Monitoring of combustion locomotive state with the use of an on-board device

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Abstract

This paper presents the current state of the research on the on-board recording system application for the detection of critical situations in railways. The estimation of the rail vehicle state is based on signals registered by using a specialized on-board device. The critical situation of a rail vehicle can consist of diesel locomotive engine dysfunctions, high vibrations, exceeding of limit velocity, acceleration or inclination. The monitoring of the vehicle state needs a set of sensors. The movement parameters are acquired from a GPS device, accelerometers and gyroscopic MEMS sensors. Especially interesting here is the application of GPS signals, because GPS not only gives a geographical position, but also the vehicle velocity. The accelerometer sensors which measured the acceleration in three perpendicular directions were assigned to operate together with GPS in order to establish the vehicle position and for the detection of exceeding any limit acceleration value. The gyroscopic MEMS sensors support the position and route detection and also show any exceeding in vehicle limit inclinations. Additionally, some accelerate sensors record the vibroacoustic signals taken from chosen places on the engine body or other vehicle parts for the assessment of the engine state, particularly in terms of potential failures. The analysis of the additional acceleration signals was performed using specialized signal processing methods and some specialized algorithms based on artificial intelligence (e.g. Fourier analysis, wavelets, nonlinear methods based on deterministic chaos theory, short time methods and support vector machines). The first results are promising and show the possibility of using the above described approach to detect the combustion locomotive state.
Keywords: combustion locomotive, monitoring and diagnostic, combustion engine, vibroacoustic signals, on-board devices, signal processing and analysis.

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1 Introduction

The railway nowadays provides us with an economical and relatively simple transport and it significance will increase in the future. The modern railway transport needs better management, monitoring and improvement of safety and comfort. Therefore the most important component of management system in railways is monitoring of main parameters describing the vehicle state to register and detect vehicle state and some special critical situation which can appear during a ride. A critical railway situation can be described as an incident of a rail vehicle movement which can carry to damage or failure. Such accidents can be involved by excessive velocity of rail vehicle, velocity do not adjust to rail circumstances, brake damage or other damages or locomotive and cars. The risk of these accidents should be estimated basing on knowledge of current vehicle state like information on engine dysfunctions, leaks, vibrations, geographical position, rail conditions etc. [1–4].

2 Registration and analysis of signals representing vehicle state

Generally the devise which registers and analyses some chosen signals acquired in a moving vehicle is called On-Board Recording Devices ORD or Event Data Recorder EDR. This kind of devices is commonly applied in an air and automotive transport, but last time we find the need of their usage in railway. Nowadays cars contain many ORD devices. There are trip recorders, electronic system of an engine control, antiblock systems, radar systems of alert to collision etc. [5]. Most of the based on accelerometer and gyroscopic sensors mounted on vehicle body. One of the task of ORD system can be registration of vehicle trajectory and it position in case of a collision, failure or accident. Each ORD sensor is subjected to factors which give the measurement inaccurate. For a sensor or set of sensors treated as a point the main disruption factor is localization and orientation of sensors in reference to the vehicle, nonlinearity and uncalibration of sensors, measurement interference and oscillation, sampling time and filtration methods. The movement parameters are usually obtain in connected to rails global or connected to vehicle local system of references. For the forces described in global system of references the integration of signals from accelerometers gives nearly directly the trajectory. Unfortunately, the recording is usually performed in a local system of references. The mutual influence between the local and global system of references is variable in time. The gravitation force should be taken into account also. Having information on all factors which disturb the measurement the reconstruction trajectory should be a simple translation from one to another system of reference. In trajectory reconstruction both two and three dimensional algorithms are used. The three-dimensional algorithms are useful especially for roll-over accidents reconstruction. Generally the finding of strict vehicle position appears quite complicated and difficult. There are many factors which can affect the reconstruction of vehicle trajectory e.g. sensors nonlinearity and discalibration, measurements noise and oscillations, sampling time and filtration methods etc. [6–13].

