Detecting Critical Situations in Railroad Traffic through On-Board Diagnostic Systems

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ABSTRACT

The paper presents an application of an on-board recording system for critical situation detection in railroad transportation. The evaluation of the state of a rail vehicle is based on the signals recorded with the use of ORD (On-Board Recording Devices) devices. The main subject of interest are critical situations that can occur when the rail vehicle is in motion. The critical situation is any situation of engine malfunctions, leaks, high vibrations, excess velocity, acceleration or inclination. The motion parameters are acquired from the GPS (Global Positioning System) device, accelerometers and gyroscopic MEMS (Micro Electro-Mechanical Systems) sensors. The paper also presents different applications of acceleration sensors which can be used to register vibroacoustic signals from the sensors fitted on an engine block or in other vehicle locations. The vibroacoustic signals can be used to detect the malfunctions of the engine and other vehicle devices. Eventually, a prototype of a recording device was developed. It records signals measured by an inertial module such as linear acceleration, angular acceleration and position determined by GPS sensor. The data from the GPS together with the data from the inertial module, are recorded as a text file and can be visualized by geo-information instruments.

Keywords: railroad, critical situation, on-board devices, GPS, signal processing

1. INTRODUCTION

Railroad provides budget, economical and ecological transport of goods and people and its position has been increasing recently in many countries. In order to face new challenges modern railroad needs modern management for the improvement of safety, comfort and reliability.

Recording and detection of critical situations should be an important component of each modern railroad management system. A critical railroad incident means any incident when the rail vehicle is in motion that can lead to any kind of damage, failure or other risky situation such as collision of two vehicles, collision of vehicle with an obstacle or derailment that may result in passengers’ death, disability or injury, damage of transported goods and environment pollution. Such accidents can be a result of excess velocity or acceleration, improper velocity in relation to the road conditions, brake damage or other malfunctions of the locomotive and the cars. The risk of these accidents should be estimated based on the knowledge of a current vehicle state, meaning data on the engine malfunctions, leaks, vibrations, geographical position, railroad conditions etc. [1, 2].

In practice, the detection of events needs a set of recording devices fitted into a vehicle. These devices are usually known as On-Board Recording Devices ORD. They are used in transportation, under the name of “black boxes”.

This way the vehicle state should be determined based on the set of signals acquired by the ORD devices such as accelerometers, gyroscopic MEMS rotation sensors and GPS. It should be stressed that accelerometers can be used both for the trajectory recording and the recording of vibroacoustic signals that can be used to estimate the state of the engine and other elements. In turn, the use of GPS is interesting not only because GPS provides the geographical position of the vehicle, but also because it provides information on the vehicle velocity [3]. Indeed, the vehicle velocity can be determined based on the ORD signals using accelerometers or gyroscopes but such a measurement can only be approximate and the use of the GPS data seems very useful.

The signals recorded from the GPS devices need analysis and in this matter a wide range of methods can be used, including methodology based on artificial intelligence. Sophisticated
computational methods can be used for the analysis of the vibroacoustic signals.

2. ON-BOARD RECORDING AND ANALYSIS OF SIGNALS REFLECTING THE STATE OF THE VEHICLE

The name „black box” is historic and dates back to the times where such a recording device was placed in a solid, damage resistant box that always came in black color. Nowadays these boxes are rather red or of a different bright color. Usually we refer to them as ORD (On-Board Recording Devices) or EDR (Event Data Recorder). So far these devices have been used in air transportation and automotive industry, but recently we have found a growing interest in their application in railroad.

The older version of such a device in vehicles is tachograph. Today cars are fitted with many ORD devices. There are trip recorders, electronic engine control systems, brake anti-blocking systems, radar based collision alert systems etc. [4].

One of a very important task of typical ORD system is recording of vehicle trajectory and its position in the moment of collision, failure or accident. Each ORD sensor is subjected to factors that render the measurement inaccurate. For a sensor or a set of sensors treated as a point, the main disruption factor is the location and orientation of sensors in reference to the vehicle, nonlinearity and sensor discalibration, measurement interference and oscillation, sampling time and filtration methods.

The movement parameters are usually described in global (to rails) or local (vehicle) system of reference. While the forces that generate the motion are described in a global system of reference the integration of acceleration signals directly provides the trajectory. The measurements are usually carried out in a local system of reference. The displacements between local and global system of reference is variable in time. The gravitational force should also be taken into account.

If all factors disturbing the measurement were known then the trajectory reconstruction would be a simple translation from the local to the global system of reference. In fact, a vehicle position and outside conditions are uncertain and the measurements are always burdened with a given error distribution. In trajectory reconstruction both two and three-dimensional algorithms are used. The three-dimensional algorithms are particularly useful during a reconstruction of roll-over accidents [5, 6].

