DEVELOPMENT OF A COMPUTERIZED, LOW-COST, PORTABLE SYSTEM FOR VISUAL INSPECTION, CHARACTERIZATION AND MAINTENANCE MANAGEMENT OF HIGHWAY PAVEMENTS

Paper No 458

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[Categories]
1.1 Benefits and costs of roads

Keywords
pavement preservation, visual inspection, software, inspection equipment, maintenance management

Presentation type : None
Contact : nfvtrindade@gmail.com
Submission date : 2009-11-26 09:59:29
Jury validation date : 2009-10-01 14:37:14

DEVELOPMENT OF A COMPUTERIZED, LOW-COST, PORTABLE SYSTEM FOR VISUAL INSPECTION, CHARACTERIZATION AND MAINTENANCE MANAGEMENT OF HIGHWAY PAVEMENTS

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ABSTRACT
The methodologies of visual inspection and characterization of highway pavements have not been up-to-date with the wide-ranging technological breakthroughs of the recent years. The traditional techniques, which use archaic instruments for positioning and tracking, continue to be massively used. Although there are a few technologically advanced solutions available, in general these involve very expensive equipment, can only be used in conjunction with an inspection vehicle and, therefore, do not enclose the level of versatility needed in most cases. In addition, these solutions are not practical for inspecting highly trafficked intersections, especially when some level of detail and precision are needed. Furthermore the office work required to organize the extensive raw data collected in the field, by traditional means, is considerable. It often involves several time-spending stages in the treatment of the data records, which can lead to errors and imprecision, before it can be available for analysis and interpretation. It is urgent to adopt more effective and versatile methods that are both economically and technically proficient and also more sustainable without the substantial costs in manpower, time and energy. The purpose of this work is to present an ongoing research focused on creating an integrated system to aid the visual inspection and characterization of pavements and manage its state of preservation. The premises of this development implied that the system should use state-of-the-art technology (in both hardware and software), allow a high level of detail in the characterization, be manifestly low-cost, user-friendly, portable and ready to be used on-foot or installed in a vehicle, significantly reduce the time and means involved in the field work, decrease the number of phases in the handling of the field data and efficiently manage the condition of the pavement. Starting with the experience acquired in practical cases where detailed pavement inspection and characterization took place, namely a section of the A1 portuguese motorway, a comparison between the means involved in the use of traditional methods and the use of this new system, will be made. In addition the several pavement pathology classification criteria available nowadays and the way this system deals with it, will be shown. Finally the repercussion that the commercialization and generalized use of this type of low-cost systems can have in the quality of the results and in the reduction of material and human resources will be discussed.

1 Introduction

The companies involved in road and pavement design, need to carry out, every year, a large number of visual inspections. In its vast majority, these are performed by using traditional techniques. More advanced inspection techniques, that involve expensive equipment, are less commonly used.
The reliability of the data acquired in the field is fundamental to guarantee a correct interpretation of the existing situation. The information that results from the visual inspection complemented with the results of the pavement tests are of capital importance for the planning and design of road pavement structures. Therefore, the development of the system, named 'INPAV', described in this paper, aims to both improve the reliability of this data, used for highway pavements design and planning, and reduce the costs and means necessary for its attainment.

