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IMPLEMENTATION AND VERIFICATION OF A NEW CALIFORNIA TYPE PROFILOGRAPH BASED ON WLAN

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ABSTRACT

In this paper, profile measurement mechanism of a conventional California type profilograph is discussed and a new analytical model to include the non-linear characteristics of the profile sensing mechanism is introduced. A new digital 7.6 m California type profilograph with the combination of a modern sensor, a roughness evaluation software, and a wireless LAN is implemented for improvement.

The accuracy and repeatability of the new developed profilograph are evaluated. After verifying that the new profilograph has good correlation with the mechanical device, some experimental data from a trial site in Korea are gathered and PrI is automatically calculated on PDA. From trial site experiments and data analyses, the usefulness of the developed device is explained.

The new profilograph has advantages that the measured data can be transferred to a remote site through network and it can be operated more safely. Its operation and training cost can be reduced much due to the adoption of wireless LAN technology.

KEYWORDS

California type profilograph, WLAN, PrI, wavelength response, TCP/IP protocol stack

1. INTRODUCTION

The interaction between heavy vehicle and road roughness results in vibrations that feel the uncomfortableness of the driver and cause dynamic wheel loads to increase to wear. It is an important interest for road manager to develop the method to measure and evaluate of the road roughness.

According to Hassan's research about profile-based index to access the viability of the road, roughness content in the waveband 4.8-19.5 m is correlated best with the mean ratings of ride quality by a panel of truck drivers. Also, these modes are considered to be the major contributors to dynamic wheel loading of road pavements [1].

There are many techniques for measuring road roughness, which mostly is derived from the vertical profile of the road surface along a longitudinal line of travel in a wheel path. The American Society of Testing and Materials (ASTM) standard E867-06 [2] defines roughness as the deviations of a pavement surface from a true planer surface with characteristic dimension that affect vehicle dynamics, ride quality, dynamic loads, and drainage.

Road roughness measurements have been started since the early 1900s. The most common roughness measuring devices are generally classified in two groups – directly measuring road profile (California, Rainhart, and Ames profilograph) and measuring vehicle response to roughness (Mayes meter and BPR roughmeter). The California profilograph has had as few as four wheels and as many as sixteen. The twelve-wheel profilograph that is in common use today was first produced in 1961. Especially, the 7.6 m 12-wheel California type profilograph may become most suited to retest short defective pavement sections for verifying the correction of such defects. It is also highly suited to bridge deck testing. Both computerized and mechanical profilographs are in use today.

Profile Index (PrI) indicating the level of road roughness is determined from the California profilograph for construction acceptance, especially in Korea. PrI is calculated from longitudinal profiles of the pavement. The PrI is affected greatly by the accuracy of the measuring profilograph or affected by the outlining to average out spikes and minor deviations caused by rocks, texture, dirt or traverse grooving. Accurate test methodology to operate and use the profilograph for measuring pavement roughness is recommended in ASTM 1274 [3].

As a state of arts of California profilograph, there is a computerized profilograph that records the measurements in a computer introduced in the mid 1980s by James Cox ad Sons [4]. This computerized profilograph can analyze the data using computer programs and generate the Profile Index of the section. The computerized profilograph eliminates the need for analyzing the profile in the office after the test was conducted in the field. The computerized profilograph is able to perform the trace reduction in the field immediately after the test was performed. It significantly increases productivity.

According to previous research [5], the California type profilograph correctly measures some wavelengths, amplifies some wavelengths, and hardly measures some wavelengths. This calls for question the suitability of using the profilograph data for construction control and suggests the need for refinement in evaluation procedures, even though having difficulties with the nonlinear data processing procedures (blanking band). The conventional California profilograph has another problem beside the above frequency characteristics. In this research, it has been founded that the problem comes from the non-linear movement of the moving center wheel of the profilograph. The non-linear movement of the sensing wheel makes the road profile to be inaccurate.

In this paper, a new analytical model to correct the non-linear movement of the sensing center wheel is introduced for the profilograph. And, a new architecture of California type profilograph with wireless LAN and PDA is introduced for improvement. It enhances the operation performance and safety, and provides the network capability that can transfer the measurement data at remote.

