DEPLOYMENT OF TIRE PRESSURE MONITORING SYSTEMS FOR TRAFFIC MONITORING AND SAFETY PURPOSES

Jan Schulz
Scientific Assistant, German Aerospace Center (DLR)
Institute of Transportation Systems
Rutherfordstr. 2, 12489 Berlin, Germany
PHONE: +49-30-67055-296, FAX: +49-30-67055-291, Jan.Schulz@dlr.de

Marek Junghans
Scientific Assistant, DLR
Institute of Transportation Systems
Rutherfordstr. 2, 12489 Berlin, Germany
PHONE: +49-30-67055-214, FAX: +49-30-67055-291, Marek.Junghans@dlr.de

ABSTRACT

In this paper, ideas and challenges of utilizing Tire Pressure Monitoring Systems' (TPMS) communication messages for traffic purposes are described. Following the principle of the frequently and successfully tested Bluetooth technology approach to derive traffic parameters, TPMS has a great potential, especially in the field of traffic management and active traffic safety. With further refinement of TPMS data vehicles can be classified, supplier relationships can be identified or the access to parking places can be managed. The utilization of TPMS can also support transport safety. Applications of TPMS with the aim to increase awareness of road hazards by increasing attention of drivers are presented as well.

INTRODUCTION

Transport policy objectives are a safe and an environmentally friendly traffic system, where the transport demand is in balance with the transport supply. Its realization requires adequate and efficient traffic management measures on the basis of lowest possible cost for determination of traffic data (e.g. the determination of travel times, densities and origin-destination and linkage matrices). In addition, traffic data should possess a high degree of acceptance and credibility concerning the significance of the measured traffic parameters. Thus for traffic authorities worldwide it is desirable to obtain highly accurate spatial-temporal traffic data without installation of costly and deteriorating infrastructure, like e.g. inductive loop detectors, radar or infrared sensors (1, 2). Probe vehicle data systems (3, 4, 5) for instance need no effort or infrastructure in road space and work quite well if an adequate number of equipped vehicles ensure statistical significance of the measured traffic data (6). In recent years another example for a low-cost approach is the frequently and successfully tested Bluetooth technology approach to determine travel times (7-19).

Very promising is the category of direct Tire Pressure Monitoring Systems (TPMS). A direct TPMS is an in-vehicle sensor and evaluation system that measures tires inflation pressure and temperatures in order to inform or even warn the driver about the states of tires. Interesting for traffic data acquisition is that the data is sent wireless together with a worldwide unique ID to an electronic unit.

Supported by the findings of Rouf et al. (35) – who have demonstrated eavesdropping the immutable 32-bit identifier of two different tire pressure sensor modules using it for tracking vehicles afterwards – the TPMS traffic data approach has become an important issue in DLR's transportation research. The application of vehicle-sensors for various traffic purposes promises a high potentially low-cost traffic sensor for a wide range of applications with a possibly high detection rate combined with a low set up effort. This paper gives an outlook on applications that appear promising: A vision of TPMS' deployment for traffic purposes.

This paper is structured as follows: First, facts about TPMS are briefly described. Then, advantages of the addressed system to derive traffic parameters are mentioned to describe the utilization of TPMS afterwards. The paper closes with a conclusion.

TPMS

A Tire Pressure Monitoring System (TPMS) is an in-vehicle sensor system designed to monitor the inflation pressure of each tire of a vehicle. If a pressure loss occurs in any of the tires the system is capable of giving an in-car-warning to the driver. TPMS are subdivided into two categories: direct and indirect systems. Indirect TPMS do not use physical pressure sensors. They compare the rotation speeds of tires. Together with data from previous runs the system can compute if a tire is changing diameter. A reduction of diameter is interpreted as loss of pressure. Direct TPMS employ physical pressure sensors inside each tire. Each sensor evaluates the inflation pressure or the variation of pressure over time. In-tire sensor modules transmit their own ID along with their pressure, temperature and other data via a radio frequency transmitter to a pressure control unit (20).

