AUTOMATED DISTRESS EVALUATION

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ABSTRACT

Automated distress collection systems have been developed over the years to evaluate the condition of road pavements. The simplest method is to have a person ride or walk along the road and visually evaluate it. However, at network level, there are a number of problems with this approach, related to the total length of roads to need survey. Automated systems have been developed in an attempt to make the evaluation procedure more consistent. This paper deals with an automated system of survey and evaluation of road pavement distresses, studied in a research program for the preparation of a mobile mapping system. The vehicle was equipped to survey the geometric characteristic of road for the realization of cadastre. The acquisition of the images of the pavement can be realized during the collection of images for the cadastre, by means of an added line scan on the vehicle.,. The distress degree can be estimated in completely automatic way on these images. In the process of asset management , the appraisal of the pavement conditions represents one of the aspects more important in a pavement management system. The automatic survey and evaluation of pavement distresses are still a relatively new technology for which an official protocol does not exist yet. The studied methodology represents fast and economic instrument to survey the condition of the pavement at network level. A pavement condition indicator can be defined from the images: the Unified Cracking Index (UCI). UCI is valuated completely automatically, without man work. This method eliminates the subjective and arbitrary nature of the evaluations due to human nature, but it eliminates the experience that only a prepared operator has. Therefore, the system gives the chance to interact with semi-automatic systems if the results of the automatic valuation need of deepening.

KEYWORDS

Automated distress collection, evaluation, image, UCI

INTRODUCTION

The general concepts to implement a Pavement Management System – PMS are well known by both the administrative agencies and the companies but the application that includes planning, programs, project design, construction, maintenance, rehabilitation, are often not satisfactory. In fact many Italian agencies have serious delays in keeping decision support system to PMS because the lack of data on their managed network. The principal reasons of this lack are the large dimensions of the network and the elevate cost of surveys.

For this reason, all over the world during last years, many researches are been conducted to improve systems and procedures of automated survey distress; the goal of those researches is to improve conditions over manual survey with an increase of operating safety and an abatement of costs.

1 PAVEMENT DISTRESS SURVEY

Quantification of pavement crack data is one of the most important criteria in determining optimum pavement maintenance strategies. The simplest method is to visually inspect the pavements and evaluate them by subjective human experts. This approach, however, involves high survey costs and produces unreliable and inconsistent results. Furthermore, it exposes the inspectors to dangerous working conditions on highways. To overcome the limitations of the subjective visual evaluation process, several attempts have been made to develop an automatic procedure. Most current systems use computer vision and image processing technologies to automate the process. However, due to the irregularities of pavement surfaces, there has been a limited success in accurately detecting cracks and classifying crack types. In addition, most systems require complex algorithm with high level of computing power. While the use of automated pavement condition surveys are becoming more and more common, many agencies still rely on manual pavement condition surveys to provide their pavement condition data.

1.1 Manual Surveys

There are two basic methods for conducting manual pavement condition surveys, walking and windshield surveys. Walking and windshield surveys are also commonly combined to provide a more complete pavement network survey.

1.1.1 Walking Survey

Walking surveys are completed by a rater who is trained to rate distresses according to the agency's distress identification specifications. The rater walks down the side of the pavement and fills out a pavement condition form that describes the amount, extent, and severity of each distress present on the roadway. Walking surveys provide the most precise data about the condition of the rated pavement (Haas, 1994), provided the raters are well trained and experienced. However, only a sample of the pavement network can be surveyed because of the amount of time a walking survey consumes. For example, the pavement network could be represented by only surveying some sampling units of each km. Some of the methods used by agencies to select a site for the sample include: sample at fixed distance intervals, make a predetermined random selection, and have the rater pick a "representative" sample. Random selection can sometimes be difficult to accept because the pavement under review may have a considerable amount of distress, but the random sample has, for example, recently been patched. However, selecting a more "representative" sample will distort or bias the data about the condition of the pavement network (Haas, 1994). Under the theory of random selection some of the samples will have more distress than the pavement actually has and some of the samples will have less distress than the pavement actually has. Therefore, the overall condition of the network will average out, provided the sample size is large enough.