2 Pavement inspection and characterization

2.1 The process of visual inspection and characterization

The process of visual inspection and characterization typically involves three phases: the visual inspection itself, carried out in the field, the treatment and analysis of the collected data and finally, the compilation of the characterization reports, which include the photographic report and diagrams/lists of distress location.
Traditionally, the visual inspection can be executed on foot or on-board of a motor vehicle. The visual inspection carried out on foot requires, most of times, two operators, which divide among themselves the tasks of analysing and registering the pavement pathologies, in distress survey sheets, its position, by using a road distance measuring wheel and collecting photographic data of the existing situation. Commonly, one operator takes out the mission of measuring distances and positioning and the other analyses and registers the occurrences. The circulation of the operators is done through a traffic lane which requires the use of a road security protection unit, through the shoulder or outside the road, beyond the guard-rail, which, most of the times does not require security protection. This kind of inspection allows higher precision but it requires a longer period of time to be completed.
The visual inspection on-board a motor vehicle also involves two operators, the driver, that observes and analyses the pavement and the passenger that registers the occurrences. The position is determined by using the car odometer or a distance measuring wheel. This type of inspection has lower precision, always requires road security protection but it is usually faster than the inspection on-foot. The capture of images of the pavement is more difficult because it has to be made from within the vehicle, through the windows or require that the vehicle is stopped so the picture can be taken with more detail outside.
A third option is the use of dedicated pavement inspection vehicles, equipped with automatic visual inspection aid systems. These vehicles incorporate an on-board computer, wherein, the operator registers the observed pathologies. The positioning is made with an odometer or GPS receptor and the image capture is accomplished with a camera mounted outside the vehicle. Some of these systems restrain its activity to the capture of high definition images of the pavement surface and the process of observation and classification of distresses is carried out in a subsequent stage.

2.2 Examples of traditional visual inspection and characterization operations

From the several campaigns of visual inspection and characterization carried-out during 2009 in Portugal, three examples, with different characteristics, are described bellow:
1. " *25 Abril*" bridge road network (about 3 km of main road and 6 km of intersection branches) – Because it included some of the most trafficked sections in the country, and because the circulation of the operators through the exterior shoulders and beyond the guard-rail could be done with safety, the inspection was entirely made on foot. A security protection vehicle was needed in a short extension, where the shoulder was not wide enough and the circulation beyond the guard-rail was not possible. The total duration of the inspection was 3 days.
2. " *Vasco da Gama*" bridge road network (about 18 km of main road and 9 km of intersection branches) – In the main road, the inspection was made on-board a vehicle, and an additional security protection vehicle was used. In the toll plaza and intersection branches, the inspection was carried-out on foot. The total duration of the inspection was 4 days.
3. Section of the A1 motorway (about 18 km of main road and 6 km of intersection branches) - The inspection was entirely made on foot, through the most interior lane of each carriageway (left lane), with constant protection of several security vehicles, except in the intersection branches, where no additional protection was necessary. The inspection was made with high detail, since there was no existing information about the maintenance condition of

the pavement. The total duration of the inspection was 6 days. The circulation of the operators was made through the left lane due to a number of reasons, including the facts that the exterior shoulders where not wide enough in some places and because of the need to register the condition and characteristics of both the New Jersey barrier median and the road drainage, by other technicians. The extensive security protection measures included 3 protection vans and 5 people from a specialized security protection company that progressively interrupted the traffic in the left lane and 2 police officers with 1 vehicle for traffic control and collision prevention.

All of these inspections where made by two operators, using traditional methods and all the highways have dual carriageway with 3 lanes in each direction.
The field inspection was followed by the office stage. Initially, the distress survey sheets were manually transcribed to a digital spreadsheet, so the information could be easily accessed in posterior phases. Based on this information the visual inspection and characterization report was prepared, including the photographic report and the diagrams/list with the location and characteristics of the pavement pathologies observed in the main road and intersection branches. The total duration of this stage was, in average, four to five times superior to the duration of the field inspection.

3 Description of the system

3.1 Objective

As shown in the previous chapter, it is frequent that visual inspection missions require the mobilization of a considerable amount of means. This results in high monetary and environmental costs. Furthermore it involves abundant time and human resources. Therefore, even small optimizations aimed to reduce the spending can result in large savings at a global level.
The objective of the INPAV system is to both be used as an auxiliary tool in visual inspection (allowing the increase of precision and commodity and the decrease of the time and number of people involved) and to overcome the lack of integration between the three phases previously mentioned, which is typical of traditional methods.

