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THE DIAGNOSIS OF ROAD SURFACE DISTRESSES THROUGH IMAGE-BASED MODELING TECHNIQUES. EXPERIMENTAL SURVEY ON LABORATORY-RUTTED SAMPLES.

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Abstract

In the past few years, there has been a drastic increase in the use of image-based modeling (IBM) techniques to create high quality, reality-based 3D models. The low costs of these techniques, as well as their attractive visual quality, have led many researchers and professionals to invest their energy and resources in several tests. IBM is rarely used in the field of road surface distresses as diagnosis is usually performed using other techniques and devices. Road safety statistics reveal that about a half of the total number of accidents occur mainly due to the deterioration of the pavement. The goal of effective road network management is often incompatible with economic resources designated for maintenance and rehabilitation. For this reason, IBM diagnosis of distresses seems necessary in order to both increase the level of road safety and to avoid incorrect interventions and treatments of road pavement.

One of the strengthens of multi-view stereo techniques is the possibility to capture millions of points in a very short time, and to produce a 3D, textured polygonal model that can easily be used for visualizing and communicating digital assets.

Our goal was to implement the IBM techniques on a laboratory-rutted sample and to verify the metric accuracy of the model and its validity for the distress diagnosis in terms of severity (rut depth). In order to assess the IBM technique, we compared its 3D model to the blue LED 3D scan (Artec Spider) of the same rutted sample.

1. Introduction

The municipal road pavement management department utilizes decision-making tools to determine priorities and identify the most suitable maintenance and rehabilitation activities to be performed under the budget constraints. For this reason, maintenance and rehabilitation (M&R) plans must be analyzed as real economical investments in order to select the most effective, long-term strategy (over a consistent time period equal to at least five years).

The Life Cycle Cost Analysis (LCCA) is the well-known analytical method that allows for the evaluation of various costs of different investment alternatives over an established time period (i.e. analysis period) [1]. With the aim of implementing a good strategy in terms of technical and economic effectiveness, the method must first be able to identify the type and severity of pavement distresses. Fatigue and rutting performances, as well as skid resistance, are the main qualities of pavement that create safety and ride quality problems.

Generally, in the urban road network, distress analysis is based on visual monitoring, even though the number of urban road accidents is much higher than the sum of the accidents occurring on motorways and highways. Highway and motorway analysis, on the other hand, can be surveyed by utilizing terotechnology (Tab 1).

The IBM technique could be crucial in evaluating road pavement distresses, especially in urban areas where it is not possible to use terotechnology. It would be a further improvement to distress analysis, which is currently carried out, mainly, by means of visual survey. For this reason, we have tested the IBM technique on a rutted sample, in order to measure the metric accuracy necessary for establishing the distress severity. The metric reliability was evaluated by comparing the IBM model to the 3D scanner (Artec Spider) as 3D virtual reference to the most realistic reconstruction. The result is calculated measuring the deviation between both models through the Root Mean Square (RMS) value. Our final goal is to implement an Urban Pavement Management System (UPMS) through the use of IBM techniques.

TABLE 1 - ITALIAN NATIONAL ISTITUTE OF STATISTICS DATA ON ACCIDENTS

Road Safety Data in Sicily (2013)					
Road category	Accidents	Dead	Injured	Death rate	Injury index
Urban road	9,400	103	13,373	1	142
Motorway	756	25	1,313	3	174
Highway	1,665	126	3,038	8	183

1.1. State of the art

This field has not been widely studied and there are few studies applying this technology to road pavement applications.

Previous work in similar fields focused attention on the survey of defects on asphalt pavements. The surveys were carried out using images from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) [2] and high spatial resolution images [3, 4, 5]. According to the most recent studies [6], a 3D laser system and sensors portable by drones could represent the best solution to investigate wearing course conditions.

The present study inserts itself into the already mentioned background information. In particular, it is a pilot study to investigate the accuracy and the feasibility of the IBM technique within road pavement survey. It was carried out on the rutting phenomena, hereinafter explained. This study will lead to a full-scale survey.

1.2. Rutting phenomenon

Rutting is a phenomena consisting of a gradual dip in the road surface, more or less localized; namely a depression in the wheel path (Fig. 1). It may also present with pavement uplift along the side of the rut.

The causes of such distress can widely vary from the traffic loads, to the climate, to an incorrect asphalt mix-design, to a bad pavement design.

Fig. 1. Full scale rut depth: depression in the wheel path.

For this reason, it is important to accurately diagnosis the distress so management teams can perform the best treatment under the constraint of economic resources.

Basically, a road pavement consists of several overlapping layers, namely a wearing course and a load-bearing structure made of other layers. The wearing course is the layer directly in contact with traffic load and, generally, contains superior quality materials.