1.1.2 Windshild Survey

A windshield survey is completed by driving along the road or on the shoulder of the road. The pavement is rated by a rater through the windshield of the vehicle. This method allows for a greater amount of coverage in less time; however, the quality of the pavement distress data is compromised. The entire network could possibly be surveyed using this method or samples may still be used.

1.1.3 Walking+ Windshild Survey

Combining a walking survey with a windshield survey is a good method to achieve detailed pavement distress data and complete pavement surveys on a greater percentage of the network. Haas (1994) states that this method is acceptable only if the same procedure is used on every section in the network, and a random method is used for selecting the sample where the walking survey will be performed.

1.2 Automated Survey

The data collection technologies fall into two general classes: imaging of the pavement surface through photographing, videotaping, or digitizing: and the measurement of pavement longitudinal and transverse profile through the use of various noncontact sensors.

Information on American agencies activities are reported in table 1.

Table 1

		Data Item		
Activity	**Entity/process**	**Cracking**	**IRI**	**Rutting**
Automated collection	Agency	30	54	30
Automated Processing	Agency	14	-	-
Image capture	Analog	16	-	-
	Digital	17	-	-
Sensor data collection	Laser	-	44	30
	Acoustic	-	3	15
	Infrared	-	4	2
Protocol use	AASHTO	4	12	6
	ASTM	-	19	-
	LTPP	5	-	-
	Other	21	16	38

Although there are numerous variations, they tend to be differences within between the monitoring frequency used for pavement surface distress (imaging) and that used for the sensor-measured features (roughness, rut depth, and joint faulting). Essentially, that difference pertains to the relative difficulty in collecting and processing imaging data. The data monitoring frequency depends on the class of highway and its traffic, on weather conditions and depends on pavement design too (asphalt or concrete) (table 2).

Table 2

Frequency	Cracking	Smoothness/roughness	Rut depth
1 year	9	26	24
2 years	18	20	20
3 years	2	4	4
Other	1	2	2
Total	30	52	50

Rut depths typically are concurrently determined with measurements of roughness because the same sensor technology can be used.

An initial effort was made to address pavement condition data sampling interval. However, it was determined that most agencies using automated means of data collection sample continuously, or very nearly so, on the outer traffic lane. In a few instances, a worst lane is selected for evaluation. In no case is an agency evaluating all lanes. The essentially universal practice is to evaluate the outermost traffic lane (no parking spaces) in one direction for pavements having fewer than four lanes and in both directions for roadways having four or more lanes. Images usually provide continuous coverage at 3 to 5 m longitudinally per image, whereas sensor measurements often are made at intervals of 25 to 100 mm.

A major input to location-referencing systems is the linear referencing element (table 3). There is a strong preference for the use of mile posts or mile points, and the two terms seem to be used interchangeably, although technically there is a real difference: Mile points refer to a specific location on a roadway, whereas mile posts are the physical markers for those locations. There is currently a definite trend toward the use of GPS coordinates (latitude and longitude) for location-reference purposes, although the technology has not been broadly accepted as the only method. In all except two cases, agencies reporting the use of GPS coordinates also continue to use mile points. Furthermore, discussions with highway maintenance personnel strongly suggest that physical mile posts will be in use for working purposes well into the future.

Table 3

Method	Cracking	Smoothness/roughness	Rut depth
Mile point	36	47	36
Latitude/longitude	12	15	14
Link node	5	5	5
Other	2	1	1

Numerous procedures for asphalt pavement crack identification and collection are in use in various agencies, reported the adoption of ASTM "Standard Guide for Classification of Automated Pavement Condition Survey Equipment", although four agencies reported the adoption of AASHTO Provisional Standard PP44-01, "Standard Practice for Quantifying Cracks in Asphalt Pavement Surface". Pavement surface distress is captured by several different methods.
The major methods of pavement imaging are generically termed "analog" and "digital". Analog refers to the process wherein images are physically imposed on film or another medium through chemical, mechanical, or magnetic changes in the surface of the medium. Digital imaging refers to the process wherein images are captured as streams of electronic bits and stored on electronic medium. Digital imaging is fast becoming the most popular method, owing to the quality of images that can be produced, the ease of data manipulation, and the applicability to automated data reduction.