Several countries implemented TPMS programs to improve tire efficiency and safety. In the United States TPMS are mandatory for every new passenger car by model year 2008 (21). In the European Union (EU) all passenger cars type approved after November 1, 2012 must install TPMS systems as well as all passenger cars manufactured after November 1, 2014 (22). Japan, China and South Korea identified proper tire inflation as relevant for tire safety and efficiency as well. Thus South Korea has proposed mandatory standards in 2010, in Japan standards are under consideration and China mapped out a voluntary standard similar to the US one (23). In the US underinflation detection threshold lies at 25%; in the EU the detection threshold is set at 20% in phase I. A 15% threshold to be introduced in a second phase is under consideration (24).

The tightened EU TPMS legislation is both safety and economical driven and increases the demand on TPMS accuracy. While in the U.S. direct TPMS are mandatory for all new cars since 2008 (33), EU legislation does not give details on the required system, so that either indirect or direct measuring technology can be used. However, in general the car industry favors indirect systems, the tire industry the direct ones (27, 29, 30, and 32). The international automotive supplier Continental recommends direct TPMS technology to fulfill the rising requirements to inflation pressure measurements (25). According to Schrader Electronics, as well a developer and supplier of direct TPMS, the change from phase I to phase II will be cost-neutral to most car companies. As today's direct TPMS can deliver accuracies of +/- 2% (26). Indirect systems are less accurate than direct systems and more dependent on proper calibration but are as well less expensive (23, 29).

A weakness of indirect systems is that drivers have to re-calibrate the system whenever tire conditions have changed. Without or with wrong calibration the indirect system becomes ineffective (27). Another weakness is that indirect systems need more time to report a tire problem, in opposite to direct systems which inform the driver within seconds (29, 28, and 32). A comparison between direct and indirect TPMS can be found in a Study of the European Parliament published in 2008 (33).

However, General Motors Europe recommends to the European Parliament that requirements should be chosen in such a way that they can be reached with future developments of indirect TPMS (31). In the EU the discussion on direct and indirect technology is still on going. For TPMS traffic measurement applications the best choice would be tight requirements prescribing indirectly direct TPMS.

DERIVING TRAFFIC PARAMETERS

Tracking TPMS sensor's unique identification numbers makes it possible to track vehicles. If road networks are equipped with a multiplicity of systems capable overhearing the communication of wireless tire pressure sensors comprehensive travel times, Origin-Destination (OD) matrices and linkage information can be provided. However, additional questions on how to cope with the highly redundant data from the all the tires of the vehicles on the streets have to be solved. From this basis further data such as average speed, traffic density and traffic flow can be derived. Also the refinement of data to time spaces between bunches of vehicles and lengths of queues or occupation time in front of traffic lights are imaginable using information given by TPMS messages. Besides the capability of detecting and tracking single vehicles this method offers advantages in contrast to state-of-the-art-sensors:

- Firstly, it is assured that only motor vehicles will be detected compared to systems using the Bluetooth standard. Thus there is no need for special filter algorithms to split up motorists from pedestrians carrying Bluetooth devices.
- Secondly, TPMS has no dependencies on weather conditions, lighting conditions or covered vehicles as in video based systems for instance.
- Thirdly, it is not possible to link the identification number with the owner of the car. Thus, personal information is protected and obviously more data privacy is given compared to tracking single cars than with Automatic Number Plate Recognition (ANPR) systems.
- Fourthly, since the number of pressure sensors for each vehicle equals the number of tires, the addressed TPMS method has an inherent measurement redundancy that increases the probability of detecting a passing vehicle at the moment of transmission.

To trigger vehicle detection it is conceivable to send an activation signal to the tire sensors (35), which is normally used by car dealers to install tires. That guarantees that tire sensors transmit data in the range of TPMS detectors at least once. Following the probe vehicle approach it is imaginable to install TPMS-detectors inside vehicles to determine the current traffic situation of a road network.

