GPS/GPRS/INS system for real-time monitoring of the urban railway

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Abstract: - The current paper describes the information and communication system, based on micromechanical inertial sensors (MEMS), GPS receiver and GSM modem to measure the dynamic response and to send the data to the control center to establish the status of the urban railways or tram bogy. The combination of the selected inertial and communication systems allow realizing the real-time monitoring of the urban railway and the tram body dynamics. The data processing is accomplished by the frequency analysis of the inertial data while the positioning device locates the points with dangerously high accelerations to create a map with dangerous places.

Key-Words: - MEMS, inertial sensors, railway

1 Introduction

The MEMS sensors are widely used to measure the frequency, amplitude (strength) and spectrum (signature) of vibrations [1,2] enabling the ability to perform active monitoring of device status. The measurement of the dynamic forces also is accomplished by the strain gauges, which are stick on the wheel [3] or translation sensors and tensometers on the rails [4]. The force amplitude is used as a criterion for valuation of the railway safety and its loading capacity [5,6].

If the low cost MEMS inertial sensors are combined with GPS system and the data are transferred via GPRS network, the real-time monitoring of the railway or tram bogy status may be accomplished. This system also may alarm if the tram acceleration overcomes the defined limit and the tram stability may be decreased. The dangerous points of the tramway may be marked and colored on the map in the control center. The measurement of the railway current condition may be accomplished with specialized motor cars [7] but this procedure is too expensive for long-time exploitation. This is the reason to develop and evaluate the measurement systems, which are capable to measure the dynamic reactions between the railway and the tram.

The current paper describes and discusses the results of the experimentation data from the system installed on the 6-axes tram motor car T6M 400. The data processing is based on the frequency analysis which allows determining the vibration severity, identifying frequencies and patterns, associating the peaks and patterns with mechanical or electrical components, forming conclusions and, if necessary, making recommendations for repair.

2 System description

The low cost of the GPS receivers and MEMS inertial sensors allows developing low cost measurement systems, which may be installed on the trams to ensure real-time monitoring of the railway condition. The measurement system is a single device which is completely separated from the motor car electrical system and has its own power source based on 12V rechargeable battery. The main system components are shown at Figure 1 and consist from the measurement device, database server and monitoring station.

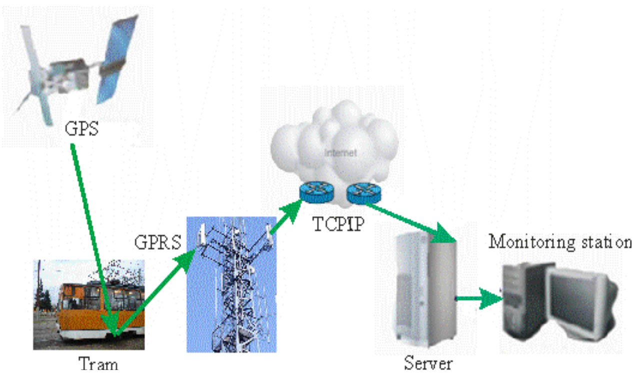


Fig.1. Components of the measurement system

The block diagram of the data acquisition system is shown at Figure 2. It consists from the following main modules:

➢ *Power supply block*. The module transforms the input DC voltage from the external 12V rechargeable battery to 3,3V (accelerometer supply and microcontroller power), 5,0V (gyroscope) and 3,8V (GSM power supply). The designed power supply is based on the switching regulator to form the GSM supply voltage and LDO regulator to convert the 3,8V to 3,3V;