Analog imaging

The predominant use of analog imaging of pavements is in photographing (usually with 35-mm film) and videotaping.

Images obtained can be of high quality, but they are not easily converted to digital format for computer storage and manipulation. Analog imaging has been less frequently used in recent years owing to the maturing of digital technology.

The photographic method, popularly known as photologging, essentially consists of photographing the pavement surface, usually with 35-mm film, and reduction of distress data through review of the film at a workstation. Photologging vans typically use a downward-facing camera and possibly one or more facing forward or in another direction, depending on user needs.

Also videotaping technology is a method of choice for pavement imaging and consists of the capture of pavement images on high-resolution videotapes, usually of the S-VHS variety. Typical survey vehicle configuration consists of one or more downward-facing video cameras, at least one forward-facing camera for perspective. As with photologging, pavement cameras may use special lighting to reduce shadows that can mask distress features. Reduction of distress data from videotape images also involves the use of workstations and manual review of the images to classify and quantify distresses. The method is cumbersome and has given way in recent years to digitizing of the images for more ready data handling and processing.

Digital Imaging

Survey vehicle configuration for digital imaging is similar to that for videotaping: one or two cameras capture the pavement image and special lighting may be used to overcome shadowing problems. A major force behind the move toward digital imaging of pavements is the opportunity to reduce distress data from those images through automated methods. Another advantage of digital imaging is the availability of random access to the data. Furthermore digital images lend themselves to automated analysis because of the ability to analyze variations in grayscale as those variations relate to pavement features. There are two types of cameras currently used to digitally image a pavement surface. These are known as the "area scan" and the "line scan" methods.

1. Area Scan method refers to that in which an image consisting of thousands of pixels depicts some defined pavement area, usually one-half to full-lane width and 3 to5 m long, depending on camera features (lens, camera angle, placement) and vehicle speed. In pavement imaging, camera angle is of great importance, for distorted pixels (and images) will occur if the camera is not perpendicular to the pavement surface. Area scanning uses a two-dimensional (2-D) array of pixels in a conventional sequence of snapshots.

2. Line scan imagers use a single line of sensor pixels (effectively one-dimensional) to build up a 2-D image. The second dimension results from the motion of the object being imaged. The 2-D images are acquired line by line by successive single-line scans while the object moves (perpendicularly) past the line of pixels in the image sensor. Thus, line scan pavement imaging is performed through the digital capture of a series of transverse lines that are full-pavement-lane width. These lines are "stitched" together to form a continuous image or an image broken at intervals set by the user. A particularly onerous problem with line scan imaging can result from any shadows cast by the survey vehicle itself. Because of the line scan feature, any shadow from the vehicle that falls onto the pavement surface will appear as a continuous shadow in the scanned image. If this shadow falls in a critical area of the pavement, a wheel path, for example, the image can be rendered virtually useless. Special precautions and sometimes special lighting must be used to avoid this problem with line scans.

1.3 Manual vs automated pavement condition surveys

There is no question that automated pavement condition surveys are more efficient and safer than manual pavement condition surveys; however, the quality of automated survey data has been under heavy skepticism since its conception. This skepticism has prompted numerous studies comparing manual and automated pavement condition survey data.

Gregory et al. (2003) conducted a study using the Pavement Condition Index (PCI). The automated data were collected using a data collection vehicle equipped with a digital line-scan camera, profiling devices, and laser sensors. The pavement images were reviewed using a computer monitor to visually determine distress type, severity, and quantity. Results of the study indicated that in general, distress type and quantity were consistent between techniques and the severity was somewhat inconsistent.

Wang et al. (2003) conducted a network crack survey. A Digital Highway Data Vehicle (DHDV), developed at the University of Arkansas, was used to acquire high-resolution digital images and analyze cracks with an automated real-time Distress Analyzer. A manual survey was also conducted on the same network of pavements. The automated survey covers the entire network, and the manual survey covers 5% of the same area. The Universal Cracking Indicator (CI) was used to quantify cracking for the comparison. It was found that in most cases the results of the two surveys were statistically similar, particularly when cracking presence was small to moderate. Overall, the automated survey produced higher CI values than the manual survey. Wang et al. (2003) states two possible reasons for this discrepancy: the automated procedure may have found more cracks because it grades 100% of each mile and the automated survey picked up some noises for cracks, such as stains, tire tracks, or train rails.