The standard OBD (on-board system) in modern car gives the possibility of reading many movement parameters, e.g. braking forces can be taken from anti-lock braking system ABS, a position of throttling valve from power control module PCM, turn of steering wheel from traction control system TCS etc. Unfortunately most of rail vehicle (especially in Poland) are rather older devices and they are not fully equipped. Obtaining of important movement parameters needs a rail vehicle to be equipped in special on-board registering devices. The big facilitation can be the fact that rail vehicles are moving on stable trajectories described by rails [12].

Together with accelerometers and gyroscopes the essential element of each nowadays ORD system is GPS device for geographical position determination. But a typical GPS do not work in places like tunnels or areas between high buildings and hills. From this point of view only the combination of data from GPS with accelerometers and gyroscopes data gives an estimation of vehicle position in all circumstances [1]. The GPS application needs some special software and hardware to the full exploration of it potential. In practice, each commercial GPS receiver uses communication protocol NMEA, but not all NMEA commands are usually implemented. What is worth to underline a GPS gives also information on velocity. Usually this is the direction of velocity in degrees in system of reference connected to the ground and velocity module in km/h or knots. In NMEA binary mode there is an access to some additional information depending on manufacturer and sensor type, for example to velocity vector components (along axes: longitudinal, latitudinal and vertical). The velocity in GPS usually is not determined from trajectory calculation but form Doppler Effect. From the practical point of view application of GPS seems especially interesting together with geographical information systems GIS [14, 15]. The GIS and GPS connection can allow not only in finding a rail vehicle position in case of accident, but can also give an information on e.g. weather condition, presents of other vehicles in the vicinity etc. [9, 16]. Generally the application of GPS together with GIS gives perspectives in the area of detection, prediction and recognition of accidents, control and management of traffic and traffic organization [6–11, 13–20].

The processing of signals registered by an ORD device contains not only high technology registration systems but also some sophisticated algorithm and software. The most important seems a finding of parameters which observation can predict dangerous situations. Many methods which have their source in artificial intelligence and signal processing can be useful in this area [1–4, 9, 17, 21–29].

3 Experiments, measurements and results

The general concept of a project is an on-board computer system which receives a broad spectrum of input signals and data and gives information on vehicle position and potential accidents and risk. Input signals should be acquired from accelerometers and gyroscopes (for trajectory reconstruction) and additional accelerometers (diagnostic signals which represent state of an engine and other vehicle parts). The on-board system basing on this data should perform the diagnosis, give a position, movement parameters and also identify potential critical situations.

As the part of the project some prototypes of on-board recording systems were done. First prototype has used GPS sensors Garmin GPS16. This gives the possibility of producing more accurate position coordinates using differential corrections in RTCM SC-104 standard. Another approach was the post-processing of collected data off-line what gave that a live data link during measurements was not required.

Nowadays while wireless technology became cheap and easy available GPS applications can be implemented using modems which had built-in script interpreters, such as Python or Java. This way the user can add its own functionality without external specialized microcontrollers. The first tests were done with a Telit GM862-GPS module using evaluation kit EVK2. Despite the power of the unit was not very high, it appeared quite good in simple tracking, receiving, processing and answering text messages, e-mails and data transmitted via GPRS (TCP/IP and UDP protocols).

The signals obtain directly from sensors were worthless for reconstruction of trajectory and they have need some special algorithms for compensation of a drift and temperature.

Another part of experiment consisted in recording of vibroacoustic signals for diagnostic purpose. The experiments were performing for misfire detection (Diesel engine 16 H12A Henschel – 12V of a Diesel locomotive 401Da – 427). The misfire was generated by a disconnection of one cylinder in the engine. A 16-channel digital recorder TA11 produced by Gould was applied and the signal was registered in three directions: parallel to the main locomotive axis, horizontal-transversal and vertical-transversal to the main locomotive axis. Same other experiments were also performed for one-cylinder experimental Diesel engine SB 3.1 using a signal recorder TEAC RD-135T, a charge amplifier NEXUS 2692 and piezoelectric sensors Brüel & Kjær type 4391.

The next part of experiments was performed for Diesel engine diagnostic basing on vibroaocustic signals taken from an engine body to distinguish a state before and after a repair. The experiments were done on a Diesel engine 14D40 of a locomotive ST44. The measurements have been performed under a load for a given power condition in determined measurement points. Each measurement point registered acceleration in two directions: vertical and horizontal transversal.

