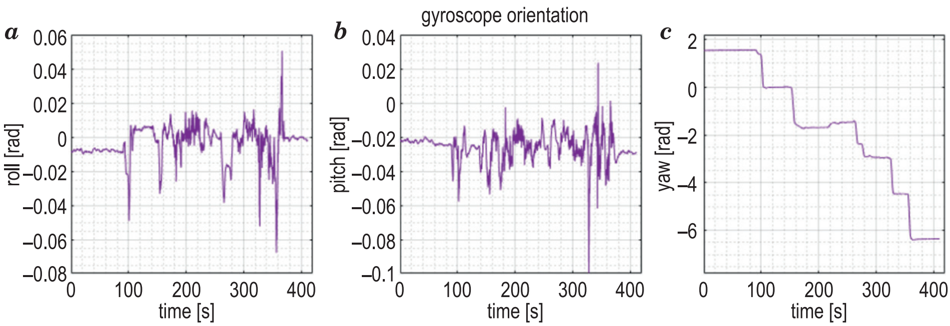

Fig. 7. Recorded gyroscope orientation around x axis (a), y axis (b) and z axis (c)

The three sources of velocity data are presented in Figure 8. The first is the inertial navigation system assisted by Zero Update Velocity (ZUPT) which detects stationary states for resetting the inertial sensor. The second source is the OBD system, and the third source is the reference speed from a calibrated GPS sensor.

The velocity measurements acquired by the assisted inertial navigation method contained errors relative to the data obtained by the OBD-assisted odometry method. The iterations of inertial velocity data could be responsible for significant differences in estimates of the vehicle's position.

The path shape estimated by the inertial navigation system aided by OBD odometry is similar to that estimated by GPS (Fig. 9), with some differences (Fig. 10) caused by hardware errors.

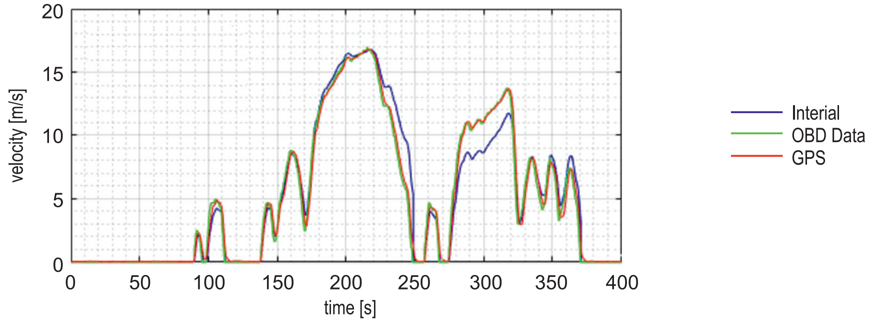

Fig. 8. Registered velocity

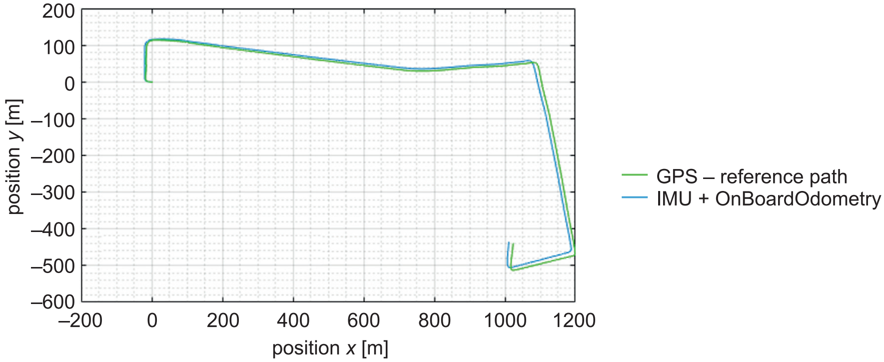

Fig. 9. Obtained trajectory

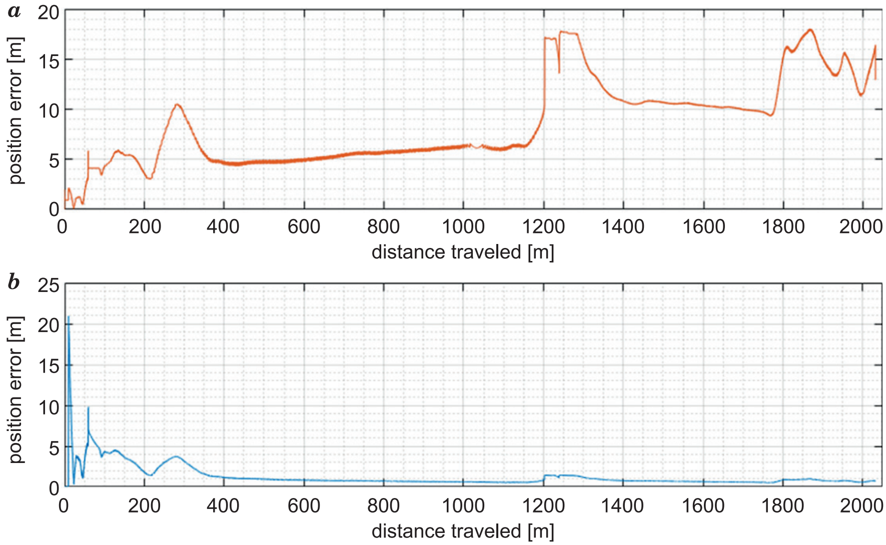

Fig. 10. Position error in meters (*a*) and percentage of travelled distance (*b*)

Fewer navigation errors were generated than in the standalone inertial navigation system. During the experiment, the position error remained stable over time. Position errors as a function of the travelled distance are presented in Figure 10.

Conclusions

A practical application of non-GPS navigation based on inertial sensors and odometry data from a vehicle's On-Board Diagnostic system was presented in this article. Unlike in pure inertial navigation systems, the number of errors in odometry-assisted systems increases only with the travelled distance. Position errors remained stable during the experiment, but the tested solution cannot be applied in long-term navigation scenarios. Additional sources of data are needed to minimize the increase in the number of position errors.

An algorithm for determining a vehicle's initial position without a GPS signal will be implemented in future research.

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