Groeger et al. (2003) completed a study using ARAN vehicle and WiseCrax.. In their analysis, if the manual data showed that the pavement was in "Good" condition and the automated data determined that the pavement was in "Poor" condition, a deviation of three was recorded. If both methods indicated "Very Good", a deviation of zero was recorded, and so on (Groeger et al., 2003). Also, only longitudinal and transverse cracking, without regard for whether the cracking could be classified as fatigue cracking, were considered.

1.4 Analyse captured images: Software

Computer vision systems distinguish cracks through identifying disturbances in the brightness range of the surrounding texture and must be designed to seek connected regions through mathematical algorithms.

Ideally surface distress classification software would have real-time processing capability with acceptable consistency, repeatability, and accuracy. The following obstacles go against in achieving this goal:

1. Real-time surface distress classification at any practical speed requires very high performance computing equipment.
2. Despite advancements in recent years, image processing as a field of study is still evolving.
3. Pavement surface texture and foreign objects on a pavement make surface distress detection and classification difficult.
4. Currently there are no standard indices to quantitatively define the types, severity, and extent of pavement surface distress.
5. Incompatibility of hardware and software between different vendors results in non-comparable survey data.

Despite these difficulties, there are numerous surface distress classification software systems available today. Not all of this software provides real-time surface distress analysis; however, they do all analyses automatically.

After a revue of some of them, Piccrack has been aquireed by DITS (dipartimento di idraulica, trasporti e strade) of university "La Sapienza" (Rome) to enhance a research program on the automated distress evaluation. Piccrack, developed by Prof. Hosin Lee, uses the Unified Crack Index (UCI) concept (described later in this paper) to quantify the total amount of crack without considering the crack types.

2 UNIFIED CRACK INDEX

We know that a PMS is focused at two topical activities: one at network level, one at project level. Network level analysis is of greater interest to the decision makers and budget directors and is doubtless the most powerful of pavement management approaches, because it involves:

1 Identification and ranking of candidate pavements for improvements;
2 Network-level short and long range budget forecasts;
3 Network-level pavement condition assessments;

4 Forecast of future conditions.

In the international literature there are many indexes to evaluate the pavement conditions. One over all is adapt for automated survey: the Unified Crack Index (UCI).

To calculate the crack index a robust tile-based automated crack imaging software package was been developed, which applies a median filtering technique to each tile to remove background noise caused by the pavement's rough texture while maintaining minimal degradation of sharp crack edges. The original image is overlaid with a tile of predetermined dimensions of a pavement surface. The size of the tile may be made of different numbers of pixels depending on the resolution of the digital camera and how high the camera is mounted above the pavement surface.

First, an optimum median filter is identified for various types of pavements by varying the median filter size from 3 x 3 to 9 x 9 pixels, depending on their roughness levels. Second, a thresholding equation based on the average gray-scale of each tile is developed to obtain the optimum threshold value. To improve the accuracy of the automated crack imaging procedure, variable optimum threshold level is selected for classifying a tile as cracked or not. Finally, automated crack analysis result is compared against the one produced by the manual image analysis software. To calculate crack index, first, the value of the central pixel is compared with its neighbours at 5 x 5 pixels, and its value is adjusted to the median of these neighbours. The developed automated crack imaging procedure applies a regression equation based on the average gray scale of each tile to obtain the optimum threshold value.

This technique determines an optimum threshold value for each tile as a function of its average gray-scale value. For each tile, the gray value of each pixel is compared against the optimum threshold value. The pixel is classified as a crack pixel if its gray value is less than the optimum threshold value. The decision to classify each tile as cracked or not is based on the percentage of crack pixels present in a tile. The number of cracked tiles is then divided by the total number of tiles to compute a unified crack index for each pavement image.

The range of UCI is from 0 to 100 (percent), where 0 represent an awful condition and 100 an optimum condition of pavement.

