Automation of the Schonfeld Method for Highway Surface Texture Classification

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The research reported here concerned the development of a system for measurement and automatic classification of pavement surface texture properties in accordance with the Schonfeld method. Electronic stereophotogrammetric techniques, previously used in the field of aerial mapping, were first adapted to obtain digital height data from stereophotographs of the pavement surface. Algorithms were then developed to process these data on a computer and automatically classify the surface texture in accordance with the Schonfeld method, properly accounting for such effects as tire-pavement interaction and deep voids in the surface. Application of the computer algorithms was demonstrated to yield Schonfeld parameter values that correlated reasonably well with those obtained by the manual method, thereby proving the feasibility of an automated approach to the Schonfeld classification process. Preliminary designs of camera systems that could be mounted on highway vehicles and could collect the required photographic data were also developed and shown to be feasible. The automated procedure allows a much more comprehensive investigation of surface texture to be carried out than that allowed by the manual method. The detailed information obtained on pavement texture can provide valuable data for understanding the mechanics of skid resistance and the generation of noise due to vehicle tires. It can also be effective in the specification and control of pavement construction and for monitoring wear and polishing of pavements.

A considerable amount of research has been performed in recent years to identify those pavement surface texture properties that affect skid resistance. Typical parameters of the pavement texture that are studied include average texture depth, mean void width, profile ratios (ratio of length of actual profile to length of horizontal baseline), average number of peaks per unit length, and maximum height variation (1, 2, 3, 4).

Robert Schonfeld of the Ontario Ministry of Transportation and Communications is a researcher who has extensively investigated this problem and has developed a classification system that is more comprehensive than those used previously. In his system, the pavement texture characteristics are visually examined and classified into six categories. These category values can be combined so that they correlate well with the skid number of the pavement as measured by a locked-wheel skid trailer (5).

The particular application with which this study is concerned is the automatic classification of pavement texture in a manner consistent with this Schonfeld system. The existing Schonfeld method uses visual stereointerpretation as a means of classifying the texture of the pavement sample. Automation of this procedure will have the effect of removing the human subjectivity associated with visual stereointerpretation and lead to more efficient implementation of the Schonfeld method of pavement texture classification. Furthermore, the automated technique, by using a much larger data base, has the potential for allowing much more effective classification techniques to be identified.

Stereophotography has been used for many years as a means of recording three-dimensional information. It has been used for scientific investigation and in commercial enterprises since the time Abbé Moigne equipped a stereoscope with early stereophotographs (daguerreotypes) in 1849. The original technique for measurement of the depth information depended on the stereoscopic visual acuity of the particular human observer. Not until the 1950s, when the first contours were automatically produced from an instrument developed by Bausch and Lomb, was the practicality of automatic stereoscopic measurement demonstrated (6). Now modern stereoscopic equipment has shifted the dependence from human judgment to mechanical devices under computer control. These stereocompilers are capable of rapidly deriving accurate information from stereopairs and recording the data directly on computer-compatible magnetic tape.

The primary emphasis for stereophotography, particularly in recent years, has been in the field of aerial mapping and reconnaissance. To our knowledge, it was first used only for classifying pavement structure texture by the British in 1967. At that time, the depth information contained in the stereophotographs was obtained mechanically by laboriously measuring the parallax information through the use of a stereocomparator (4). The work reported here couples the use of the Schonfeld texture classification procedure with the techniques of high-speed electronic stereocompilation to

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yield an efficient tool for pavement texture characterization.

TECHNICAL APPROACH

To develop and validate the automatic classification scheme, we first selected a number of stereophotographs that covered a wide range of pavement textures. These pavement texture samples were obtained from the Ontario Ministry of Transportation and Communications, and had previously been manually analyzed by Schonfeld.

