Automatic Pavement-Distress-Survey System[a]

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Abstract: An automatic pavement-distress-survey system that uses laser, video, and image processing techniques has recently been developed. This system consists of a survey vehicle and a data-processing system. The survey vehicle can measure cracking, rutting, and longitudinal profile simultaneously, without contact, rapidly and accurately. The data-processing system can convert the measured data automatically into formats that can be used in the pavement data bank. As for cracking, cracks over 1 mm wide can be measured, and it is easy to output the various parameters calculated from length, width, direction, position and number of cracks. The cracking processor uses a unique line-finding algorithm that can extract a crack in a noisy road image by analysis of projection curves. This algorithm is implemented in special-purpose high-speed hardware. In this hardware, up to 512 32-bit microprocessors execute in parallel. This system allows automatic crack recognition that has conventionally only been performed by humans.

Introduction

Pavement-management systems (PMS) (Haas et al. 1978; Hudson et al. 1979; Yeaman et al. 1979; OECD: *Pavement* 1987) can work effectively only when they are constructed by organically combining all activities concerned with road pavement (planning, design, construction, maintenance, rehabilitation, evaluation, economic analysis, and research) and the data bank. Then, the most important items are the establishment of a serviceability index, which represents pavement quality, and a prediction of performance, which is represented by the relation between time (and/or traffic) and the index. Pavement quality consists of two primary factors: riding quality and skid resistance. The factors influencing riding quality are pavement distress and/or roughness. Three major factors of pavement distress are cracking, rutting, and longitudinal profile. The requirements for acquiring these three factors are the following: (1) That data-acquisition cost is as cheap as possible; (2) that data analysis can be done in a short time; and (3) that data acquisition doesn't influence the speed of other traveling vehicles, in particular on roads with heavy traffic.

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To collect the three factors efficiently, vehicles that can measure them while traveling at high speed (in other words, noncontact measurement is required) have been developed in Japan (Kashahara et al. 1988), North America (Kobi et al. 1979), and Europe (Willis 1986; Autret et al. 1974). From the viewpoint of contactless measurement, laser (Willis 1986; Autret et al. 1974; Still et al. 1980) and ultrasonic waves (Kobi et al. 1988) are used in measurement of rutting and longitudinal profile, and the measured data are processed automatically and input to the data bank directly. As for cracking, continuous photographing with a 35 mm film camera is generally adopted in the measurement. But the analysis of film data requires a great deal of time and labor, and the efficiency of data entry to the data bank is low, because it is performed by humans. Additionally, it is possible that results will vary depending on individual interpretation and judgment. In the present paper, an outline of an automatic pavement-distress-survey system and an automatic crack-recognition system, developed to solve such problems, are described.

Outline of Automatic Pavement-Distress-Survey System

The whole system is shown in Fig. 1. The writers developed the survey vehicle, cracking processor, and rutting and longitudinal profile processor. The appearance of the survey vehicle is shown in Fig. 2. It can measure the three distress factors (cracking, rutting, and longitudinal profile) simultaneously and without contact while traveling at a speed of 60 km/hr. The cracking processor and the rutting and longitudinal profile processor convert the measured distress data automatically into formats that can be used in the