Any image is divided in rows and columns, where every matrix element is a tile. Every matrix element is classified as 0 if there aren't cracks and as 1 if there are cracks. So we obtain a matrix like one presented in figure 1.

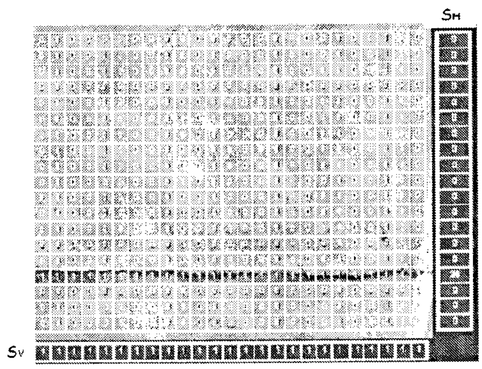

Figure 1

After, tot up the 0 and 1 in rows and columns to obtain an other column and an other row contain the total of cracked tiles in every row and column. The column Sh is composed by 0 if there are not cracked tiles on the corresponding row; if there are cracked tiles, the sum is giver on the Sh column. It's the same for row Sv.

Nr is the number of rows, and Nc is the number of columns:

$$S_V[j] = \sum_{i=1}^{N_R} cracked\_tile[i, j] \text{ for every j[1,Nc]} \quad \text{(Eq. 1)}$$

and

$$S_H[i] = \sum_{j=1}^{N_C} cracked\_tile[i, j] \text{ for every i[1,Nr]} \quad \text{(Eq. 2)}$$

The complement to 1 of outcome divided by total number of tiles is the value of UCI.

Making a comparison between the two totals of rows and columns it is possible obtain a qualitative evaluation about the typology of pavement distress. After the evaluation of cracked tiles, the absolute value of the difference between the value of the n+1 row and the value of n row in the Sh column is worked out. Equally for the Sv row.

The sum of those values is developed for both Sh and Sv:

$$D_V = \sum_{j=1}^{N_C-1} |S_V[j+1] - S_V[j]| \quad \text{(Eq. 3)}$$

and

$$D_H = \sum_{i=1}^{N_R-1} |S_H[i+1] - S_H[i]| \quad \text{(Eq. 4)}$$

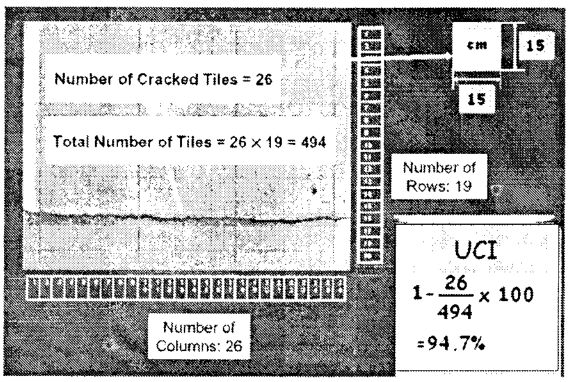

Figure 2

The difference of outcome provides the *Unified Crack Type Index* (CTI).

$$CTI = D_V - D_H \quad \text{(Eq. 5)}$$

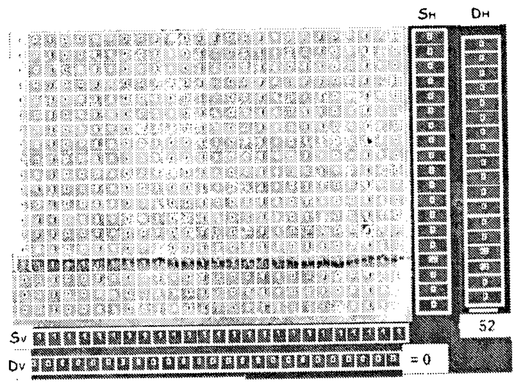

Figure 3

The evaluation of crack type is based on CTI value:

1. If CTI value is close to zero, the cracks are uniformly allocated on pavement surface, so we can say there is an alligator cracking (or block cracking).
2. If the CTI value is negative, the cracks are allocated in transversal way on the pavement surface, so we say there is a transverse cracking.
3. If the CTI value is positive, the cracks are allocated in longitudinal way on the pavement, so we can say there is a longitudinal cracking.