The selected stereophotographs were electronically digitized to convert the texture information contained in the stereophotographs to digital data. Algorithms were then developed for yielding information on particle width, height, angularity, and density in accordance with the Schonfeld method. These algorithms were then applied to the digital pavement data and comprehensive statistical data obtained for the macrotexture and microtexture on the pavement surfaces. This information was then condensed to yield the six Schonfeld parameters for the surfaces and compared with the manually obtained parameters for validating the automated technique.

Electronic Stereocompilation of Pavement Samples

The process of converting the light-intensity and parallax information in the stereophotographs into digital form can be performed efficiently and accurately by using commercially available photomappers. For the purpose of this study, the digitizing services of Gestalt International Limited were procured. The equipment used for automatic stereocompilation was the second generation Gestalt Photomapper (GPM-2). During stereocompilation, the GPM-2 creates an orthophotograph (essentially a projection viewed from infinity) of the information contained in the stereopair. An example of an orthophotograph for one of the texture samples analyzed is shown in Figure 1. The reference wedge and ruler used in the Schonfeld procedure are visible in the upper portion of the figure. The pavement texture that was analyzed by the computer algorithms is contained within the white border in the lower half of the photograph.

In addition to the orthophotograph, a contour sheet is produced by the GPM-2. This sheet is a graphical display of the relief information contained in the stereophotographs. The contour sheet corresponding to the texture sample of Figure 1 is shown in Figure 2. The reference wedge and ruler are again visible in the upper portion.

The GPM-2 produces the orthophotographs, contour sheets, and the digital information for the pavement samples in a patchlike but systematic manner (7). The digital data associated with these patches is stored on computer-compatible magnetic tape. It is this digital information that is eventually used to classify the pavement texture through the use of a comprehensive set of computer algorithms. Based on studies performed at Gestalt International Limited, the GPM-2 is capable of digitizing the data within root-mean-square (rms) errors of 20 μm (787 μin), 25 μm (984 μin), and 38 μm (1496 μin) in the X, Y, and vertical Z directions respectively, provided the stereophotographs are of sufficient quality. In this study, the resolution required was only 180 μm (0.007 in) because of the limitations of the original stereophotographs.

Schonfeld Method of Pavement Texture Classification

The Schonfeld method of pavement texture classification assigns six parameters to the surface. Three of the parameters relate to the average widths, heights, and angularities of the macroparticles. The fourth parameter describes their density on the surface. A fifth parameter is used for characterizing the texture between the macroparticles (background microtexture), and the sixth parameter characterizes the microtexture on top of the macroparticles. These are characteristics of the pavement surface that are known to affect skid resistance.

In the original Schonfeld method, to obtain the parameter value for a given pavement sample, an operator performs the texture code assignment on 10 randomly selected square centimeters. The location of the 10 square centimeters is determined by placing a transparent grid over one of the photographs during stereointerpretation. The results obtained from classifying the 10 random square centimeters are then combined to yield the six texture code parameters for the pavement sample under investigation.

Automatic Classification Scheme

The computer algorithms developed for the automatic classification of pavement texture are divided into two sets.

The first set consists of algorithms that prepare the digitized stereophotographic data for processing in the computer. Here one algorithm takes the patchlike data obtained from the stereophotographs and links them together into profile form. A second algorithm is then used to produce a computer plot of the resulting profiles for visual verification of the data.

The second set of algorithms analyzes the appropriately formatted data to obtain the Schonfeld numbers. Here the first algorithm assigns to each of the individual particles on the surface (macroparticles and background microparticles) a width, height, and angularity consistent with the Schonfeld definition. It also measures the base area of each macroparticle for determining the Schonfeld density parameter. The microtexture on top of the macroparticles is then extracted and classified in a similar manner. A summary statistical algorithm next takes the individual particle statistics to form a complete width, height, and angularity distribution for all the particles on the surface. The six Schonfeld parameters for the surface are then obtained by taking appropriate averages of this particle statistical data.

It should be noted that the computer algorithms analyze the stereophotographs much faster and more completely than the manual method. Furthermore, because the whole photograph is analyzed (rather than 10 randomly selected square centimeters), the computer algorithm yields much more representative results for the Schonfeld parameters than the manual method does. In addition, other valuable information (topographic distributions, orientation of particles, and the like) is available from the computerized approach.