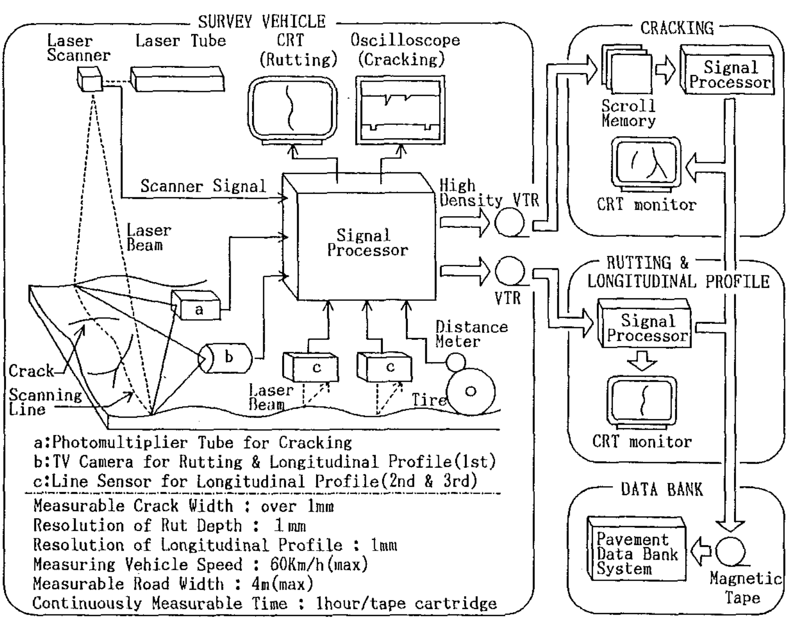

FIG. 1. Flow Diagram for Pavement-Survey System

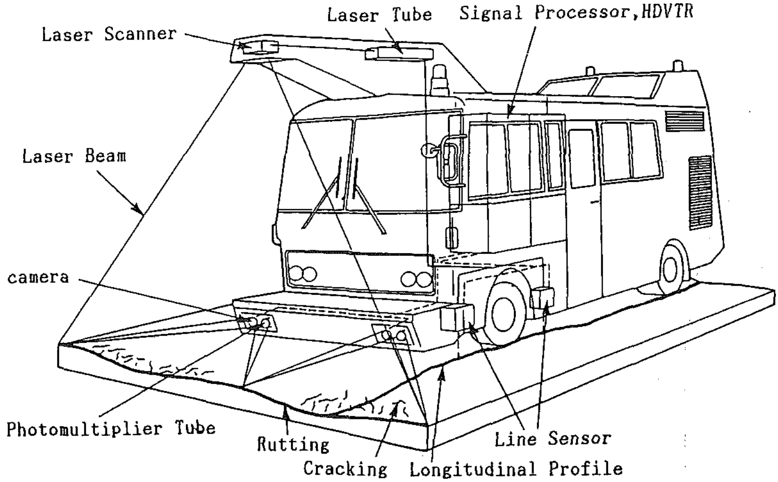

FIG. 2. Pavement-Distress-Survey Vehicle

pavement data bank, and input to the data bank.

In Fig. 2, while the vehicle is travelling, a road surface is illuminated with argon laser light that is scanned by a laser scanner in the lateral direction. The scattered light from a road surface is detected at an angle to incident direction by a photomultiplier tube (PMT) and a video camera in a front bumper. If there are cracks on the road surface, the quantity of received light of the PMT is reduced. A change of output from the PMT gives information about the existence of cracks at scanning position. If there is unevenness such as rutting, the scanning line observed from an oblique angle is curved. The position of the scanning line in view of the video camera gives information about rutting. While the vehicle is traveling, the measurement on each laser scan is repeated, and then the distance is also recorded.

Measuring accuracy depends on the speed of the vehicle, and maximum resolution is acquired at the speed of 10 km/hr. The cracking data is measured as an 8-bit gray image sampled with a step of 1 mm in the lateral and longitudinal directions on the road surface. As the maximum measurable width is 4 m and the maximum continuously measurable distance is 10 km (limit of videotape recording time), a continuous 4×10^3 (lateral) $\times 1 \times 10^7$ (longitudinal) pixel image is measured. Cracks of 1 mm wide can be distinguished in this image. The rutting data is measured as a lateral-profile curve with a distance of 48 mm in the longitudinal direction. The longitudinal profile parameter is calculated from three data points; the distance between the survey vehicle and road surface as measured at three points spaced at 1.5 m intervals in the longitudinal direction (Fig. 1). One data point is acquired from rutting measurement. The others are measured by two line sensors under the body of the survey vehicle. The line sensors use the same principle as rutting measurement, but in this case a lateral laser scan is not necessary.

The cracking, rutting and longitudinal-profile data are measured as described and recorded with a high-density videotape recorder (HDVTR) (an HDVTR has a recording density of 100 Mbps) and a general-purpose VTR (videotape recorder). The rutting and longitudinal-profile data are processed automatically in real time (that is, at the measuring speed), and converted to the format for the data bank, and input to data bank by the magnetic tape. The cracking data are similar to a photographic image of a road surface. The cracking processor analyzes the data and checks the number of cracks, length, and existence of branches, and cracking parameters are calculated with the data and input into the data bank. In the conventional photographing measurement, photographs are checked by displaying the pictures with projector, deciding the cracking parameters, and writing them down in optical card reader (OCR) sheets. On the other hand, in the writers' system, human performance is not necessary because the measured data can be input to the cracking processor directly as a digital image, and crack recognition and parameter calculation can be done automatically.