2. CALIFORNIA PROFILOGRAPH

Profilograph Model

Fig.1 shows the configuration for the California profilograph to be discussed. The profilograph consists of a rigid beam or frame with a system of support wheels at either end, and a center wheel. Twelve wheels are attached to the ends of a L_0 (7.6 m) long truss and mounted on a multiple axle carriage that includes four wheels spaced L_1 (0.432 m) from the truss centerline and two wheels spaced 0.432 m on the opposite side of the truss centerline. The support wheels are commonly spaced at L_2 (0.82 m) intervals and positioned near the ends of the truss, and establish a datum from which the deviations of the center wheel can be evaluated. The center wheel is linked to a strip chart recorder or a computer that records the movement of the center wheel from the established datum. Profile traces are recorded by vertical displacement of the measuring wheel to a horizontal scale of 1:300 (i.e., 1 in. = 25 ft) and to a vertical scale of 1:1.

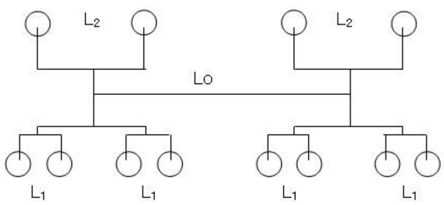

Figure 1. Configuration of the profilograph

However, it has been founded that the profilograph in study shows that the center wheel rotates with respect to the fixed axis, even though it is supposed to be recorded from the vertical movement of the center wheel. The profile is in reference to the mean elevation of the points of contact with the road surface established by the support wheels.

Figure 2 shows the model for the movement of the center wheel. The center wheel is rotated along the circle C1 with the radius R (0.6 m) at the fixed axis O (0, 0). The strip line started from the recorder is connected to the joint point P2 through the top point S (Sx, Sy). The joint point P2 located at the top of the center wheel frame is connected to the strip chart line, and is rotated along the circle C2 as the center wheel is rotated. The length of the strip line is varied as profile height is changed. The length change of the strip line $Z(\theta)$ tells the profile height change.

In order to investigate the difference between the measured and real profile, the test that the measures profile as the wheel is raised from a low -80 mm to high height +80 mm vertically is made for every 10 mm. Figure 3 shows the experiment result that there is a difference between the measured and real wheel height. Compared to the real height, the measured height gets lower as the center wheel moves away from the reference height. From the difference between real and measured height, the circular movement of the center wheel is verified. This says that the measured data should be corrected to get the real profile height.

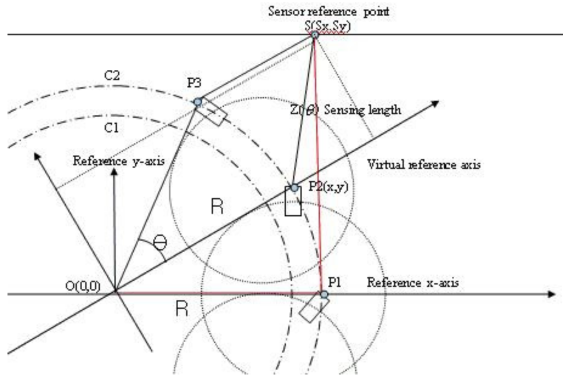

Figure 2. Model for the trace of the sensing wheel

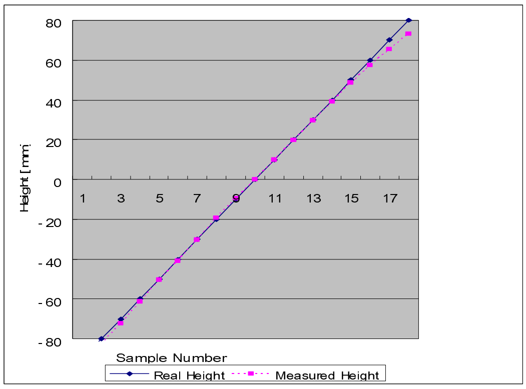

Figure 3. Difference between real and measured height

Frequency Response of Profilograph

A mathematical model of California profilograph [6] is given by the following equation (1):

$$\hat{P}(x) = P(x) - \sum_{i=1}^{N} C_i P(x - d_i) \quad (1)$$

,where $\hat{P}(x)$ = measured road profile

P(x) = real road profile

x = longitudinal position coordinate

N = number of supporting wheels

d_i = distance between i-th wheel and the center of the measuring wheel parallel to the axis of the profilograph