The weight of rutting is also determined using the Present Serviceability Index (PSI), which is mainly used by technicians and researchers [7] [8]. The exact measure of the rut depth is necessary both for evaluating the severity of this distress and for establishing the time and the cost of M&R interventions.

Rutting is one of the phenomena that is taken into consideration early on in pavement design methods such as in ken PAVE and MEPDG, which are empirical-mechanistic methods. Furthermore, it is possible to evaluate its size using a predictive approach, when the parameters that influence rutting performance are known according to Col AHM [9].

In the field of experimental applications, rut depth can be estimated by means of a Wheel Tracker Machine (WTM).

2. Methodology

2.1. Sample manufacturing

Sample manufacturing was carried out according to the standard UNI EN 12697-33 and UNI EN 12697-35 (mixing and compaction in laboratory). The equipment used for the slab manufacturing was the Roller Compactor (UNI EN 12697-33). In order to use it, a mold (350 x 350 x 50 mm) was filled with bituminous mixtures coming from a previous survey on the material carried out according to SUPERPAVE methodology by means of Gyratory Compactor (ASTM D6925–15) (Fig. 2).

This investigation provided information about the quantity and typology of materials.

Fig. 2. Wheel Tracker Machine used in DICAM's laboratory.

Lastly, the bituminous mixture was dumped in the heated mold. Then, the material was pre-settled by a vibrating flat surface.

In order to obtain a slab with a thickness equal to 50 mm, the compaction was carried out with three different loads relative to three different cycles according to [UNI EN 12697-25].

In the end, the slab was tested for rutting behavior [UNI EN 12697-22] by means of a Wheel Tracker Machine (WTM). The final rut depth was 9.1 mm.

2.2. Image Based Modeling techniques on a rutted sample

IBM techniques have been tested, particularly in the field of architecture, both for the diversity of materials and for the size of the scale of the object [10]. However, even today, in the road pavement sector, there are no tests that indicate a methodology pipeline.

2.3. Data set

In a particular sample, like the rutted one, there are some small problems that we must overcome to guarantee the final result of the processing: the dark color, the uniformity of the material, the reflectance and homogeneity of the surface. These aspects are subject to alignment problems during the algorithmic process due to the overlap of the homologous points. For these reasons, we drew some chalk markers on the rutted sample and disposed the sample on colored sheet. (Fig. 3).

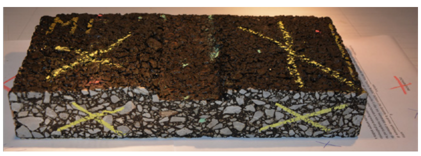

Fig. 3. Rutted sample and marker application.

2.4. Employed package: Agisoft PhotoScan

Agisoft PhotoScan is an advanced, image-based 3D modeling solution aimed at creating professional quality 3D content from still images. Based on the latest multi-view 3D reconstruction technology [11], it operates with arbitrary images and is efficient in both controlled and uncontrolled conditions. Photos can be taken from any position, providing that the object to be reconstructed is visible on at least two photos. Both image alignment and 3D model reconstruction are fully automated (Fig. 4).

Property	Value
Effective overlap	2.9669
Reprojection error	0.565089 (1.73231 max)
Alignment parameters	
Accuracy	High
Image pair preselection	Disabled
Constrain features by mask	No
Matching time	1225.17 seconds
Alignment time	55.601 seconds
Depth Maps	
Count	51
Reconstruction parameters	
Quality	High
P1	40
P2	2000
Processing time	8638.27 seconds

Property	Value
Model	
Faces	1144075
Vertices	574009
Reconstruction parameters	
Object Type	Arbitrary
Geometry Type	Smooth
Quality	High
Face count	2000000
Filter threshold	0.5
Processing time	1271.56 seconds
Texturing parameters	
Mapping mode	Generic
Blending mode	Mosaic
Width	4096
Height	4096
Processing time	171.448 seconds

Fig. 4. Screenshot of Agisoft Photoscan properties.

A data set of photographs appropriate for use by PhotoScan is shown in Fig. 5, once the markers have been applied [12]. After building the mesh, it may be necessary to edit it. Once the geometry (i.e. the mesh) is constructed, it can be textured and/or used for orthophoto generation [13] (Fig. 5).