Features of Crack-Recognition System

As the road image is very noisy owing to surface roughness, it is difficult for conventional image-processing techniques to detect a thin line such as crack. The writers have adopted the line-extracting algorithm called variable-sized slit method (Nagao 1984) using projection curves, which enables high-performance crack recognition.

High-resolution and large-sized image processing is necessary to detect the thin cracks of 1 mm width required for data bank. But the performance of a general-purpose computer is insufficient to realize a processing speed equal to human ability. Therefore, a high-speed multimicroprocessor system using a parallel processing technique was developed. Up to 512 32-bit microprocessors (MC68020) and seven transputers (T800) are equipped in this system. As the processor number can be altered, we can adjust the system scale to required performance.

Segment Extraction

The recognition of a crack has two steps, a segment extraction [process of Fig. 3(*a*–*b*)] and a connectivity determination [process of Fig. 3(*b*–*c*)]. In segment extraction, a section of cracks in the measured image is approximated by a rectangle called a segment. The segment data has simple information such as width, length, direction, and position of crack. This step is carried thus: (1) The measured image is divided into small square 32×32 pixel areas called slits, and the projection curves to the two orthogonal directions along the sides of the slits are calculated. A value of the curve is an average gray level of pixel series in a projected direction in the slit, and a dark area such as a crack has a higher value, as the curve is reversed. (2) To calculate the projection curves for rotated slits (that is, to calculate projection curves in different directions) in the image, a peak of the crack appears, as is shown in Fig. 3(*d*), when the rotation angle θ is close to the crack direction in the slit. Then width, length, and direction of the crack in the slit can be calculated by analyzing this curve, and a part of the crack is extracted as the rectangular segment. (3) To repeat the segment extraction at an equal interval in the whole image shown in Fig. 3(*a*), the cracks are

