



HAL
open science

Using probe vehicles for pavement monitoring: experimental results from tests performed on a road network

Fabien Menant, Jean-Marc Martin, Daniel Meignen, David Bétaille, Miguel Ortiz

► To cite this version:

Fabien Menant, Jean-Marc Martin, Daniel Meignen, David Bétaille, Miguel Ortiz. Using probe vehicles for pavement monitoring: experimental results from tests performed on a road network. TRA 2016, European Research and Technology Conference on Transport and Mobility, Apr 2016, VARSOVIE, Poland. pp. 3013-3020, <10.1016/j.trpro.2016.05.438>. <hal-01660878>

HAL Id: hal-01660878

<https://hal.science/hal-01660878v1>

Submitted on 11 Dec 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



6th Transport Research Arena April 18-21, 2016



Using probe vehicles for pavement monitoring: experimental results from tests performed on a road network

Fabien Menant ^{a,*}, Jean-Marc Martin ^a, Daniel Meignen ^a, David Bétaille ^a, Miguel Ortiz ^a

^a IFSTTAR, Route de Bouaye, CS4 344 Bouguenais, France

Abstract

Recently, IFSTTAR has taken an interest in the use of probe vehicles for the road monitoring of some characteristics such as the pavement longitudinal profile. After studying the feasibility of the method on a metrological angle, a measurement chain and an automated data processing tool have been developed. The process begins with the data collection using low-cost sensors embedded in each probe vehicle and ends with the presentation to the road managers of the profile quality indicator matched on a map. Thereafter, this innovative pavement monitoring method has been tested with the deployment of a dozen of probe vehicles on a road network of about one thousand kilometers long. This article aims to present, in a first step, the different tools developed by IFSTTAR (data collection systems, map-matching algorithms, database format, etc.) and then, in a second step, to comment the results coming from the application of the pavement monitoring method on the road test network (level of accuracy, technological and scientific limits, opinion of the road manager, etc.).

© 2016The Authors. Published by Elsevier B.V..

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM).

Keywords: Pavement monitoring ; longitudinal evenness ; probe vehicles ; low-cost sensors ; automated data processing

1. Why the use of probe vehicles is interesting for pavement monitoring?

Currently, in France such as many countries, road managers must deal with stronger and stronger financial constraints. These require to be even more attentive to the evolution of road networks and so to be able to quickly detect any aggravation or new significant defect. In France, the monitoring of the longitudinal evenness, like other road characteristics, is carried out during some measurement campaigns involving specialized vehicles equipped with high-level instruments (Sayers (1998) and IDDRIM (2014)). With this method, very accurate data could be sure obtained for a given geographic area and for a given date but a few limits appear in return. These limits, which are described below, mainly derive from the small number of specialized vehicles, their condition of use and their cost:

- First, two successive measurement campaigns provided to a same road are usually spaced out from several years (at best every 3 to 6 years in France). With this periodicity, it is very difficult to carefully observe the apparition of a new defect as well as the progression of an existing defect.

* Corresponding author. Tel.: +33-240845772.

E-mail address: fabien.menant@ifsttar.fr

- After, the measurement campaigns are most of the time focused on main roads. In other words, data are rarely recorded into the secondary roads while they sure support less traffic but remain widely used by drivers and also have a strategic significance for the development of local economy.
- Last, as the measurement campaigns are commonly scheduled in advance, the intervention of specialized vehicles is triggered without any optimization because they do not operate in the most relevant geographic area (*i.e.* where road defects need to be measured accurately) and at the most opportune moment.

Considering these remarks, it is clear that the current method should be improved if we try to reach a nearly real-time monitoring applied to a large part of a road network. This challenge requires finding a different approach based on both a better use of specialized vehicles and the development of a new generation of tools and methods which are economically acceptable for road managers. This paper refers to this goal by testing the use of probe vehicles with embedded low-cost sensors (smartphones) for the monitoring of the longitudinal evenness on a road network.