In this area of diagnostic vibroacoustic signals some special signal processing methods were used. Together with classical Fourier methods, some other more sophisticated methods were used also (short-time analysis, nonlinear methods, wavelets and multiresolution analysis) [8, 21–28].

In the area of nonlinear methods [21, 23, 26] the research showed that the Lyapunov exponents can be considered as the good diagnostic parameter. The dominant Lyapunov exponents were higher for the case of misfire. What is also interesting is that the dominant Lyapunov exponents showed higher values for signals after a repair in comparison with the signals before. These results can have some diagnostic significance because they allow selecting given diagnostic parameters to distinguish between engine states corresponding to the wearing and normal work.

In the area of short time methods [22, 24–27] some interesting results were obtain in comparison of engine state before and after the general repair. Together with short time Fourier analysis some global statistical parameters like mean, median or standard deviation were used also to this purpose [26, 27].

Also wavelets and multiresolution analysis was proposed into diagnostics aim [27, 28]. The problem with wavelet using is the choice of right different wavelet type and fitting the parameters. The big problem here is also a practical diagnostic which do not need estimation of two dimensional time-frequency images but rather a choice of some parameters, which gives a fast on-line diagnostic. But the most interesting results were obtained using multiresolution analysis basing on wavelets. The component of multiresolution analysis shows the decomposed part of the original signal in the given frequency band.

So far the results of the above research are not fully satisfactory. Taking into account the great complexity and variety of possible measurement schemes the so far experiments do not cover all interesting methods. Additionally taking into account the costs and accessibility the measurement on real object (a combustion locomotive) do not guarantee sufficient number of evidence data.

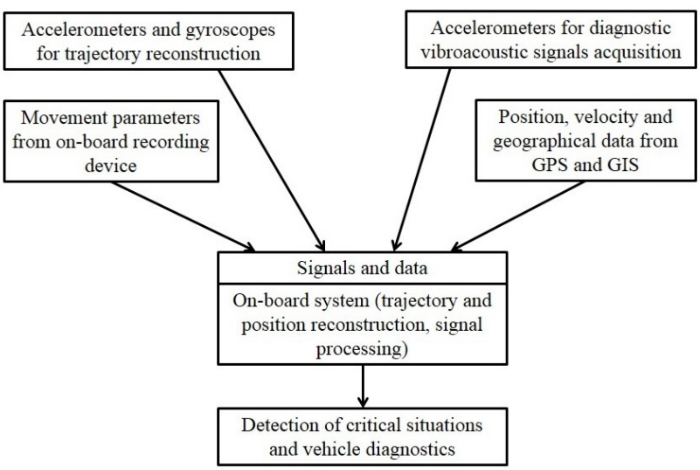

Figure 1: The general schema of the prepared recorder.

4 Conclusion

The current research in the area of ORD devices applications has shown a large complexity of a problem. It covers sensors and circuit fitting and adjustments and the presence of outside disturbances. It was also found that for different rail situations the recorded signals give us a broad range of variability depending on the type of an event. The general concept of system prepared in the project is given on fig. 1. Summing up the main function of the device will be

- reconstruction of trajectory, path and position (recording of vehicle acceleration and tilts, geographical position, velocity etc.),
- detection of critical situations like exceeding of limit velocity, acceleration or inclination (the system should record the place of an accident),
- registration of vibroacoustic signals for on-line locomotive diagnostic,
- detection of critical situations like exceeding of vibration of vehicle elements or damages (the system should record the place of an accident),
- integration of GPS, accelerometers and gyroscopes measurement results.

The results in the area of chosen signal processing methods are promising but they must be examined for bigger amount of possible signals and methods. The short time and nonlinear methods seem maximally useful in diesel engine diagnostic. Also the application of wavelet multiresolution decomposition allows distinguishing between the vibroacoustic signals taken in different engine states. Generally the research indicates the usefulness of the proposed methods to detect critical situations in railway transportation and to record of rail vehicles state.

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