The main tasks during a reconstruction of dangerous accidents are the selection of motion parameters, system of reference and the moment of recording. Any vehicle in motion is usually considered as a rigid body; hence the full description needs a determination of three linear and three angular coordinates. The use of on-board sensors (accelerometers and gyroscopes) enables determining of linear and angular accelerations. For a sensor set treated as a point object the main factors that affect the reconstruction of the vehicle trajectory are the position of the sensors and the direction in reference to the vehicle, the sensors non-linearity and discalibration, measurement noise and oscillations, sampling time and filtration methods.

The standard on-board system in modern cars enables the reading of many motion parameters, e.g. braking forces can be taken from the anti-lock braking system, the position of the throttling valve from power control module, the position of the steering wheel from the traction control system etc. Unfortunately, most of the rail vehicles used in transportation is old rolling stock and they are not fitted with this type of devices. Hence, the obtaining of important motion parameters needs a vehicle to be fitted in additional on-board recording devices. A huge facility is the fact that rail vehicles are moving on stable trajectories described by rail tracks [5].

Together with accelerometers and gyroscopes the next important element of the designed ORD system is the GPS device. Typical GPS does not work in places such as tunnels or areas between tall buildings and hills. From this point of view only the combination of the data from the GPS with the data from the accelerometers and gyroscopes allows the estimation of vehicle position in all circumstances [7]. Moreover, the GPS is not a simple ready to use application. It needs special software and hardware.

The GPS device needs special software and hardware in order to fully utilize its potential. In practice, each commercial GPS receiver uses communication protocol NMEA (National Marine Electronics Association). Usually, not all NMEA commands are implemented. Some NMEA announcement gives the direction of velocity in degrees in a system of reference connected to the ground and a velocity module in km/h or knots. In NMEA binary mode there is an access to some additional information depending on the manufacturer and type of sensor. For example velocity vector components (along axes: longitudinal, latitudinal and vertical). It is worth mentioning that the velocity is usually not determined from the calculation of the path over time but from the Doppler effect. In general, algorithms applied in a GPS system can be different and the velocity correction can be done in many ways.

From the practical point of view the application of GPS system seem particularly interesting together with GIS systems (Geographical Information Systems). GIS systems are computer systems that acquire record, manipulate, analyze and present geographical information [8]. Together with GPS data, GIS allows representing and tracing of a route and position of a vehicle on a map [3]. Such a GIS and GPS connection allows not only finding a vehicle position on the map in case of an accident or damage, but also immediately feeds such parameters as weather conditions, rail conditions, presence of other vehicles in the vicinity etc. [9, 10].

In the area of detection, prediction and recognition of accidents control and management of traffic and information on traffic organization many sophisticated methods are used [11, 12, 13]. We can find here special signal processing methods and some methods based on artificial intelligence – fuzzy methods, neural networks and genetic algorithms (see e.g. [14]). These methods are commonly developed in transportation, particularly in public transportation. The most popular and most developed are systems of vehicle motion control on expressways [10, 15]. In this area there are applications to detect expressway accidents. This kind of systems has a huge potential hence they are now used in railroad transport, e.g. in modeling, prediction and prevention of railroad accidents [1, 2].

The analysis of signals registered by ORD devices is a complex process. It contains both high technology of signal recording and sophisticated algorithm and software for signal processing. Many methods are used based on widely understood artificial intelligence, e.g. artificial neural networks, fuzzy methods, genetic algorithms, support vector machines etc.
Very often signals which represent the different states of a rail vehicle can be distinguished by a human expert. This fact is, among others, a main reason for the use of artificial intelligence methods in this matter (see e.g. [16, 17]). What is also important is that very often in a system of recognition of critical situation there is no sufficient emphasis on obtaining precise history of vehicle trajectory and state. More important is finding parameters whose observation can show and prevent dangerous situations. Many supervised and unsupervised methods can be useful in this area. One can find here an application of neural net [16] or special clustering algorithms [15].

Usually, before a typical classification the signals are preprocessed. It should be emphasized that the preprocessing can be treated as the first phase of classification and recognition. Together with classic spectral processing methods the application of nonlinear methods based on chaotic theory seems also interesting [18, 19, 20]. The basis for the development of intelligent traffic management system should be effective on-board recording systems that combine the GPS and GIS potential. Such systems are developed in the area of public transportation and their application in railroads seems particularly interesting [17]. The application of GIS systems in transportation started at the end of 1980s and is sometimes referred to as GIS-T systems [8].