Details of Computer Algorithms

The algorithms employed to characterize each particle on the surface are briefly described in this section. [More complete details can be found in the final report for phase 1 of this research project (9).]

The digital data describing the pavement surface contain long wavelength undulations introduced from variations in both the average level of the texture and from

the electronic stereocompilation. (The undulations introduced by the electronic processing are caused by the stereophotographic alignment procedure.) These undulations are effectively removed by applying a two-dimensional filter to the data that is implemented recursively in the computer to save processing time. A CalComp plot of the filtered data for half of the pavement sample of Figure 1 is shown in Figure 3. (To reduce the plot density, only alternate profiles were

Figure 1. Orthophotograph of pavement texture sample 1.

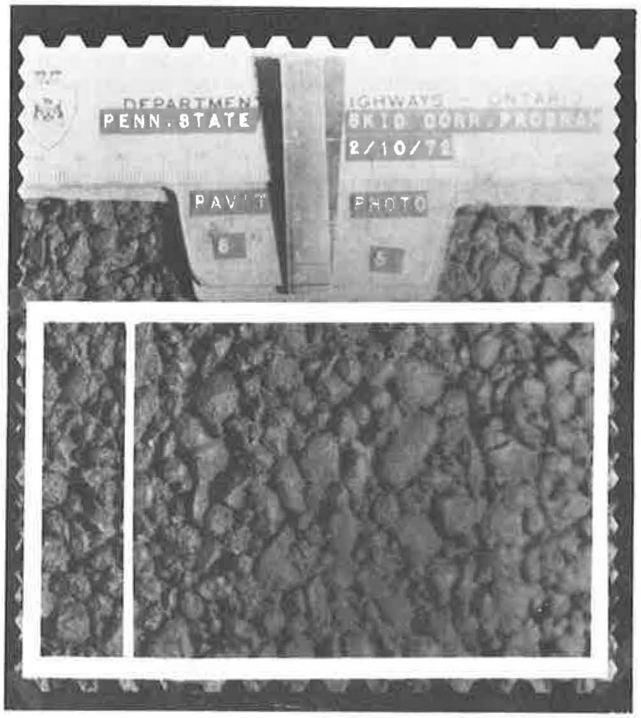
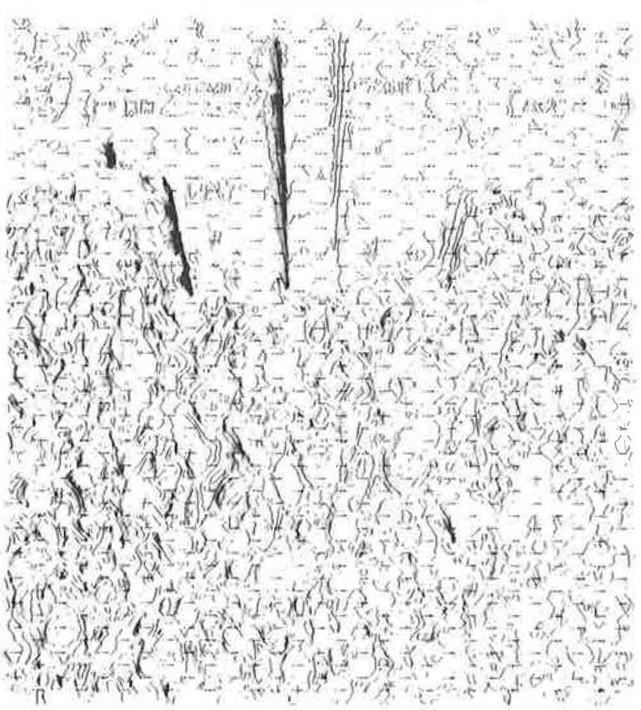


Figure 2. Contour map of pavement texture sample 1.



plotted.) The same two-dimensional digital filter is used to separate the microtexture from the top of the macroparticles when classifying these particles and to obtain other texture-interaction surfaces as will be described.