TPMS UTILIZATION

Apart from the standard applications sketched already, more challenging applications may be within reach with TPMS. The availability of identifiers transmitted together with inflation pressure and temperature values opens a wide scope of opportunities in the field of traffic management and traffic safety. In the following paragraphs selected approaches are presented.

REFINEMENT OF DATA

Due to different inflation pressures of passenger cars and heavy goods vehicles it is imaginable to use in future TPMS information to classify vehicles. Continental recommends in their inflation tables (36) inflation pressures for passenger cars between 1.9 and 3.3 bar, for trucks and busses values between 4.5 and 9.0 bar. Thus, a differentiation in at least two classes is possible. Taking the number of sensors into account makes the estimation more robust. Furthermore the individual constellation of inflation pressure values can also be used to differentiate vehicle categories.

Probe data of TPMS sensors can also be used to suggest whether a vehicle is loaded or not. Therefore the correlation of vehicle weight and tire pressure is assumed. First the vehicle has to be measured in a road network several times. By analyzing the measured inflation pressure values supplier relationships can be identified.

TPMS can also be utilized to manage the access to parking places. Before entering a parking area the TPMS identification number is checked at the barrier. To wake up TPMS sensors at the barrier a 125 kHz activation signal is used. A multiplicity of TPMS detectors installed in the parking area allows investigating the driver’s behavior when searching free parking space. Moreover it is conceivable to use the activation signal to check whether a parking lot is occupied or not. Monthly parking pass holders can be identified based on their TPMS identification number.

IMPROVING ROAD SAFETY

Besides the basic idea of warning drivers when a loss of inflation pressure occurs in any tire, TPMS data can further help to improve road safety. Therefore utilization of TPMS in collaboration with special algorithms, further car components and road infrastructure is imaginable and promises high potential to decrease the number of accidents, injuries and fatalities. For these applications TPMS sensors with high sampling rates and very accurate measurements of pressure and temperature are needed. Such TPMS sensors are existent (see (34) for example), but at present too expensive for the mass market. Below, three ideas with the aim to increase awareness of road hazards by increasing attention of drivers through advices announced inside vehicles are presented.

Traffic Sign Assistance

Drivers who are not familiar with the area might drive up the highway the wrong way. With special road markings in combination with a smart approach of analyzing the variation of inflation pressure values over time the driver’s attention can be called to make him aware of his mistake. This can prevent serious accidents. Thus special road markings, which cause a unique inflation pressure signal sequence when passed, have to be developed specifically for this application. However, different combinations of road markings are imaginable, e.g. for warning messages such as “wrong way”, “sharp turn ahead” or “deer pass”. This approach supports the function of traffic signs in order to enhance the transport safety by preventing car drivers from dangerous situations.

Roads Surface Analyzer

If it is feasible to detect road markings by TPMS data, it is obvious to determine the road conditions by the evaluation of the TPMS inflation pressure values too. Today the road surface check is still done manually by visual control (37). By introducing a TPMS roads surface check this procedure can be automated. With this method not only the road maintenance fleet but every other motor vehicle equipped with a positioning and communication unit can technically evaluate the roads surface conditions. This could be a great opportunity to detect and fix road damages faster before they become worse and more expensive to repair. Furthermore this opens up the opportunity to lower the costs for the road maintenance, because the number of test drives is considerably reduced.

Sensitizing for Tail-gating

A new approach of analyzing signals of TPMS can help drivers to maintain a safe following distance and to avoid tail-gating in an affordable way. To measure the distance to a vehicle in front, the cars' vicinity is scanned periodically for signals of unknown TPMS sensors. To ensure that a received unknown sensor IDs belong to a car permanently driving ahead the signal must be received several times. TPMSs have a limited radio range. Based on the signal strength indicator value and vehicle speed, thus the following distance could be estimated. If a threshold is exceeded, the driver receives a visual, acoustic or tactile message.