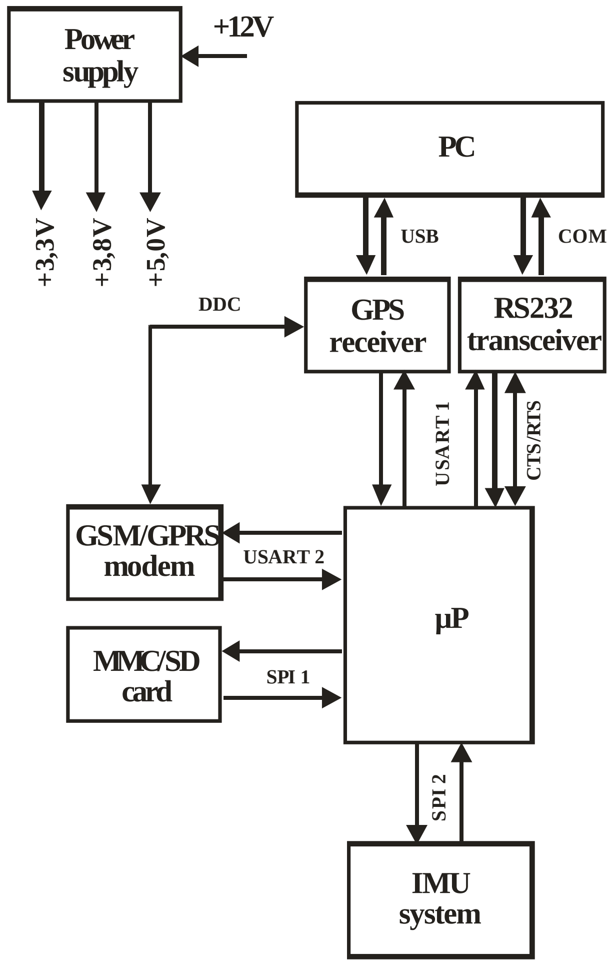


Fig.2. System block diagram

➢ *GPS receiver*. The module is based on LEA-6S module which sends the appropriate NMEA 0183 messages to the microcontroller. This module has been designed for low power consumption, low costs and UART, USB and DDC (I^2C compliant) interfaces. The GPS receiver is capable to update the navigation data up to 10Hz;

➢ *GSM/GPRS modem*. The module is used to send the navigation and inertial data to the database server at a real-time. It is based on the quad band GSM (LEON G100) produced by the same company due to the simple integration of u-blox GPS and A-GPS and quad-band GSM/GPRS, class 12.

➢ *Microcontroller*. The 8-bit high performance RISC PIC18 microcontroller is used to read the navigation and inertial data and to control the external devices according to their position. The PIC18 microcontrollers are optimized for C programming and have advanced peripherals (SPI/I²C™, UARTs, PWMs, 10-bit ADC, CAN, etc.).

➢ *IMU system*. The module scans the 3 - dimensional linear accelerometer and angular rate sensor (gyroscope) to establish the current object accelerations. The data acquisition system is based on the MEMS accelerometer sensor AIS326DQ – a three axes digital output linear accelerometer, produced by *ST*. This sensor includes a sensing element and an IC interface able to take the information from the sensing element and to provide the measured acceleration signals to the external world through an I^2C/SPI serial interface. The MEMS sensor has a user selectable full scale of ±2g, ±6g and it is capable of measuring acceleration over a bandwidth of 640 Hz for all axes. The inertial MEMS sensor reads the data with a sampling frequency of 40Hz to satisfy the Nyquist criteria. The inertial system includes 1D gyroscope ADIS16100 also produced by *ST*.

The orientation of the inertial axes is shown on Figure 3.

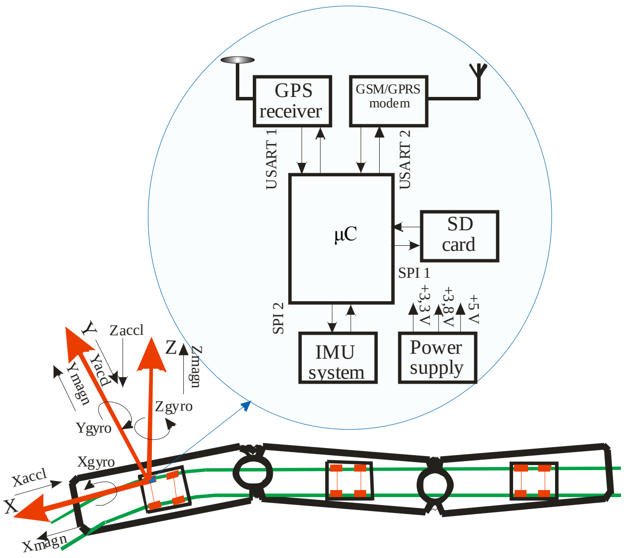


Fig. 3. The measurement system and its orientation relative to the vehicle axes

➢ *MMC/SD card*. It stored the GPS RMC messages and inertial sensor data as archive information (backup function), which allows offline-tracking analysis. This module is optional and supports MMC/SD cards up to 4GB (FAT16 file system format);

➢ *Serial interface*. The system supports some serial interfaces to enable the communication with external devices, especially with computer-based platforms. The supported serial protocols include RS232, RS422 and synchronous serial transfer;

➢ *I/O ports*. The optional I/O digital and analog ports allow connecting the additional external sensors such as temperature sensors, fuel level sensors, passenger detectors, etc. The microcontroller supports I/O ports to ensure the low and high priority of the external sensors.