3.2 Components

The system is constituted by three fundamental components: the field module, the base module and the management module. A fourth component can be considered, the server, which runs unnoticeably to the end user but has an essential role in the interoperability amongst all the components of the system. Although each module is able to operate autonomously, meaning that a possible critical fail in one of the modules will not disrupt the operation of the remaining modules, it is the network integration of all components that adds significant and tangible value. The dataflow of the system is illustrated in the following diagram (Figure 3.2.1).

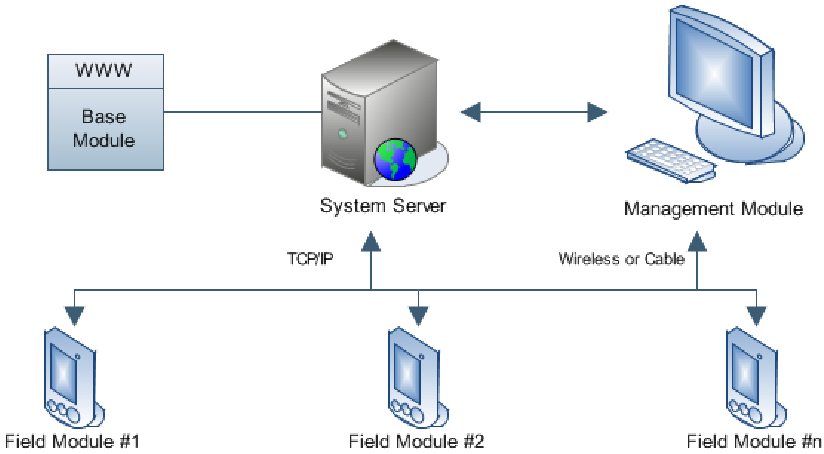

Figure 3.2.1 – System dataflow diagram

3.3 Field Module

The field module is the systems most innovative component, playing a fundamental role in the attainment of the objectives proposed in the beginning of the development.

The purpose of this module is to assist the user in the visual inspection of highway pavements. It is constituted by a Personal Digital Assistant (PDA), running software that enables the registration of pavement distresses, its severity and location. This latest generation equipment incorporates a touch-sensitive screen, cell phone, mobile access to the Internet, a Global Positioning System (GPS) receiver, Assisted GPS (A-GPS), wireless connectivity, 5.0 megapixel digital color camera, accelerometer/gyroscope, sound recording capabilities and the latest version of the most commonly used mobile operating system worldwide.
The primary element for the location and measuring of distances is the GPS. The A-GPS and the accelerometer/gyroscope are used as secondary elements for measuring and calibration. The input from the user is made through the touch-sensitive screen, the digital camera and the sound recorder.
Using the interface, the operator initially sets up the characteristics of the road section, the process of inspection and the distress classification criteria to be used. The module will then initiate, through the GPS receiver, the recording of the successive position of the user. The input of the pavement pathologies is made through a list of distress types (Figure 3.3.1). This list is totally customizable and elements can be added (other types of distresses or specific occurrences like transverse pavement joints or changes in the number of lanes) or removed, according to the specific needs of the inspection. The user can also choose the level of severity, the transversal location of the distress or define points to delimit the area affected by that distress. Photos, videos, written or voice recorded notes can also be attached to each occurrence.
It is difficult and time-spending for the person analysing the pavements to effectively characterize some situations where some level of complexity is involved, like in carriage ways with multiple lanes and many different types of distresses and severities, which appear systematically. To overcome this problem, the field module is able to perform the simultaneous monitoring of several distresses. The occurrences are put on a “waiting line”, where its length, area and other properties can be modified, before they are definitely closed.
The progression of the inspection can be visualized geometrically, superimposed to a map or in a list of occurrences. This list can be edited in any moment to correct eventual slips or errors.
According with the characteristics of the inspected area, it can be advantageous to use several field modules and inspect, at the same time, different areas of a road network. For instance, one operator covers the main road while another covers the branches of an intersection and a third, the toll plaza.
Due to the fact that the hardware enables access to the Internet, the field modules can maintain constant exchange of data among themselves or with the base module, which will be examined later in this text. Therefore it is possible for each operator to know the location and progression of the others and exchange specific information regarding the development of the work.