In the Schonfeld classification scheme, regions on the pavement surface with sparsely spaced macroparticles are treated differently from regions with densely packed macroparticles because dense macroparticles, when they are sufficiently high, can reduce the effective tire-pavement interaction area. Also regions where there are deep cavities or cracks must be specially treated and the cavities must be "removed" before the Schonfeld analysis. In both cases, this is done by using a threshold analysis. After identifying the regions of tire-pavement interaction and deep cavities, a reference texture-interaction surface is generated that is stored in the computer to account for these effects.

Before the width, height, angularity, and density contributions of individual particles can be obtained, the boundaries of the particles on the surface have to be identified. To accomplish this, each of the profiles that make up the surface is divided into a set of intervals. The end points of the intervals are determined (based on relative heights and slopes of critical points occurring in the profiles) so that the interval represents a probable cross section of a particle. Each of these intervals in a profile is then compared to intervals in adjacent profiles for identifying the boundaries of the particle bases.

After the base of the particle has been identified, the height of the particle is taken as the distance from the apex of the particle to the average height of the boundary points that define the base of the particle. The width of each particle is taken as the length of the minor axis of an ellipse that is fitted to the boundary points of the particle. The angularity of a particle is taken as the smallest radius of curvature over the surface of the particle and is determined by fitting a parabola to each joint on the particle surface. (The curvature in two orthogonal directions is considered.) The density contribution of a particle is defined as the ratio of its base area to the total surface area of the sample. The base area is determined by carrying out an integration over the particle base points.

The individual statistics for all macroparticles and background microtexture on the surface are calculated by the above procedure and are stored on magnetic tape. After completion of this first phase of the classification process, the algorithm extracts the microtexture from the top of the macroparticles. This extracted microtexture is then classified by a procedure similar to that for the macroparticles.

At this stage, complete information is available on the width, height, angularity, and density contributions for the macrotexture, background microtexture, and asperity microtexture. This comprehensive information on all the macroparticles and microparticles on the surface is subsequently condensed into Schonfeld form, yielding the six texture code parameters.

Stereocamera System Designs

Two camera systems were designed that are capable of taking the necessary pavement texture stereophotographs. [Detail designs of these two systems are given in the final report (9).] One system that uses a high-speed strobe is designed to be operable from on board a moving vehicle at speeds up to 64 km/h (40 mph). This would enable stereophotographs of the pavement surface to be taken with negligible interruption of road traffic. The second system is a higher resolution portable sys-

tem designed for stationary picture-taking. With this system, the assembly would be placed directly on the road surface to be analyzed and the picture would be taken. Although this could be completed in less than a minute, there would naturally be a short interruption of road traffic when this system is in use. However, the advantages of this stationary system (higher resolution and lower cost) may make it preferable to the moving system.

VALIDATION OF AUTOMATIC TECHNIQUE

The results obtained from the automatic classification procedure for the four texture samples analyzed in this study are given in this section and are compared to the results obtained manually by Schonfeld. (Clearly, a larger number of texture samples is required to completely validate the computer classification algorithms. As a consequence, in a subsequent phase of this research project, a further 14 pavement samples are being processed.)

Two computer analysis runs were made for each sample under investigation. The first one involved a small portion of the texture sample corresponding to the smaller of the two rectangular areas shown in Figure 1. The second run classified the entire texture sample shown enclosed by the larger rectangle. As can be seen in the data given in Table 1, the agreement between the automatic and manually obtained results is reasonably good when one considers the differences in sampling and the subjectivity associated with the manual method. Furthermore, in the automatic scheme, use of the smaller sample seems adequate to obtain representative results for the pavement characteristics.