The measurement system is installed on the terminal clam and is firmly fixed to ensure proper transfer function between the rails and the system. The integrated GSM module transmits the GPS data to the server to realize real-time monitoring of the tram position. The acceleration data are not transmitted via GSM network due to their high volume but they could be analyzed directly in the device to detect the critical points.

The experimental data are collected using the described measurement system, which is installed on the 6-axes tram motor car T6M 400. Its suspension consists from three carts: power ones (I and III-rd) T65 and supporting one (II-nd cart) type $T_{sp}65$. The carts consist of two-stage spring suspension (cylindrical springs) and the H-shaped open type cart frame. The measurement system is installed on the axle shaft as is shown at Figure 4.

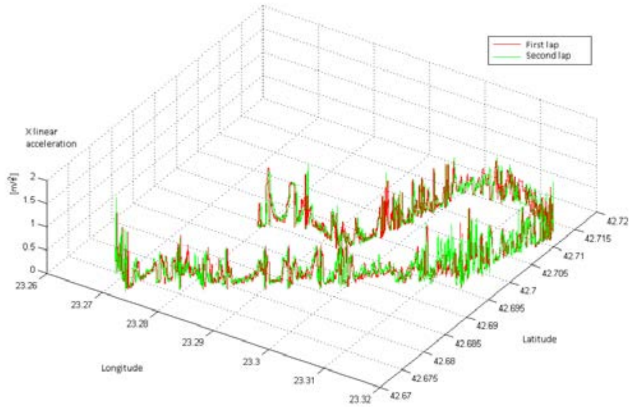
Fig.4. Measurement system installation

3 Data processing and results

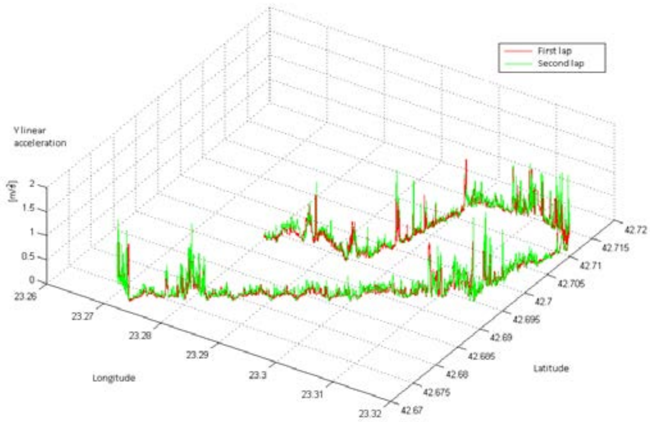
The measurement of the railway status is accomplished in two laps – one for the right tram direction and one for the opposite direction to detect the dangerous places on the railway where the linear accelerations exceed the limits. The linear accelerations are sampled with 40Hz and the effective accelerations are calculated according to the equation (1) where N=25 (the time duration of the window is equal to 1s).

$$RMS\{A(n)\} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} A^2(n)} \tag{1}$$

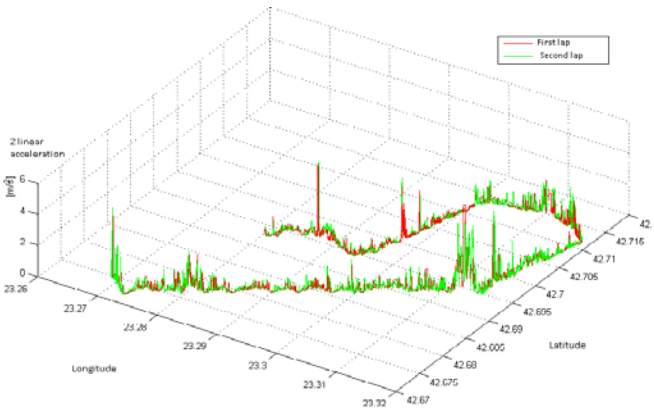
The effective linear accelerations for X, Y and Z axis are given at Figure 5a,b,c respectively. The results show that the measured accelerations for all axes are approximately similar at the both directions and this conclusion is clearly visible at Figure 6 where the marked points represent the places where the effective Z accelerations exceed the limit of $1.5 m/s^2$. These marked places furthermore are sent to the support company to check and repair the railway.