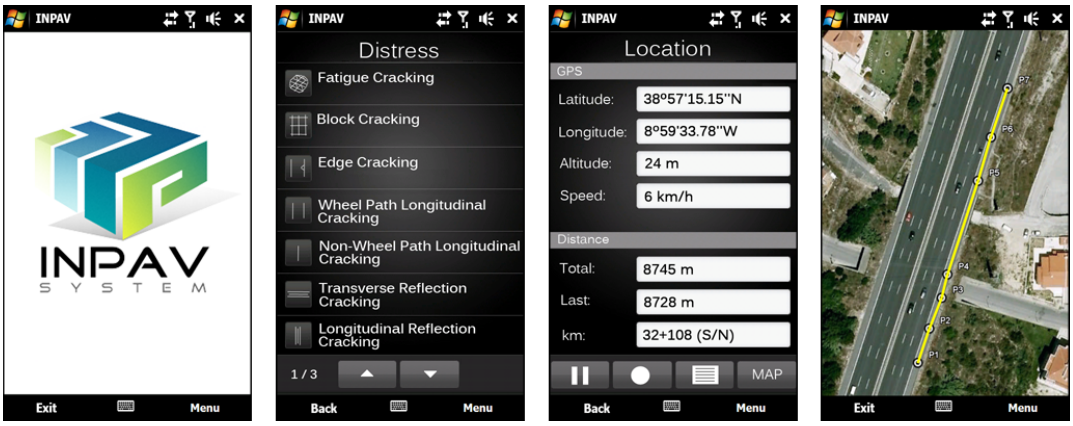

Figure 3.3.1 – Field Module Screenshots

In general, roads are situated in open spaces, where the reception of quality GPS signal is always guaranteed. However, in some specific cases, like very narrow urban areas, the GPS signal may suffer deterioration. In these cases, the precision of the location can be calibrated with the use of the A-GPS, the existing kilometric markings and a third resource, included in the software, the digital pedometer. The digital pedometer takes advantage of the instruments accelerometer/gyroscope, incorporated in the equipment, to provide an approximate measure of the distance travelled. Its precision is obviously low, but, nevertheless, it can be used to confirm distances and orientate the user when no other type of reference is available.
Although the operative advantages of the field module are maximized with on-foot inspections, it can also be used

on-board a motor vehicle, without significant loss of precision and with gains in several aspects over the traditional methods. The equipment can be connected to external devices like GPS receivers or cameras, if needed.

3.4 Base Module

The base module makes it possible for a coordinator to interact in quasi real-time with the operators of the field modules, to receive information and control the development of the visual inspection. This module is a web-based application (www.inpav.com), which means it can be accessed with any web browser, from any location in the world. Its interface allows the programming of the inspection tasks and to remotely modify the configuration of the field modules.
The base module can identify the location of the several field modules and access a series of statistics about each one, like the distances travelled and the elapsed times. Moreover, it permits the visualization of the path of each operator in a map, its current position and the position of each registered occurrence (Figure 3.5.1).
The data regarding the distresses, its characteristics and location, as well as the media files associated to each one of them can be received as they are registered in the field modules or downloaded as a group to a local computer.
The web interface also allows the exchange of messages with each field module, regarding the development of the work, like changes to the initial sequence of tasks, the need to analyse a certain area with higher detail or to photograph a specific element.

3.5 Management Module

The management module is constituted by software, prepared to be installed in any personal computer, which can process and manage the field data. The data can be transferred directly from the field modules to the management module, using cable or wireless connectivity or remotely transferred from the field modules, using the Internet and the system server as a data buffer. By using the second alternative, it is possible for the processing of the data to take place while the inspection is still in progress.
This module can automatically generate the main components of the visual inspection and characterization report, including, but not limited to, photographic reports, lists and linear or two-dimensional diagrams of pathologies (Figure 3.5.1). The layout of these elements is completely customizable.
The management module can also integrate all the data in a maintenance management database. Information from pavement field tests and planned or performed interventions can also be added to the database, which can be queried and outputted in a number of different ways.