Prof. Lee suggest the limits in figure 4 to define the type of cracks .

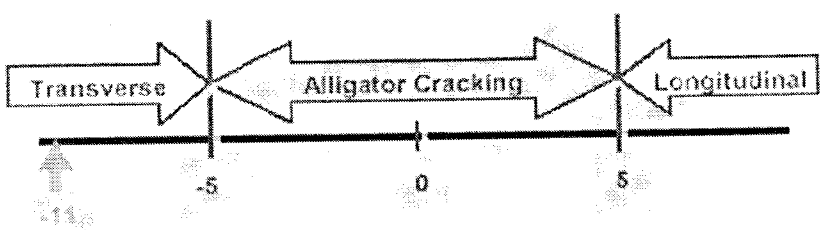

Figure 4

3 METHODOLOGY: THE THRESHOLD VALUE

The PMS is divided in 3 parts: collection, detection and evaluation of pavement distress. In the automated process many errors and noises arise in the production and capture of a signal, originating from a variety of sources such as variations in the detector sensitivity, environmental variation the discrete nature of radiation, transmission or quantization errors, stains, tire tracks, or train rails, etc. Those noises and errors, difficulty eliminable, modify the grayscale and its the threshold value and the evaluation of images. A semi-automated survey, is more accurate than automated but it requires too many time and human resources. On the other hand, manual survey is the most accurate and also the most expensive typology.

For those reasons in this paper an action rating based on UCI value is been developed.

Uci 90÷100% optimum	No action
Uci 80÷90%	Survey after 1 year
Uci 50÷80%	Semi-automated survey
Uci 20÷50%	Manual survey
Uci 0÷20%	Immidiately action

Figure 5 :Action rating table

The action rating table (figure 5) finds its reference in the table n°28 of CNR 125-88 "guida per la valutazione dello stato delle pavimentazioni per strade a basso traffico – priorità ed annotazione difetti per le pavimentazioni flessibili".

As showed in table, the range of steps are large because a greater precision is hard to obtain by automated survey. On the other hand, the manual survey precision is greater but it's more expensive due to human resource and time and also less safe for raters.

After carrying out automated survey and UCI calculation, the methodology requires an other step if UCI value is from 20 to 90%.

If UCI value is from 90 to 100% any action isn't required

If UCI value is lower than 20% an immediate action is necessary, so next step is a project-level design.

If UCI value is from 80 to 90%, it means that, despite some cracks are allocated on pavement surface, it maintains standard performance to guarantee a good and safe roadway: in that case would be necessary programming a new automated survey after 1 year

If UCI value is from 50 to 80%, a semi-automated survey is required to improve the precision of outcome. The semi-automated survey procedure allows a rater to measure the extent and severity of different types of cracks from a computer screen by an interactive system. Therefore, it can be used also as a quality assurance system for any automated crack measuring system.

If UCI value is from 20 to 50%, a manual survey is required to improve the precision of outcome: in this way it's possible to design the best rehabilitation technique; the manual survey could be carried out on some sample sections not all.

4 CONCLUSIONS

The methodology showed in this paper can be summarized in the following points:

1. images collection: an equipped vehicle provides to collection pavements images riding on roads. The system consists of two line scan cameras intended to collect

downward digital information from pavements, an odometer, GPS device capable of delivering high accuracy information about the location and a computer to collect data from cameras. The vehicle possesses a lighting system composed of neon lights used to illuminate the road to ensure good quality image.

2. Data base implementation: all captured images are stored in a data base. The DB development has two fundamental goals: calibrating grayscale threshold and creating a reference for following surveys. As a consequence it would be used as training of raters.

3. Image Analysis: first the images must be adjust to remove noises, than they can be analyzed by a software to calculate UCI and CTI values.

4. definition of action rating: for the higher values any action is required; for the least an immediate action is necessary; for the medium values a semi-automated or manual survey required to improve the precision of outcome.

This methodology tries to take good elements from both automated and manual pavement distress survey and combines them.

The big advantage of this methodology over the others is that it is cheap and quickly because uses every kind of survey in its convenience range.

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