Black Ice Warning

Today's black ice warnings are mostly inaccurate, because they do not belong to individual positions of vehicles. Weather service warnings are broadcasted for whole regions and warnings displayed at variable message signs are measured at defined points. Notifications given inside the vehicle are related to temperature sensors in the bumper, which measure the air temperature (38). The recurrence of black ice accidents raises the question, how to detect black ice for each individual vehicles in a new way, perhaps in an even more reliable way.

The solution can be the application of an augmented TPMS, whose sensors measure temperatures very close to the road's surface. The aim of traffic and transportation research is to derive road's surface temperature indirectly based on the in-tire temperatures. Today more and more vehicles are equipped with rain sensors. It is conceivable to combine them with TPMS in order to enhance the method's performance. The related algorithm has to take the flexing work of the tire into account as well as its isolation characteristics. The impact of flexing work can be estimated from the value of inflation pressure and the time the vehicle is moving. Additionally the whole driving cycle from the point of starting the engine has to be analyzed and considered.

CONCLUSIONS

The deployment of TPMS for traffic purposes offers great opportunities to satisfy the significant interest for economic traffic procedures and traffic sensors. With the broad availability of battery-free sensors the approach to enforce transmissions of TPMS sensors via an activation signal is likely to be accepted. These days, battery-free TPMS sensors used in the field of racing (34) are too expensive for the mass market. The future development of TPMS is expected to focus more on security concerns leading to encrypted protocols and authentication. That could make tracking and triggering of TPMS sensors more difficult.

Nevertheless, research has started to develop a system for gathering traffic related information from wireless communication signals, also implementing the TPMS approach. The test and evaluation of those new sensor systems need field operational tests which have to to be conducted in ITS test-beds. One example for such a platform is the Application Platform for Intelligent Mobility (AIM) which is currently under construction in the German city of Brunswick. AIM offers a unique way to link research, development and applications for intelligent transportation and mobility services (39, 40). AIM is set up by DLR in cooperation with the state of Lower Saxony, the city of Brunswick and other partners.

REFERENCES

(1) T. Fließ, A. Leich, H.-J. Jentschel, „Bildverarbeitung im Straßenverkehr – Überblick über den Stand der Technik“, progress report, Dresden University of Technology (Dresden, 2001)

(2) A. Leich, M. Junghans, H.-J. Jentschel, “An Approach to Video based Wide Area Traffic Surveillance”, in *Proceedings of 8th ITS World Congress* (Chicago, 2002)

(3) R. D. Kühne, R.-P. Schäfer, P. Mieth, S. Lorkowski, X. Bei, “Vehicle Probes as Data Collectors for Asian Metropolitan Areas”, in *Proceedings of 4th Asia Pacific Conference*, (China, 2005)

(4) R. P. Schäfer, U. K. Thiessenhusen, E. Brockfeld, P. Wagner, “A traffic information system by means of real-time floating-car data”, *in Proceedings of 9th ITS World Congress* (Chicago, 2002)

(5) F. Zheng, H. van Zuylen, Y. Chen, (2010), “An investigation of urban link travel time estimation based on field sparse probe vehicle data”, *in Proceedings of TRB 2010 89th Annual Meeting (*Washington, D.C., 2010)

(6) F. Gössel, „Informationsentropische, spektrale und statistische Untersuchungen fahrzeuggenerierter Verkehrsdaten unter besonderer Berücksichtigung der Auswertung und Dimensionierung von FCD-Systemen“, Ph.D. Thesis, Dresden University of Technology, 2005. Available at http://www.qucosa.de/fileadmin/data/qucosa/documents/1293/1116572388287-5050.pdf

(7) M. Spangler, A. Leonhardt F., Busch, C. Carstensen, T. Zeh, “Deriving travel times in road networks using Bluetooh-based vehicle re-identification: Experiences from Northern Bavaria”, FOVUS - Networks for Mobility, ISBN: 978-3-00-031958-7, 2010