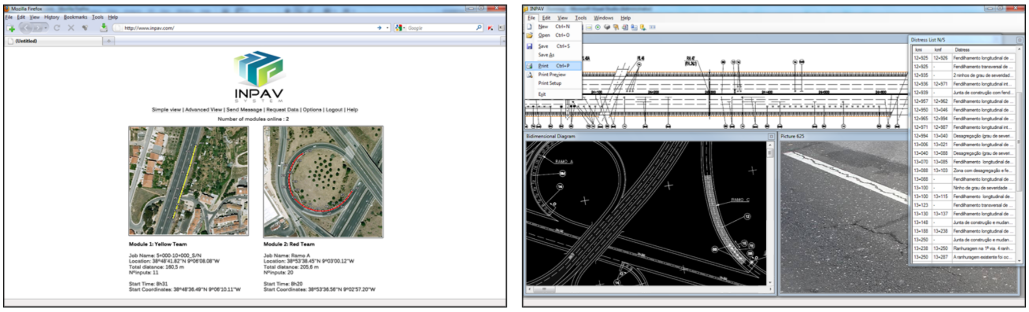

Figure 3.5.1 – Base and Management Modules Screenshots

3.6 System Server

It is in the system server that the exchanges of information between the different modules of the system take place. It is available 24 hours a day, 7 days a week and works concurrently as a data exchange server and a web server, because it also houses the base module interface. It offers a client accounts structure and for each inspection campaign, a new account can be created. To ensure privacy and security, all the exchanged data is encrypted with the standard AES (Advanced Encryption Standard).

3.7 Building the System: Main Challenges

For the system to be efficient, it was necessary to ensure that the performance of each component was optimized according to the phase it was meant to be used in. This was possible due to the field and office experience acquired in several visual inspection campaigns, namely in the three examples mentioned above.
The field inspection phase was critical, because it was this phase that could, more likely, be optimized through

technological innovation. To that extent, a careful selection of the hardware had to be made. The requirements for the equipment included primarily, integrated GPS, digital camera with appropriate quality and access to the Internet. Until very recently, the development of such system would not be possible, since the existing PDA did not meet the requirements in terms of processor speed, GPS receiver quality and especially the battery capacity. The batteries simply could not provide enough autonomy for the equipment to be functional in the field.
One of the major challenges was to obtain sufficient accuracy to deal with the positioning demands of a highly detailed visual inspection. The degree of accuracy that the civilian GPS system provides has increased in recent years, not only due to the reduction of the induced error in the emitted signal but also due to the increased quality of the receivers. It is not the scope of this work to discuss the precision and the margin of error of the GPS system, but nonetheless, even using a good quality receiver, the positioning data given by the GPS signal had to be filtered and refined through a series of somehow complex software algorithms to guarantee the adequate precision.