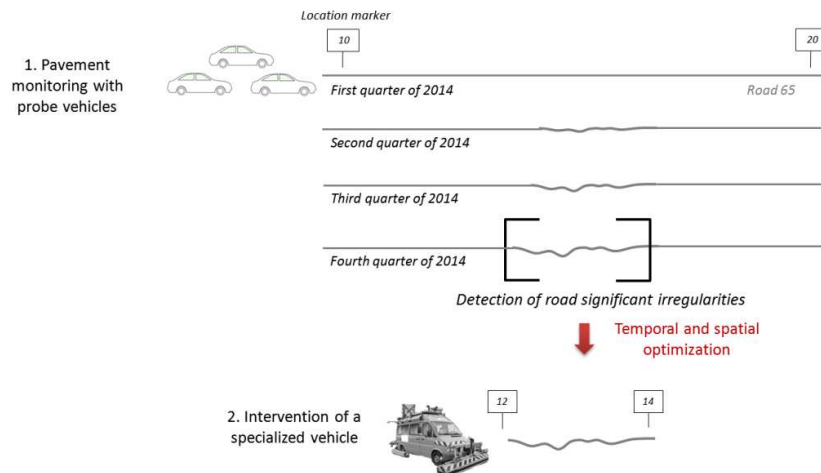


Fig. 1. The use of probe vehicles is considered as a first level of intervention for the pavement monitoring

The use of probe vehicles offers many advantages as the ability to collect high-frequency data (*i.e.* every day) on the entire road network. Moreover, this method should be inexpensive providing the use of low-cost sensors in each probe vehicle. In this article, this kind of vehicles refers to industrial fleets (e.g. patrol vehicles) which regularly use the road network (main roads as well as rural roads) but which don't aim first at the measurement of road irregularities. Up to now, the use of probe vehicles has not seriously been considered for a pavement maintenance service on the opposite of others like road safety service and traffic management. And yet, if we consider a smartphone as both a sensor and a data logger, each "standard vehicle" could become a "measurement vehicle".

This kind of pavement monitoring method should find an interesting place among the current possibilities to get data on a road network. Obviously, this cannot replace the use of specialized vehicles in case of acceptance of works for example or other situation where a very accurate measurement system is essential. But, for the monitoring activity, the use of probe vehicles should be considered as a complementary method:

- For main roads, a pavement monitoring with probe vehicles should optimize the temporally and spatially action of specialized vehicles (Fig. 1). In this case, the use of probe vehicles could be thought as a first level of intervention tool whose goal is the generation of alerts by reporting to managers the road sections with significant irregularities. Depending on the seriousness of the defect, the road managers may, if they judge it necessary, ask for specialized vehicles in order to have more accurate measures. Economically, we can also assume that the optimization of the use of specialized vehicles should decrease the cost of pavement monitoring activity and then is consistent with the expectations of road managers.
- For lower traffic networks, road managers are not used to involve specialized vehicles because of their cost. The use of probe vehicles then offers the possibility to have some information certainly less accurate but enough to aim at a given level of service and to keep it.

2. The data collection and automated processing with the MIRANDA system

The MIRANDA system is an automated measurement and data processing chain recently developed by IFSTTAR (Fig. 2). This system ensures a succession of five functions which are described hereinafter.

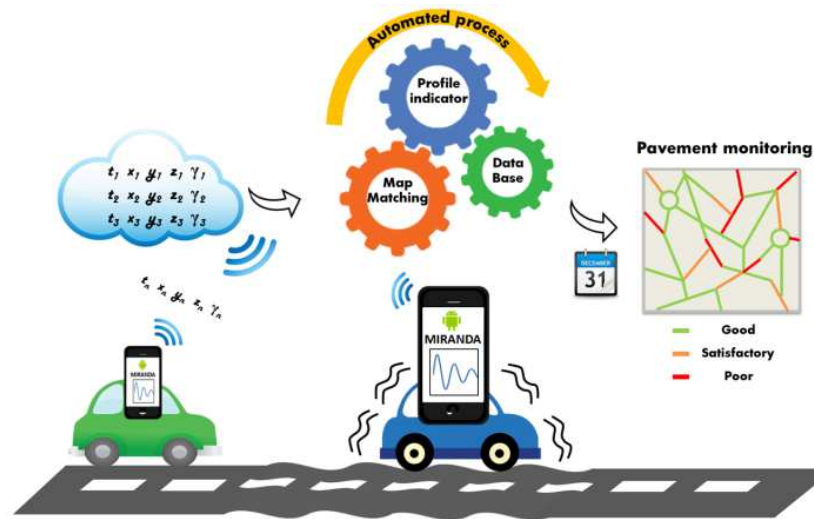


Fig. 2. Illustration of the MIRANDA system

2.1. Collecting data with a smartphone embedded into a probe vehicle

To develop this first function, it is necessary to think about the following questions if we want to collect relevant data in order to estimate the level of irregularities on the road surface:

- What kind of physical quantity each probe vehicle have to measure ?
- How to do these measures ?
- What are the level of accuracy and reliability of the measures ?