C_i = coefficient representing the effect of the i-th wheel on result of measurement

When considering the circle movement of the center moving wheel, the compensated profile $P_\theta^\wedge(x)$ is given as follows:

$$P_\theta{}^\wedge(x) = \left\{ P(x) - \sum_{i=1}^{N} C_i P(x - d_i) \right\} Z(\theta) \qquad (2)$$

,where compensation rate, $Z(\theta) = Z_m(\theta) / Z_t(\theta)$, defines the measured height versus the true height. As an example, Z(0) =1 at a reference height. The true height $Z_t(\theta)$ = P_{3y} – P_{2y} where y-axis components P_{2y}, P_{3y} represent the real profile height at position P2, P3, respectively. The measured height $Z_m(\theta) = \overline{SP}3 - \overline{SP}2$ (the length difference between $\overline{SP}2$ and $\overline{SP}3$). R = the radius from the origin O to the joint P2.

Z(θ) shows the non-linear function of the angle θ where the angle θ represents a relative angle from the virtual reference axis. As an example, the angle θ for the virtual reference axis is zero.

Next, the mathematical model is modified as the equation (3).

$$\hat{P}_\theta(x) = [P(x) - \frac{1}{2}\left\{ \frac{1}{2m} \sum_{l=1}^{m} [P(x+\delta_l) + P(x-\delta_l)] \right\} + \frac{1}{2}\left\{ \frac{1}{2n} \sum_{r=1}^{n} [P(x+\delta r) + P(x-\delta r)] \right\}] Z(\theta) \qquad (3)$$

,where m=4, and n=2 for 12-wheel profilograph,
δ_l = distance between the l-th wheel and the center of the measuring wheel measured in the x-direction (l= 1, 2, 3, 4)
δr = distance between the r-th wheel and the center of the measuring wheel measured in the x-direction (r= 1, 2)

In this study, an analytical expression for the magnitude of the profilograph transfer function is derived. The Laplace transformation of the profilograph model equation (2) gives

$$\hat{P}_\theta(s) = \{ P(s) - \sum_{i=1}^{N} C_i P(s) e^{-d_i s} \} Z(\theta) \qquad (4)$$

,where s is a complex variable and $\hat{P}_\theta(s)$ and P(s) are Laplace transforms of $\hat{P}_\theta(x)$ and P(x), respectively.

The system frequency response transfer function in the form of Laplace variable s is defined in an exponential form as

$$T(s) = \frac{\hat{P}_\theta(s)}{P(s)} = \{1 - \sum_{i=1}^{N} C_i e^{-d_i s}\} Z(\theta) \qquad (5)$$

By substituting s = jw, the frequency response transfer function is obtained:

$$T(jw) = \frac{P_\theta{}^\wedge(jw)}{P(jw)} = \{1 - \sum_{i=1}^{N} C_i e^{-d_i jw}\} Z(\theta) \qquad (6)$$

The equation (6) is simulated by using MATLAB program. The amplitude of the frequency response is affected by the angle. Figure 4 shows its simulated frequency response with assumption of Z (0)=1. It measures some wavelengths correctly, amplifies some wavelengths, and some wavelengths are hardly measured [7]. Especially, it gives the minimum measurement for wavelengths around 4m, and gives the peak response for wavelengths around 8 m by as much as two times. For the other θ value, the pattern of the frequency response will not change, but the amplitude of the frequency response will be changed.