(8) P. Tarnoff, “Made To Measure”, *Traffic Technology International*, UKIP Media & Events Ltd, UK, April/May 2009

(9) T. Brennan, J. Ernst, C. Day, D. Bullock, J. Krogmeier, M. Martchouk, “Influence of vertical sensor placement on data collection efficiency from Bluetooth MAC address collection devices”, *Journal of Transportation Engineering*, 2010

(10) Y. Malinovskiy, Y. Wu, Y. Wang, U. Lee, “Field Experiments on Bluetooth-Based Travel Time Data Collection”, in *Proceedings of 89th Transportation Research Board Annual*

Meeting (Washington D.C., 2010)
(11) R. Hoyer, C. Leitzke, „Verfahrenstechnische Bedingungen für die Reisezeitbestimmung mittels Bluetooth-Technologie“, in *Proceedings of HEUREKA 11* (Stuttgart, 2011).
(12) J. Wasson, J. Sturdevant, D. Bullock, “Real-Time Travel Time Estimates Using Media Access Control Address Matching”, *ITE Journal*, 06/2008.
(13) M. Hamedi, A. Haghani, F. Sadabadi, “Using Bluetooth Technology for Validating Vehicle Probe Data”, in *Proceedings of 16th ITS World Congress* (Stockholm, 2009)
(14) A. Haghani, M. Hamedi, K. Sadabadi: Freeway Travel Time Ground Truth Data Collection Using Bluetooth Sensors”, in *Proceedings of 89th Transportation Research Board annual meeting*,(Washington, DC, 2010)
(15) S. Quayle, P. Koonce, D. DePencier, D. Bullock, “Arterial Performance Measures Using MAC Readers: Portland Pilot Study, in *Proceedings of NAMTEC 2010* (Seattle, 2010)
(16) P. Tarnoff, J. Wasson, S. Young, N. Ganig, D. Bullock, J. Sturdevant, “The Continuing Evolution of Travel Time Data Information Collection and Processing”, in *Proceedings of 88th TRB 2009 Annual Meeting* (Washington, DC, 2009)
(17) D. Bullock, M. Day, R. Hasemann, H. Premachandra, T. Brennan, J. Wasson, J. Sturdevant, “Visualization and Assessment of Arterial Progression Quality Using High Resolution Signal Event Data and Measured Travel Time”, in *Proceedings of 89th Transportation Research Board Annual meeting* (Washington, DC, 2010)
(18) R. Haseman, J. Wasson, D. Bullock, “Real Time Measurement of Work Zone Travel Time Delay and Evaluation Metrics Using Bluetooth Probe Tracking”, in *Proceedings of 89th Transportation Research Board Annual meeting* (Washington, DC, 2010)
(19) A. Haghani, M. Hamedi, K. Sadabadi, S. Young, P. Tarnoff, “Freeway Travel Time Ground Truth Data Collection Using Bluetooth Sensors”, in *Proceedings of 89th Transportation Research Board Annual meeting(*Washington, DC, 2010)
(20) S. Velupillai, L. Guvenc, “Tire Pressure Monitoring”, *IEEE Control Systems Magazine*, p. 22 -25 (2007)
(21) Department of Transportation, National Highway Traffic Safety Administration, “Federal Motor Vehicle Safety Standards; Tire Pressure Monitoring Systems”, 2005. Available at http://www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/FMVSS-TPMS-ResponsePetitions-August2005.pdf
(22) European Parliament, “Position of the European Parliament and of the Council concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefore”, (EP-PE_TC1-COD(2008)0100), Article 9 and 13, 2008. Available at http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TC+P6-TC1-COD-2008-0100+0+DOC+PDF+V0//EN
(23) The International Council on Clean Transportation, “Opportunities to Improve Tire Energy Efficiency”, 2011. Available at