As the road indicator we want to estimate is linked to the longitudinal evenness, we have naturally decided to record the vertical vibrations « felt » by each probe vehicle using the accelerometer included into the smartphone. Actually, it is clear that a relationship exists between the level of vertical vibration of a vehicle and some characteristics of the road profile. At the same time, in order to localize the measurement of the road irregularities and to build a distance abscissa, GPS coordinates are also recorded by the smartphone (Fig. 3). So, to measure both of them, a mobile phone application (for Android devices) has been developed. With this application (named Miranda App), the driver of a probe vehicle, after entering some general information (e.g. vehicle identification), should merely press a button to start the measure and press again to end it. No more action is necessary to manage the measure. At the end of the measure, a file containing the collected raw data is automatically created and sent to a computer server using a wireless connection (WiFi or 3G/4G network).



Fig. 3. Installation of the smartphone on board and screen capture of the MIRANDA App

Since the acceleration signal and the geographic coordinates, a signal corresponding to the estimated road profile is computed by the server. Obviously, in this measurement configuration, the estimated profile only contains a part of the road irregularities. Some experiments realized previously on a vibration test equipment and then under real conditions of use have revealed that road irregularities whose the wavelength approximatively belong to the interval [3m ; 45m] are correctly measured (Fig. 4). To be more precise, by comparing with a reference, the irregularities which belong to this interval are slightly overvalued while those with smallest wavelengths are strongly attenuated by the effects of the tires, springs and dampers.

In France, the characteristics of the longitudinal profile are gathered into an indicator named NBO which attributes a score from 0 (poor level) to 10 (very good level) with a 0.5 point range according to the volume irregularities present at the surface for a given road length (Robert (2009) and NF(1995)). This calculation is performed on the filtered signals which are coming from the decomposition of the estimated road profile signal into three separate wave bands (Long, Medium and Short). Considering the previous results, a probe vehicle equipped with a smartphone as a sensor can only provide an indicator for the LW and MW bands. The inability to measure the defects in the SW band (excepting for significant defects like potholes) is of course a real limitation of the method. But, a correct estimation in the others bands is both enough to know the level of comfort of the road and to detect some relevant structural problems.

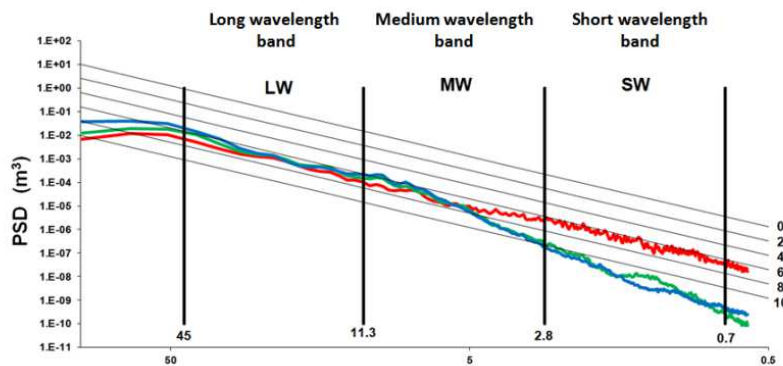


Fig. 4. Comparison between the power spectrum density (PSD) of two estimated profiles coming from probe vehicles and a reference signal

2.2. Projection of all the trajectories of the probe vehicles on a same geographical reference

The second function of the MIRANDA system aims at projecting each raw trajectory of a probe vehicle on a same geographical reference (a map or a reference trajectory) and to compute new coordinates (Fig. 5). Clearly, the successive geographical positions recorded by the GPS of the smartphone are rather imprecise because of the characteristics of the sensor and sometimes because of a low satellite reception (e.g. in woody areas). The map-matching operation which is automatically applied to all the measurement files is very essential but is also a complex operation especially for the processing of areas with geometrical singularities (e.g. road junctions). At the end, all the trajectories coming from all the runs of the probe vehicles are well positioned with respect to the road location markers (Bétaille (2015)).

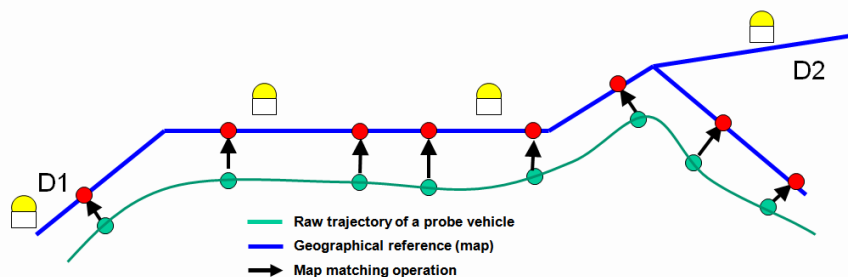


Fig. 5. Illustration of the map-matching operation

2.3. Calculation of the final road profile indicator

When all the trajectories of the probe vehicles are correctly matched on a geographical reference, it is then possible to process the different values of the road profile indicator corresponding to a same road section. This process aims at the calculation of a final indicator (*i.e.* a final score) on each road section since all the indicators delivered by the fleet of probe vehicles. For this purpose, an algorithm based on data fusion techniques has been developed since they are well adapted to the imperfection of the measures and their repeatability (Menant (2015)).