The general concept of the prepared prototype of the on-board device is as follows: The on-board computer system should receive a broad spectrum of input signals. The signals come from accelerometers and gyroscopes, MEMS signals are used for trajectory reconstruction and the accelerometers diagnostic signals represent the engine state and the state of other vehicle parts. The signals also provide information on the vehicle velocity. There are also other special on-board devices (optional), GIS information containing the information on the state of the railroad (optional) and the GPS signals representing the position and velocity. The on-board computer system based on the above mentioned input signals should perform the analysis providing detection and identification of critical situations.

The prototype of the designed recorder received a name of R.M.S. 09. It uses a GPS sensor Garmin GPS16. This gives the possibility of producing more accurate position coordinates using differential corrections in the RTCM SC-104 standard with technology DGPS (Differential Global Positioning System) which is an enhancement to GPS that uses a network of ground-based reference stations and RTK (Real Time Kinematic) which based on the use of carrier phase measurements. The differential GPS data for DGPS or RTK technologies needs to be fed to the sensor serial input in real time while the results are to be available during the measurements. Another approach can be post-processing of the collected data off-line and then a live data link during measurements is not required. The latter technique is widely used in geodesy in land surveying. Nowadays, however, wireless information technology has become widely and cheaply available, so various solutions of aided GPS are more and more common in diverse applications. The simplest is the delivery via the Internet in generally accepted protocols using TCP/IP and UDP data services (e.g. NTRIP, GNSS Internet Radio).

Some projects of this kind are subsidized by The European Union, and member states are required to develop and make DGPS/RTK data streams publicly available to interested parties on their territories. The intended use spreads widely from geodesy to real-time navigation for vehicles and vessels. Not all projects in this area meet the anticipated deadlines, but sooner or later the data streams across Europe should be commonly available to the public.

Nowadays while wireless technology became cheap and easy available GPS applications can be implemented using modems with built-in script interpreters, such as Python or Java. They allow users to add their own functionality without external specialized microcontrollers. The first tests were conducted with a Telit GM862-GPS module with the evaluation kit EVK2. The unit has a built-in GPS receiver, GSM (Global System for Mobile Communications) modem with GPRS technology (General Packet Radio Service) and a Python script interpreter. It comprises only one 10-bit analogue input and some general-purpose input/output lines that can be accessed and used from the user application. The processing power of the unit is not very impressive, however suffices for simple tracking purposes, receiving, processing and answering text messages, e-mails and data transmitted via GPRS (TCP/IP and UDP protocols). It amends them with acquired information, such as location (from internal GPS sensor), binary signals or temperatures, pressures, levels, etc. Some simple applets were written to test its suitability for vehicle tracking and remote diagnostic. For instance, gathered information (location, velocity, heading from GPS sensor and

3. MEASUREMENTS AND EQUIPMENT

Artificial intelligence methods are applied in the area of modeling, reasoning and prediction of rail accidents [1, 2]. It needs systematic research and analysis of rail accidents [1] and should lead to a preparation of the railroad security system models [1]. The main aim of such research is to keep the rail operating risk on an acceptable level. In some AID (Automatic Incident Detection) systems the Bayesian decision systems and artificial neural neurons were used.

An approach where the data from the GPS and the GIS systems are combined is sometimes called a 3G technique. 3G means an integration of three kinds of data - GPS, GIS and, additionally, GSM - the most popular standard in cellular telephony providing communication between control centers, GIS terminals and GPS on-board units.
some other diagnostic data) can be sent in a text message, in a response to an SMS containing valid password and one of the available commands. The SMS solution is not an optimum one for each application, so subsequently; other means of available communication such as SMTP/POP3, TCP/IP, UDP protocols are to be evaluated.

It is worth mentioning that acquired in experiments semiconductor gyroscope signals are worthless in reconstruction of the movement trajectory of vehicles without an application of special dedicated algorithms for compensation of drift and temperature susceptibility. Depending on the temperature the integrated position readings of motionless system consist of three ADIS16255 gyroscopes after the time of several hundred seconds reach a value of a full turn 360°.

4. RESULTS

On board tests with the use of the R.M.S. 09 recorder were performed and measured three accelerations in three perpendicular directions in space. The device is fitted with a color LCD display, foil keyboard, independent battery supply and a SD/MMC memory card (typically 1 – 16 GB) to keep the measurement results. The device was build with the use of an initiation set and based on Atmel AVR32UC3A0512 processor. The device allows a measurement, data acquisition and transmission to a PC computer by a build-in USB port. Using the serial port the standard GPS receiver can be connected that communicates in the NMEA standard recording synchronously with the data from the inertia sensors [24, 25].

The data from the R.M.S. 09 recorder can be visualized and presented as a route on a map. The messages generated by the GPS describing the current position of an object, its velocity and movement direction together with the measurement data from the inertial module, are recorded as a text file. The prepared scripts and software allow a conversion of the text messages in NMEA standard from GPS to a form which allow an easy visualization with the use of commonly applied formats and instruments such as Google Earth (applying KML/KMZ - the most popular format of geo information data).