4 Advantages of using the system

The use of this system has advantages in the reduction of material and human resources and environmental costs, when compared with the traditional methods and even, in some aspects, with the existing automatic visual inspection aid systems, combining the versatility of the first to the sophistication of the latter.
In comparison with the traditional methods, the system allows the effective reduction of the time spent in collecting information about the pavement state of preservation. The registration of occurrences can be done without the need of frequently stopping to write down in the survey sheets the type of pathology, its location and extension. In the case of the A1 motorway, where, due to the need for high detail, it was absolutely necessary to perform the inspection on foot, the reduction in the time spent to register each occurrence, would make a significant difference, due to the enormous amount of security protection means involved. With regard to the photographic record, there is no need to manually correlate each picture with a given occurrence, since the system will do it automatically.
Furthermore, the operation of the field module requires the intervention of a single operator. This means that the second person, in charge of positioning the pathologies with the road distance measuring wheel can be let off.
Despite the fact that the field module biggest advantages are reached in on-foot inspections, its use on-board a vehicle can be advantageous in situations like the inspection of the “ *Vasco da Gama*” bridge road network, where the speed in collecting pavement data can be significantly increased. The field module is also user-friendly, with a simple but versatile interface, designed to prevent errors and guarantee the maximum precision and reliability of the collected data.
Unlike many automatic systems, the configuration of the field module, before initiating the visual inspection, is exceptionally straightforward and almost immediate, not requiring time-consuming calibration procedures. Also, unlike some automatic systems, the INPAV system does not impose changes in the methodology and criteria of distress classification. Because of the fact that the pathology classification criteria are customizable, the system is able to deal with both the most common criteria, like the ones from the Strategic Highway Research Program (SHRP) (1) and the “ *Catálogo de Degradações dos Pavimentos Rodoviários Flexíveis*” from “ *Junta Autónoma de Estradas*” (2), which are included by default in the software and with local criteria from a particular country or according with specific needs.
The movement of the operators through the shoulder or outside the road, beyond the guard-rail, often implies walking on uneven surface, which can get in the way of operating the measuring wheel and reduce its precision. This problem is avoided in the field module, because the positioning depends exclusively on the GPS signal.
Contrary to many existing automatic systems, the field module, due to its absolute portability, is indicated for the inspection of both the main road and highly trafficked intersection branches, not requiring the use of security protection vehicles or the interruption of traffic lanes, as long as the basic security conditions, for the movement of the operator on foot, are met. With some of the existing automatic systems, it is possible to make use of a detachable console for on-foot operation. However, this equipment is usually bulky, not very handy and with very short autonomy, which makes it only appropriate for localized observations. In cases such as the “ *25 Abril*” bridge road network, because of the long extension of the intersection branches, this characteristic is very important, enclosing large savings in security protection measures and therefore also from the environmental point of view (consumption of fossil fuels and release of greenhouse gases from the vehicles involved).
Because it is extremely light (the equipment used weights only about 120 grams), the field module is handier than the measuring wheel, survey sheets and digital camera, not getting in the way of the operator movements, which results in improved security.
The field modules can exchange information and be monitored centrally by the base module, which results in better coordination and planning of the work and reduced spending. This also prevents the misuse of time and leads to

the application of the proper means in the right places. This feature is particularly useful in large highway concessions in which the sections to inspect are separated by long distances.
One of the undisputed advantages of the field module relates to the fact that the equipment used is inexpensive. Instead of the many thousand of Euros that the equipment of a typical automatic system of pavement inspection aid costs, the equipment used in the field module costs a few hundreds Euros. The field module software can even be used in equipment with lower end specifications, which cost the equivalent to a quality road distance measuring wheel. Therefore, the initial investment in equipment is almost negligible and its return, nearly immediate.
As mentioned above, the total duration of the office stage is about four to five times the duration of the visual inspection. The complete integration between the field modules and the management module makes it possible for the duration of one of the most error-susceptible and time-spending phases, the treatment of the field data, to be reduced to almost nothing. In addition, the process of making the photographic reports and diagrams/lists of pathologies is automatic. Therefore, only the selection of the relevant data and the correction of eventual positioning imprecision are needed. This corresponds to a drastic reduction in the time and human resources involved in this stage, which represent a very significant share of the total cost of the process of visual inspection and characterization.
Additionally, the data can be directly integrated in a maintenance management database.

5 Conclusion
The INPAV system is still in an embryonic stage of development. Some of the functionalities presented in this paper still need refinement, in order to be prepared for operation in the field and others are still conceptual. Nevertheless, the system has potential advantages over the traditional methods of inspection and, in some aspects, over the existing automatic inspection aid systems. Its network architecture, the parallel operation of the modular units and its portability, confer the system the ideal characteristics to be used in major road projects. Contrarily to the existing automatic systems, the fact that the INPAV system is manifestly low-cost makes its generalization feasible, with subsequent savings on a global level.
Future improvements of the system include the portation of the field module to other hardware platforms, the development of an interface for airport pavement inspections and the extrapolation of the inspection system to other areas, including road drainage and signage.

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