The data collected by the probe vehicles are indeed imprecise and/or uncertain because of the characteristics of the sensors included in the smartphone (accelerometer and GPS) and because of the measurement conditions (speed variation of the probe vehicle, lateral wheel path variation, properties of the tires/springs/dampers, etc.). Consequently, the fusion algorithm may be faced with data partially or totally in conflict. In order to better resolve this kind of situation, it is necessary to know the global level of measurement uncertainty of the method. So, the impact of each of the factors previously mentioned has been estimated in the scale of the profile indicator. In addition, as several different probe vehicles may use the same road section (as a same probe vehicle may use it several times) the calculation of the final indicator should take account of the repeatability of the measures. The data fusion algorithm has been so designed to provide a final indicator which gives advantage at the repeated data in case of conflict instead of finding a value based on consensus.

2.4. Entering the information into a database

When a probe vehicle sends a measurement file to the server, the raw data are automatically processed (map-matching operation calculation of an estimated road profile and the corresponding indicator). The result is then entered into a specific database from which the road manager can make different kind of queries (e.g. extraction of information depending on the road identity, etc.).

2.5. Reporting the final indicator with a GIS

Nowadays, the most common method to report an indicator corresponding to a road section is to use a geographic information system (e.g. QGIS, Google Maps, etc.). So, after querying the database and extracting the information corresponding to a road section and a period, the road manager can easily view the value of the associated profile indicator and his variation using a GIS. In addition to this presentation, a reporting file with a specific format can also be generated.

3. Experiments on a road network

The MIRANDA system was recently applied to the monitoring of a 1000 km network mainly composed of secondary roads during one month duration. For these experiments, about ten road service vehicles belonging to a county council in the west of France were equipped with smartphones containing the MIRANDA App. During this period, the probe vehicles have recorded a volume of corresponding data on more than 6000 km road length. As the probe vehicles regularly use the same roads as part of their functions, the level of repeatability of the measures was quite high (sometimes more than ten measures for a same road section) which enables to consolidate the road profile indicator (Fig. 6).

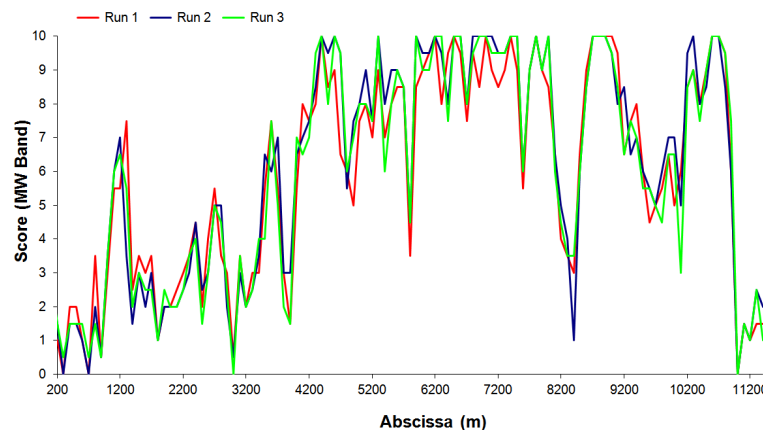


Fig. 6. Graph showing the profile indicators coming from three runs of a same probe vehicle

At the end of the experiments, a map of the road network shows the values of the profile indicator through a color scale; then, it has been presented to the road manager in order to be discussed (Fig. 7). The road manager concluded that the map is consistent with his global perception of the network. The road sections with low profile indicator were indeed nearly already all known as such by the road manager which proves the ability of the method to detect the areas with significant evenness defects. In some cases, the insufficiency of the profile indicator could easily be explained by the presence of works for example.