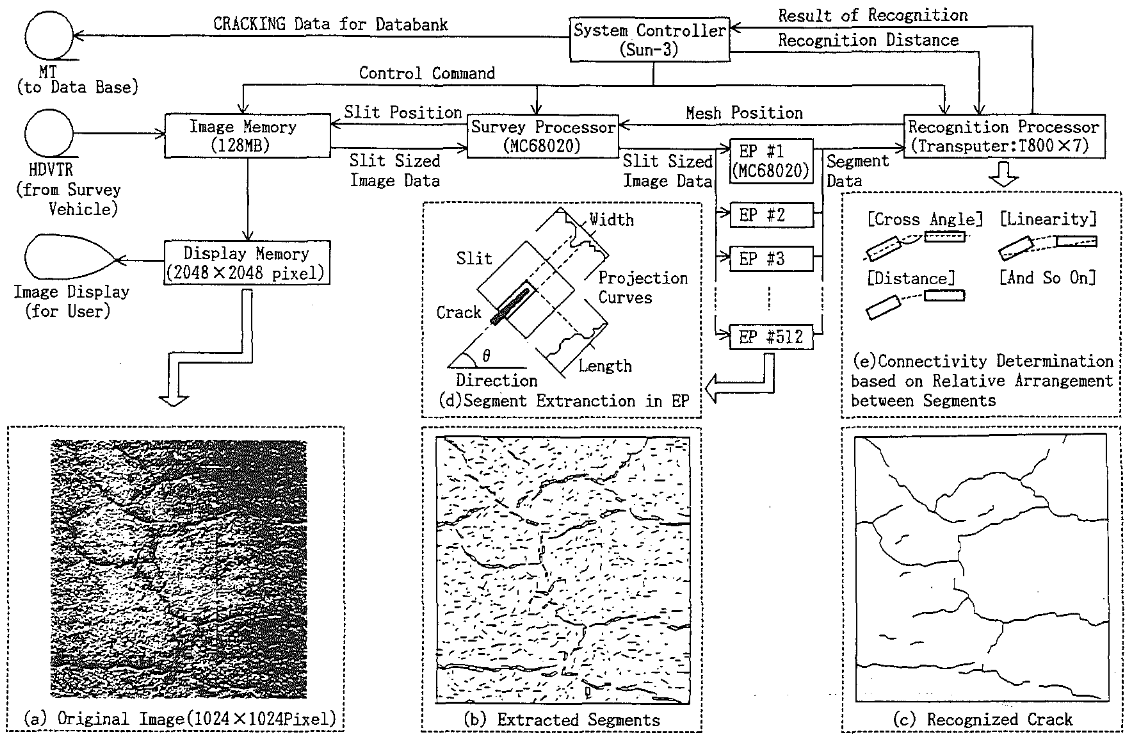

FIG. 3. System Structure and Example of Processing

represented as a group of segments, as is shown in Fig. 3(*b*).

In this method, a smoothing effect by projection can reduce the noise of the road surface, and the local discontinuity can be recovered, so the crack can be extracted stably. However, the actual crack width and/or direction varies locally, the extracted segment information can be acquired as an average value, so it is useful for the classification of the crack based on width or length.

Connectivity Determination

In the connectivity determination, the connectivity between extracted segments is evaluated, and noise segments are eliminated, and the crack is recognized as a final line image, shown in Fig. 3(*c*). The connectivity is determined by considering the relative position between neighboring segments (for example, crossing angle, linearity of arrangement, distance etc.). This step is carried out as follows:

1. Removal improper segments: if a crack lies between neighboring slits, two duplicate segments are extracted from the same crack. In that case, the segment with the smaller area is removed.
2. Connection with arrangement: segments in proper arrangement, regarded as one continuous crack, are connected.
3. Search of isolated segments: isolated (that is, unconnected) segments, neighboring the endpoint of connected-segment series, are searched, and if the arrangement is proper, then it is connected.
4. Connection of endpoint and branch: in the search area from the endpoint, if the other endpoint is found, then the two points are connected with each other. The branch is also generated in the case of the prescribed condition.
5. Calculation of cracking parameter: the cracking parameter for the data bank, based on crack length, number of cracks, and existence of cracks, is calculated from the final result shown in Fig. 3(*c*).

At present, comparing automated crack-recognition results with the performance of humans, over 80% of the automated system's results are correct.

System Structure of Hardware

A system structure is shown in Fig. 3. The crack-image data, played back from an HDVTR, is stored in an image memory [128 MB, 16 m (longitudinal) × 4 m (lateral)]. This image data is transferred to the display memory, and displayed on an image display for an operator. The image data, divided into slit size, is transferred to the extracting processor (EP) via a survey processor. Each EP (MC68020) carries out the segment extraction, and is connected to the computer bus for data transfer in the survey processor; all EPs can calculate in parallel. An EP in waiting state receives slit-sized image data transferred from the image memory in order. Then the EP carries out the segment extraction and transfers the segment data to a recognition processor. The survey processor sends a data-transfer request to the image memory, and also arbitrates the data-transfer bus for the EP. The recognition processor (transputer: T800 × 7) carries out the connectivity determination with the segment data transferred from the EP, recognizes the crack as a line image, and then transfers the cracking parameters for the data bank to the system controller. This processor also carries out a parallel processing to increase speed. The system controller (Sun-3) controls the whole system and manages the user interface. At present, 64 EPs are equipped in this system; the extension to 512 EPs in accordance with the design specification will increase the processing to human-level speed (450 m/h).

Conclusions

The measurement and data processing of cracking, rutting, and longitudinal profile have been completely automated, improving the working efficiency remarkably.

A survey vehicle that uses laser and video techniques has been developed, enabling rapid and accurate crack-data measurement. The data can be input to a computer directly.

A unique line-finding algorithm and a special multimicroprocessor system have been developed, enabling automatic crack recognition; and the problem in data analysis has been solved.

The automation solves the problem of individual difference in data analysis. Additionally, computer image processing allows easy and flexible output of various parameters calculated from information such as length, width, direction, and number of cracks for entry into pavement-data bank.

This system is being applied to the survey of cracking in the maintenance of concrete structures such as bridges, tunnels, and exteriors of buildings.

Appendix. References

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