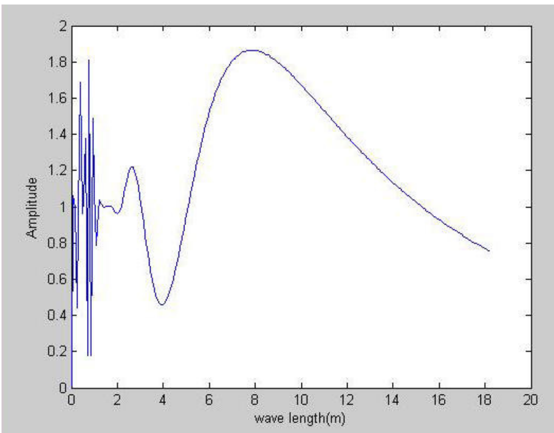

Figure 4. Frequency response of California profilograph with the assumption of Z (0)=1

Kulakowski [5] has discussed that several design parameters such as the number of supporting wheels, spacing between the wheels, total length of the main truss, wear of the tire of the measuring wheel, and eccentricity of the measuring wheel can affect the profilograph performance.

From this paper, it is insisted that the profilograph have to be compensated because the circular movement of the center wheel also affects the profile measurement. So, there is one more parameter to be considered.

3. ENHANCED PROFILOGRAPH BASED ON WLAN

A new type of computerized California profilograph is proposed [8]. The new profilograph adds revolutionary electronics to improve performance. Especially, the profilograph adopts wireless LAN (WLAN) technology for the first time. With the introduction of WLAN technology, the profilograph can transfer data and can be controlled remotely. Data measurement and analysis is made much easier, and less time-intensive. Training and operator cost are expected to be greatly reduced.

Figure 5 shows the main architecture of the proposed computerized profilograph with WLAN. The new profilograph consists of a height sensor, a distance encorder, a controller, a WLAN module, and a PDA.

Fig. 6 shows the components of the main controller where a main component, 8-bit microprocessor ATmega128, controls the peripheral devices such as a distance encorder, a height sensor, power manager, and WLAN card.

The main controller takes measurement for height as the operator starts. To enhance data collection and processing, a microprocessor aided data acquisition system is used. A simple potentiometer provides an electrical analog signal representing the position of the recording pen in the profilograph for height measurement. The height analog signals are sampled and converted into digital with 10 bit A/D with 1mm accuracy. For distance measurement, the pulse encorder, which gives pulses at regular interval of distance is used to signal. Traveled distance is measured every 1cm. The computation of the road profile are performed as a function of distance instead of time, which makes the measurements independent of profilograph speed and easier to handle. The maximum measurement length is 10km.

The height and distance data measured on the profilograph are transferred to PDA through a socket program based on TCP/IP protocol, and are stored to the PDA memory. Figure 7 shows the protocol stack to support the communication between PDA and profilograph. The simplified TCP/IP protocol stack [9][10] in the Figure 7 is implemented on the 8-bit processor to support interconnection with PDA. All the TCP/IP stack, IEEE802.11b driver [11] and other application program are implemented on only small 128KB flash memory.

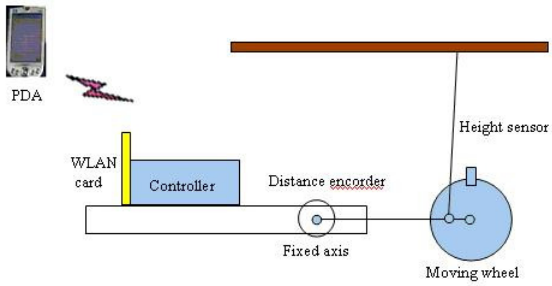

Figure 5 Architecture of the proposed profilograph

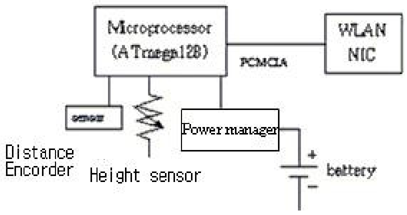

Figure 6. Configuration of main controller

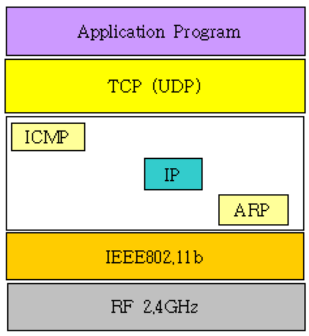

Figure 7 TCP/IP protocol stack

Application program written on Windows CE on PDA can control the profilograph for data measurement and can calculate the profile index. Entire process of data collection and processing is automated for the calculation of roughness index.