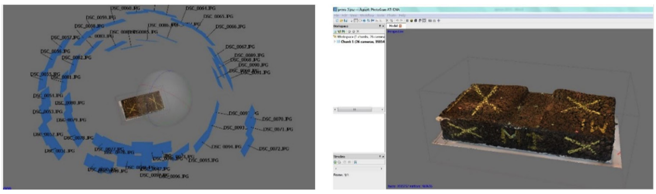

Fig. 5. Data set in Agisoft Photoscan and geometrical and texturized 3D model in Agisoft Photoscan

3. Results

The obtained models were scaled and aligned in Meshlab, and the corresponding models were created by means of the handheld 3D scanner Artec Spider (3D point accuracy up to 5x10-3 mm). Haussdorff [14] distance between the aligned model and the reference scan was processed. The calculation range was assigned according to the object's size: 0.001-0.00 m for the rutted sample (GDS 2 mm ca) [15].

The value of Haussdorff distance is RMS=$329x10^{-3}$ mm. (Fig. 6).

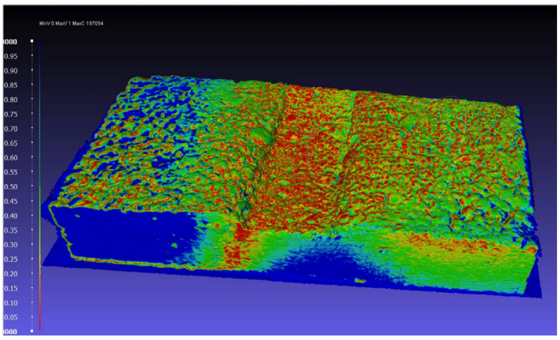

Fig. 6. Colored histogram of Haussdorf Distance: the vertices are colored according to a range that spans from red (deviation equal to 0 mm) to blue (deviation ≥ 1 mm).

Furthermore, the histograms show the deviation distribution (in terms of number of interested vertices) and the miscalculation errors of the 3D geometry.

3.1. Geome trical investigation on the captured model

After completing the procedures of reverse engineering and the numerical model acquisition, we proceeded with a geometrical-formal analysis and interpretation of the acquired 3D model, according to the needs of monitoring of road surface distresses. The CAD tools used allowed us to measure and evaluate deformations and deviations of the model's surface from reference settled geometric of the sample before rutted deformation [16].

The template file was imported into *.obj format in the working environment of the known advanced modeling NURBS (Non-Uniform Rational B-Splines) software, Rhinoceros.

The acquired 3D model was translated, scaled and rotated in order to guide and align the object in the absolute reference system, scaling it to the 1:1 dimention (units set in cm).

With the tool "Multiple sections", we created a series of spaced planar curves (parallel longitudinal sections): spaced 1 cm.

To analyse the trend surface and metrically control the amount of deformation in correspondence to the rutted part, we individuated three different geometrical section profiles. The first one (red) is the section profile of the rutted deformation in that specific place. The second one (orange) is the section profile of the non-rutted sample. The third one (blue) is the reference tangent plane in the highest point of deformation (Fig. 7-8) [17].

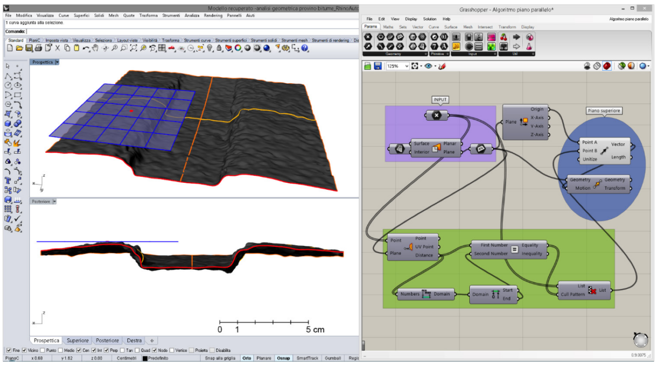

Fig. 7. Determination of the tangent plane to the surface. On the right, the Grasshopper algorithm operating scheme.

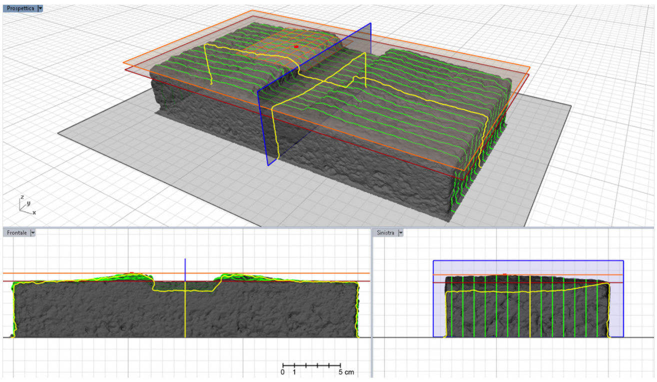

Fig. 8 -Definition of the cutting planes in horizontal and vertical attitudes to intersect the mesh and extraction of some certain curvilinear section profiles.