The R.M.S. 09 recorder can detect all excess accelerations and show the admissible values of accelerations on a railroad vehicle body in Poland (1.0 \(\text{m/s}^2\) till 5.0 \(\text{m/s}^2\) depending on vehicle type and direction).

The testing of the device acceleration and position measurements of the rail vehicles was done. The tests included the traffic of a typical passenger train and shunting of railroad cars as well as the ride of a locomotive through crossovers. The tests in this matter are still continuing. Fig. 1 presents the exemplary acceleration recording in three x, y and z directions for experiments on diesel locomotive low speed ride on sloping curve rails on the distance of 50 meters.

One of the tasks of the designed ORD system is the detection of any engine damage and malfunctions. Experiments in this area cover the investigations in the area of diagnosis of the states of the diesel locomotive engine before and after a repair and also for the state of misfire and lack of misfire. The misfire detection is fairly important in terms of the emissions but this kind of information became a standard in data acquisition in modern ORD devices (on-board diagnostic systems in cars, OBD II, EOBD). The proposed diagnosis is based on the analysis of vibroacoustic signals taken from the engine body.

To this end some special methods were used and are expected to be used in the future. We have, for example, the calculation of global statistical parameters such as mean, median or standard deviation [26, 27], nonlinear analysis [18, 19, 20], short time analysis [28, 29, 30] and the SVM method (Support Vector Machines) [31]. In a nonlinear analysis the dominant Lyapunov exponent was selected as a diagnostic parameter [20]. The measurements of an engine state before and after a repair were performed on a Diesel engine 14D40 (power output 1470kW or 2000 KM) of a locomotive ST44 2045. The measurements for the misfire detection were, performed on Diesel engine 16 H12A Henschel – 12V fitted in a Diesel locomotive 401Da – 427. The misfire was generated by a disconnection of one cylinder in the engine.

![Fig. 1. Exemplary plots of acceleration in x, y and z directions for combustion locomotive low speed ride on sloping curve rails on the distance of 50 meters.](image-url)
comparison of SVM algorithms was based on the classification results of classification. The experiments were done using SVM to classify signals corresponding to different engine states the artificial intelligence methods and algorithms in this matter. This gives us the prospect to use signals from the signals. It was found that for different rail situations the recorded signals show a large complexity of sensors, circuit fitting and adjustments. The problem of finding a vehicle trajectory turns out to be quite complex, especially in the presence of exterior disturbances and a more complex type of motion.

Eventually, a prototype of a measuring device was developed. Using a MMC/SD card it registers signals measured by an inertial module such as linear acceleration, angular acceleration and position determined using the connected GPS sensor. The messages generated by the GPS describing the current position of an object, its velocity and movement direction together with the measurement data from the inertial module, are recorded as a text file. The prepared scripts and software allow a conversion of text communications in NMEA standard from the GPS to a form which allow an easy visualization with the use of commonly applied formats and instruments such as Google Earth (using KML/KMZ format, one of the most popular format of geo-information data).

The paper presents the present state of research on building a common railroad ORD critical situation detection system. The future work will focus on the development of the prototype for general use in railroad traffic. The important point is the full integration of signals from the inertia sensors, such as gyroscopes and accelerometers with the GPS system. For sensor fusion algorithms there is a need to apply relatively powerful microprocessors. Another interesting approach is the application of GPS sensor matrices to increase the accuracy of measurement and to determine the altitude of an object. One of the main shortcomings of the GPS technology is that the use of only one GPS sensor makes it impossible to determine the object altitude and that proves to be a significant disadvantage in the reconstruction of trajectory of an object in all degrees of freedom (i.e. when altitude coordinates are necessary). Using two or more precise GPS sensors with raw-data carrier phase output can eliminate this drawback. The final version must register the acceleration, gyroscope and GPS signals together with the vibroacoustic signals providing information about the engine state. The last important point will be combination of the GPS and gyroscopic data to produce information on dangerous tilts.

Generally, the here presented results indicate the usefulness of the proposed methods of detecting critical situations in railroad transportation. They are ready for modern applications in on-board diagnostic and recording systems of rail vehicles.

**Acknowledgments:** The paper was supported by the Grant No N509 047 32/3308 of Scientific Research Committee in Poland

### 5. CONCLUSIONS

The introductory investigations on the application of various ORD devices (accelerometers, MEMS gyroscopes, GPS) have shown a large complexity of sensors, circuit fitting and adjustments. It was found that for different rail situations the recorded signals show a large complexity of sensors, circuit fitting and adjustments. The problem of finding a vehicle trajectory turns out to be quite complex, especially in the presence of exterior disturbances and a more complex type of motion.

### 6. REFERENCES