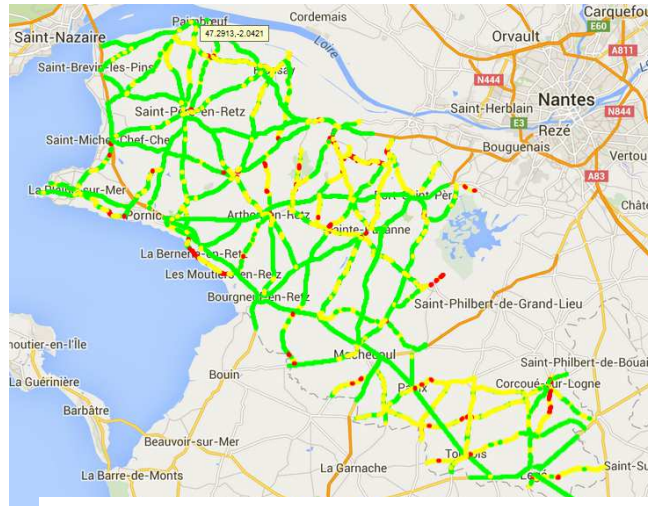


Fig. 7. Map of the network with the representation of the profile indicator (green: excellent level; yellow: satisfactory level; red: poor level)

Considering the road manager satisfaction to these results, it has been decided with him to continue the experiments in order to reach several short-term goals:

- Validate the results in a more quantitative way by comparing, on several representative samples of road sections, the measures with those coming from a specialized vehicle;
- Collect data on a longer period for observing the evolution of the profile indicator on each road section over time;

On a longer term, the road manager would like to include the indicators provided by the MIRANDA system into the input data of his pavement management system. For this, it is first necessary to correlate the list of road sections, for which the manager has already decided to maintain, with the value of the corresponding indicator of road profile. Then, several thresholds in connection with the desired level of service will be defined since the road profile indicator scale.

At the technological level, these experiments have revealed the robustness and the reliability of the MIRANDA system since no significant bug happened during the test period in the use of the MIRANDA App as well as the other software components. Only a few corrections related to the map-matching operation during the processing of very special cases had been realized.

4. Conclusion

Currently, a lot of road managers need to have regularly and in “real-time” some information about the condition of their network in order to quickly trigger some works and so to reduce the maintenance costs. Considering that the managers can’t always use the specialized vehicles because they are too expensive (in particular for the monitoring of secondary roads), a new kind of pavement monitoring tools has to be found. In this context, IFSTTAR has considered a method based on the use of probe vehicles equipped with low-cost sensors (the ones that equip a smartphone) and has developed the MIRANDA system, an automated measurement chain for the monitoring of the longitudinal evenness. Recently, this system was tested on a 1000 km road network in partnership with a county council in the west of France. For the experimentation, which lasted one month, this council has made available a part of his own fleet of vehicles as probe vehicles. The first results indicate the ability to correctly detect and characterize the longitudinal irregularities whose wavelength is above 3m (however, some significant defect with lower wavelength like potholes can also be detected). Considering this property, the method is adapted to estimate the level of service in connection with the driver comfort as well as the detection of structural problems.

Since the road manager was satisfied of the MIRANDA system, it has been decided, in the future, to continue the monitoring over a longer period and to observe the progression of the road indicators. In parallel, it would be interesting to apply the MIRANDA system to a larger network with a greater number of probe vehicles in order to test it more strongly and to possibly get aware of some limits (e.g. minimal number of probe vehicles to use in relation with the road network dimension).

When the system will be completely operational, the data delivered by the MIRANDA system may be entered into a pavement management system to fit the maintenance program depending on the road indicators progression. For the moment, only one indicator related to the longitudinal evenness has been considered but the MIRANDA system might be adapted for other road indicators.

Acknowledgements

The authors wish to thank Xavier Phelippeau, Eric Michaud and Stephan Chauveau who belong to the Loire-Atlantique council (France) for being involved in this study.

References

- Bétaille D., Peyret F., Voyer M., 2015. Applying Standard Digital Map Data in Map-aided, Lane-level GNSS Location. *The Journal of Navigation*, pp. 1-21.
- IDDRIM, 2014. Uni longitudinal, Etat de l'art et recommandations. Coll. Références, CEREMA.
- Menant, F., 2014. "Estimation de l'uni longitudinal des infrastructures routières au moyen de véhicules traceurs : développements méthodologiques et expérimentations". Ph.D. dissertation, IFSTTAR, Ecole Centrale de Nantes, France.
- NF P 98-218-3, 1995. Détermination de quantificateurs d'uni longitudinal à partir des relevés profilométriques.
- Robert B., Delaval E., Martin J-M., Boulet M., 2009. Mesure de l'uni longitudinal des chaussées routières et aéronautiques : Exécution et exploitation des relevés profilométriques. Méthode d'essai n°46-2.
- Sayers M.W., Karamihas S.M., 1998. "The little book of profiling: basic information about measuring and interpreting road profiles", University of Michigan Transportation Research Institute, Ann Arbor, MI.