a) X linear accelerations



b) Y linear accelerations



c) Z linear accelerations

Fig.5. Graph view of the effective axes accelerations

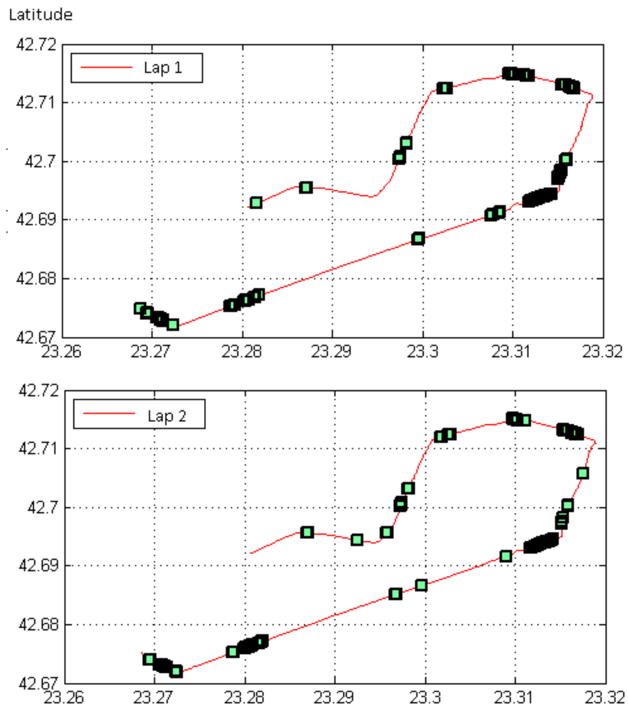


Fig. 6. Graph view of the dangerous railway places

4 Conclusion

The current paper represents information and communication system based on the latest MEMS inertial sensors and GPS receiver which is capable of real-time of offline analysis of the linear accelerations to detect the railway or tram bogy status due to the integrated GPRS modem to send the inertial and navigation data to the database server. This system may be used as a replacement of the expensive motor car measurement systems and may be also used to prevent the traffic accidents if the trams share this information to the other ones to reduce the speed or even stop the vehicles at the marked points.

References:

[1]. Josip Music, Roman Kamnik, Vlasta Zanchi, Marko Munih, Model Based Inertial Sensing for Measuring the Kinematics of Sit-to-Stand Motion, 3rd WSEAS International Conference on REMOTE SENSING, Venice, Italy, November 21-23, 2007, pp.8-13

[2]. Haytham Qasem Mahamda, Omar Gorgis, Design and calibration of an inertial navigation sensor node for precise tracking, 6th WSEAS International Conference on Circuits, Systems,

Electronics, Control & Signal processing, Cairo, Egypt, Dec 29-31, 2007

[3]. Per Gullers, Lars Andersson, Roger Lunden, High-frequency vertical wheel–rail contact forces—Field measurements and influence of track irregularities, Elsevier Wear 265, 2008, 1472–1478

[4]. Yoshihiro Suda, Hisanao Komine, Kosuke Matsumoto, Yasunobu Endo, Takuji Nakai, Masuhisa Tanimoto, Feedback friction control between wheel and rail by detecting yaw moment of wheelset, Elsevier, Wear 265 (2008) 1512–1517

[5]. E. Verheijen, A survey on roughness measurements, Journal of Sound and Vibration 293 (2006), pp 784–794

[6]. H. Tsunashima, T. Kojima, Y. Marumo, A. Matsumoto and T. Mizuma, Condition monitoring of railway track and driver using in-service vehicle, Reliability and Safety in Railway, 2012, pp.333-356

[7]. E. Sackl, The EM-SAT 120 Track Survey Car, an integrated part of the track geometry data base of the Austrian Federal Railways ÖBB, Railway Technical Review, 2/2004, pp.39-43.