4. EXPERIMENTS

The developed profilograph must be properly calibrated vertically as well as horizontally in order to obtain accurate measurements. The horizontal scale can be checked by running the profilograph over a known distance and scaling the results on the profilogram. It is calibrated on premeasured sections in length of 100m before experiment. The vertical scale is checked by putting a board of known thickness on the pavement and running the profilograph over the board and scaling the result on the profilogram.

The trial test section is inside the KIECT in Korea. This section covers a narrow range of roughness and surface texture. Some smooth pavements are expected.

Three repeat measurements are made for the site where each run is done at walking speed. Long profile traces are sampled with DMI every 1cm. The total length of the test measurement is about 65.48m. The test data is simultaneously recorded by using analog (conventional) and new digital profilograph on the same profilograph frame. Profiles are compared by cross correlating filtered traces. Figure 8 shows the comparison between two kinds of measurements. Each graph represents the average profile for three-run tests. There is a very accurate similarity between them.

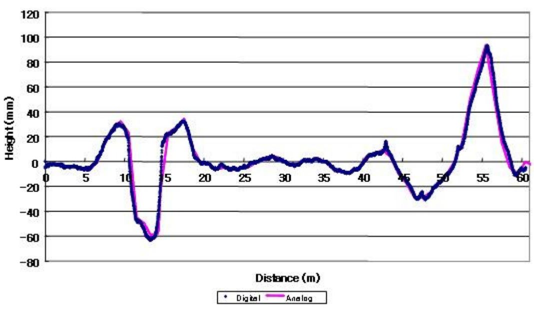

Figure 8. Comparisons for trial site test between analog and digital profilograph

The new profilograph used in this experiment is designed to make it same with the existing analog profilograph. From the correlation comparison as in Figure 9, the test result shows that the two profilograph is almost equal to.

Next, PrI values for above measurements are calculated. The result is listed on the table 1, where PrI is calculated by the summation of absolute profile obtained from null bandwidth (±2.5mm band) per the total road length. The developed profilograph uses a computer program to compute the PrI computation program written by Windows CE on PDA.

Figure 10 shows the test program operated on PDA. The measured data is scrolled to view on 320x240 screen. PrI is automatically calculated and is appeared at the bottom of the screen.

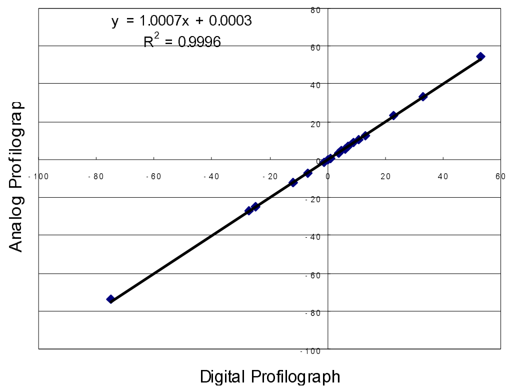

Figure 9. Relationship between analog and digital

Table 1. PrI calculations

	#1	#2	#3
PrI(cm/km)	479.54	478.77	485.64

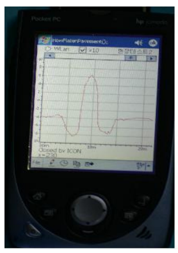

Figure 10. Operation program on PDA

Figure 11. Scene of test at trial site

Figure 11 shows the scene of test at the trial site in Korea. An operator can control start and stop the operation of the profilograph remotely. Even, the operator can monitor the traffic status during measurement.

5. CONCLUSIONS

In this paper, the height sensing system and its problem of the conventional 12-wheel California profilograph is investigated and a new analytic model is introduced to correct its non-linear characteristics. And the new digital California type with the wireless LAN is introduced and implemented.

After evaluating the accuracy of the digital profilograph, experiments are repeated and analyzed from the trial site test to get PrI and performances. The developed device shows the good accuracy and repeatability. Through development of digital profilograph up to the present, decrease of decoding error and analysis time is available.

Further filtering work to correct the non-linear characteristics of the height sensing system caused by the rotational movement of the center wheel is considered. Also, it will be investigated how much the wavelength response and PrI are affected by the non-linear sensing.

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