For texture sample 1, the average width of the macroparticles obtained by the automatic technique was consistently higher than that obtained by the manual method. Based on observations of the orthophotograph for the texture sample, the value obtained by the automatic scheme appears to be more representative for the surface. Furthermore, in the manual technique, it was reported that there was no background microtexture present on this

Figure 3. Computer plot of portion of pavement texture sample 1.

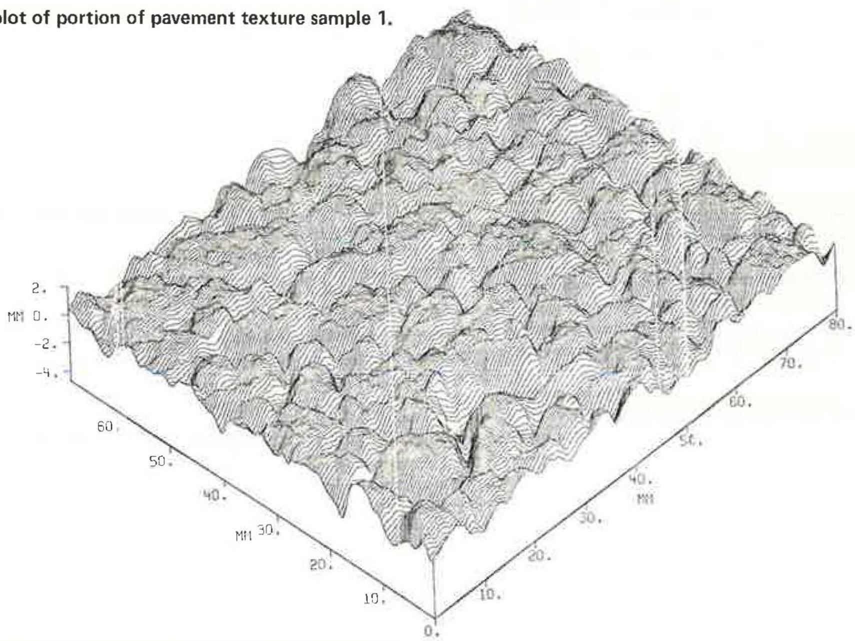


Table 1. Comparison of manual and automatic results for pavement samples 1, 2, 3, and 4.

		Average Macrotexture Height		Average Macrotexture Width		Average Macrotexture Angularity		Macrotexture Density		Asperity Microtexture Harshness		Background Microtexture Harshness		
Texture Sample	Method	Category	Value (mm)	Category	Value (mm)	Category	Value (mm)	Category	Value (%)	Category	Value	Category	Value	Area Analyzed (mm^2)
1	Manual	3.6	1.61	2.1	2.89	2.1	—[a]	3.4	85	3.2	—[a]	0.0	—[a]	1 000
	Automatic	3.5	1.477	1.3	5.131	1.6	1.050	2.3	57	2.3	—[a]	4.4	—[a]	1 440
		3.6	1.600	1.3	5.184	1.8	0.924	2.3	57	2.3	—[a]	4.1	—[a]	10 979
2	Manual	3.0	1.00	2.3	2.70	2.0	—[a]	0.2	5	3.7	—[a]	3.2	—[a]	1 000
	Automatic	1.3	0.324	1.0	3.301	1.1	1.428	1.1	27.5	2.1	—[a]	2.5	—[a]	1 440
		1.4	0.349	1.8	3.629	1.0	1.550	1.1	26.9	2.0	—[a]	2.5	—[a]	10 979
3	Manual	3.5	1.49	2.0	3.00	2.1	—[a]	0.8	19	2.8	—[a]	2.8	—[a]	1 000
	Automatic	2.1	0.571	1.9	3.357	1.4	1.200	1.1	26.1	2.1	—[a]	2.6	—[a]	1 440
		2.1	0.566	1.6	4.275	1.4	1.203	1.0	24.9	—[a]	—[a]	2.7	—[a]	10 455
4	Manual	3.5	1.54	2.4	2.65	2.4	—[a]	0.7	18	3.2	—[a]	4.0	—[a]	1 000
	Automatic	1.5	0.366	2.0	3.000	0.9	1.583	0.5	11.1	2.0	—[a]	2.5	—[a]	1 440
		2.0	0.490	1.7	3.808	1.5	1.56	0.8	20.1	2.3	—[a]	2.6	—[a]	1 817
		1.8	0.453	1.6	4.119	0.9	1.702	0.6	15.2	2.0	—[a]	2.5	—[a]	9 932