In the centreline of the long side, we divided the entire model into two symmetric parts, through the intersection with a cutting plane in vertical attitude, Fig. 8 (the vertical plane in blue colour). We reported the curved profile with the help of the command "Extract mesh edges".

4. Discussion and conclusion

The performed experimentation constitutes a starting point for further analysis on road pavement. The carried out results show the effectiveness of the method on a rutted sample reaching a RMS = $329x10^{-3}$ mm.

Furthermore, the availability of a virtual 3D reconstruction allows for a distress analysis that would otherwise not be possible: the transversal sections allow you to detect, with high metric accuracy, the data related to deformation at each point where it is considered necessary to investigate the distress phenomenon. This leads to the identification of the cause of the distresses and, consequently, to an intervention of targeted maintenance: lower costs/maximum effectiveness.

Even if the studied methodology carries out the same metric accuracy level for measuring road pavement distresses, this experiment constitutes an important tool towards a better road maintenance (often neglected for economic reasons) with the aim of improving road safety.

References

1. Di Mino G, Salvo G, Noto S. A multidisciplinary approach using LCCA and micro-simulation model for the management of the urban pavements. Advances in Transportation Studies, Special Issue, 2014, Vol. 1, pagg. 101-112.
2. Herold M, Roberts DD, Noronha V, Smadi O. Imaging spectrometry and asphalt road surveys. Transportation Research Part C, 2008, vol. 16, pp. 153-166.
3. Resende MR, Jorge SCH, Longhitano GA, Quintanilha JA. Use of hyperspectral and high spatial resolution image data in an asphalted urban road extraction. IEEE International Geoscience & Remote Sensing Symposium - IGARSS2008, 2008Boston, USA.
4. Ferreira ER, Vieira CAO. Utilização de imagens do sensoriamento remoto para detectar defeitos nas superfícies de pavimentos asfálticos. Anais XIV Simpósio Brasileiro de Sensoriamento Remoto, Natal, Brasil, INPE, 2009, pp. 951-958.
5. Ferreira ER, Vieira CAO. Análise de curvas espectrais de 350 a 2500 nm para a discriminação de padrões de pavimentos asfálticos. Anais XIV Simpósio Brasileiro de Sensoriamento Remoto, Natal, Brasil, INPE, 2009, pp. 1079-1086.
6. Wang KCP, Smadi O. Automated imaging technologies for pavement distress surveys. Transportation Research Circular E-C156, 2011.
7. Bednar J. Pavement performance curves: four case studies. Public Roads, 1989, Vol. 53, 90–99.
8. AASHTO. (1962) Road Test, Report 5, Pavement Research, HRBSpecial Report 61E, National Research Council, Washington, D.C..
9. Lt Col AHM, Dadang MM, Law TH. Pavement performance model for federal roads. Proceedings of the Eastern Asia Society for Transportation Studies, 2005, Vol. 5, 428-440.
10. Santagati C, Inzerillo L, Di Paola F. (2013). Image-based modeling techniques for architectural heritage 3D digitalization: limits and potentialities, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-5/W2, 555-560, doi:10.5194/ isprsarchives-XL-5-W2-555.
11. Santagati C, Inzerillo L. 123D Catch: efficiency, accuracy, constraints and limitations in Architectural heritage field. International Journal of Heritage in Digital Era. 2 (2), 2013, 263-290.
12. Galizia M, Santagati C. Low-cost image-based modeling techniques for archaeological heritage digitalization: more than just a good tool for 3D visualization? Virtual Archaeology Review. 2013. 4 (9), 2013, 123-129
13. Kersten T, Lindstaedt M., Image-Based Low-Cost Systems For Automatic 3d Recording And Modelling Of Archaeological Finds And Objects. M. Ioannides et al. (Eds): Progress in Cultural Heritage Preservation, EuroMed 2012, 7616 LNCS, Pp 1-10.
14. Inzerillo L, Santagati C. Il progetto del rilievo nell'utilizzo di tecniche di modellazione dense stereo matching. Disegnare Idee Immagini. 47. 2013. Gangemi, Roma, 82-91
15. Remondino F, El-Hakim S. Image-based 3-D modelling: a review. The Photogrammetric Record, 2006. 21(115), 269–291.
16. Pottmann H, Andreas A, Hofer M and Kilian A. Architectural Geometry. Bentley. Bentley Institute Press, 2007.
17. Wallner J, and Pottmann H. Geometric computing for freeform architecture. Journal of Mathematics in Industry 1/4: 1-18, 2011.