http://www.theicct.org/pubs/ICCT_tireefficiency_jun2011.pdf
(24) European Parliament, "Draft Commission Regulation concerning type-approval requirements for certain motor vehicles with regard to tyre pressure monitoring systems and implementing Regulation (EC)", No 661/2009 of the European Parliament and of the Council concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor, 2010, p. 10. Available at http://circa.europa.eu/Public/irc/enterprise/automotive/library?l=/mvwg_vehicles_working/115th_january_2010/item-5-b-gsrtpms/_EN_1.0_&a=d
(25) Continental AG, "Continental focuses on direct tire pressure monitoring systems", April 2011. Available at http://www.conti-online.com/generator/www/com/en/continental/pressportal/themes/press_releases/3_automotive_group/interior/press_releases/pr_20110418_direct_tpms_en.html
(26) Tire Technology International, "Europe tightens TPMS law", 07/2011, p. 7.
(27) European Rubber Journal, "Safety Pressure Monitoring Systems and Blind reset Buttons", 2009. Available at http://erscharter.eu/el/inaction/blog/15467
(28) The Royal Society for the Prevention of Accidents (RsSPA), Response to the EC consultation "Public Consultation on Outline Proposals for a Regulation of the European Parliament and of the Council on Advanced Safety Features and Tyres", 2007.
(29) US Department of Transportation, "An evaluation of Existing Tire Pressure Monitoring Systems", 2001. Available at http://www.rtpms.com/NHSTA.pdf
(30) European Bureau of the Fédération Internationale de l'Automobile, "Response of the Fédération Internationale de l'Automobile (FIA) to the Public consultation on outline proposals for a Regulation of the European Parliament and of the Council of Advanced Safety Features and Tyres", 2007.
(31) General Motors Europe, "Comments on the public consultation on out line proposals for a new Regulation of the European Parliament and of the Council on Advanced Safety Features and Tyres", 2007. Available at http://ec.europa.eu/enterprise/sectors/automotive/files/pagesbackground/safety/consultation/gme_en.pdf
(32) Department of Transportation, National Highway Traffic Safety Administration, Federal Motor Vehicle Safety Standards; Tire Pressure Monitoring Systems, Controls and Displays, Final Rule, Docket No. NHTSA 2000-8572. Available at http://www.nhtsa.gov/cars/rules/rulings/tpmsfinalrule.6/tpmsfinalrule.6.html
(33) European Parliament, Policy Department Economic and Scientific Policy, Type approval requirements for the general safety of motor vehicles (IP/A/IMCO/ST/2008-18), 2008
(34) TPMS Pro Data Sheet, Stack Ltd., 2010. Available at http://www.stackltd.com/pdf/data_sheets_2010/tpms_pro_datasheet.pdf
(35) I. Rouf, B. Miller, H. Mustafa, T. Taylor, S. Oh, W. Xu, M. Gruteser, W. Trappe, I. Seskar,

"SECURITY AND PRIVACY VULNERABILITIES OF IN-CAR WIRELESS NETWORKS: A TIRE PRESSURE MONITORING SYSTEM CASE STUDY". *In Proceedings of 19th USENIX Security Symposium* (Washington, 2010)
(36) Inflation Tables 2009/2010 for passenger cars and Trucks. Available at http://www.conti-online.com
(37) J. Hackl, „Neue Ansätze zur Organisation der Streckenwartung", *Straßenverkehrstechnik*, Kirschbaum Verlag GmbH, Bonn, 08/2010.
(38) J. Leohold, "Communication Requirements for Automotive Systems", Keynote Automotive Communication at 5th IEEE Workshop on Factory Communication Systems, (Wien, 2004).
(39) S. Bauer, E. Bretschneider, J. Rataj, T. Schumann, „AIM – APPLICATION PLATFORM INTELLIGENT MOBILITY", in *proceedings of 16th ITS World Congress* (Stockholm, 2009)
(40) AIM Website http://www.dlr.de/ts/aim