Notes: 1 mm = 0.0394 in.
Category numbers correspond to Schonfeld category numbers. Values correspond to actual physical measurements where applicable.
[a]Not applicable.

surface. The orthophotograph revealed that microparticles do indeed exist between macroparticles of the pavement sample, and, therefore, there should be a nonzero value for background microtexture. Because the manually obtained results categorized all of this microtexture with the macrotexture, it is not surprising that a larger final macrotexture density was obtained.

The second pavement texture sample that was analyzed corresponded to a concrete road surface with small aggregates. The automatic classification technique is only sensitive to height and does not discriminate between material composition; it was expected to identify more macrotexture than actually existed on the pavement because clusters of concrete, which are greater than 2 mm (0.08 in) in width, are classified as macroparticles by the automatic technique. This accounts for the increased macrotexture density in the automatic results compared with the macrotexture density in the manual results. Similarly, the height, width, and angularity parameters obtained automatically have a reduced value because concrete clusters that are comparable in size to aggregates are being included in the automatic method.

The correlation between manual and automatic results for texture samples 3 and 4 is very good; the only major discrepancy is in the macrotexture height parameter. The manually obtained results indicated that the average heights of the macrotexture present on texture samples 1, 3, and 4 were approximately equal and on the order of 1.5 mm (0.059 in). Visual observation of the individual stereophotographs revealed that the macrotexture in sample 1 was, in fact, considerably higher than that in samples 3 and 4, indicating a possible error. The difference in the two height values for the automatic and manual technique was therefore expected.

CONCLUSIONS AND RECOMMENDATIONS

It was demonstrated that pavement texture can be automatically classified in accordance with the Schonfeld scheme through use of electronic stereophotogrammetric techniques coupled with computer processing. Camera systems for taking the required stereophotographs of the pavement samples from either a moving vehicle or a stationary position were designed and shown to be feasible.

The computer algorithms that were developed are capable of yielding the widths, heights, angularities, and density contributions of all the macroparticles and microtexture on the surface. This is much more information than that given by the current Schonfeld manual method, which is based on average pavement properties of 10 randomly selected square centimeters. On further investigation, this comprehensive information could lead to the establishment of definitive relationships between pavement surface texture parameters and performance factors such as skid resistance and tire noise generation. To develop such relationships, a large sample of stereophotographs should be obtained simultaneously with the measurements of skid resistance and, possibly, tire noise. The connection between the texture characteristics and the skid resistance and noise performance could then be effectively pinned down by using the computerized approach developed in this contract.

Although the automatic classification scheme developed in this study is an excellent research tool for understanding the significance of pavement texture for pavement performance, it may not be effective as an operational tool for large-scale inventory of pavement surface texture because of the off-line requirement for the digitization of the stereophotographs and the high cost associated with the digitizing of the stereophotographs and required computer processing. For surveying large numbers of road surfaces on a long-term basis, a more cost-effective approach should be developed. Such an approach should be based on use of fewer data and ideally should avoid the need for stereophotographic digitization. (The stability of the results obtained in this project between small and large data samples indicates that use of a smaller data base is indeed feasible.) One method for obtaining the required data might be to use a profile scanning instrument similar to the laser proximity measurement device developed by the Transport and Road Research Laboratory (8). Simpler computer algorithms could then be used to process the data obtained from this instrument to yield pavement surface texture equivalent to the comprehensive approach.

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The opinions, findings, and conclusions expressed in this paper are ours and not necessarily those of the sponsor or other individuals involved in the project.

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