CORRECTION OF DISTORTED IMAGES FROM ROAD TRANSVERSAL PROFILE MEASUREMENT SYSTEM

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The present paper describes the corrections of distorted images obtained using a novel transversal road profile measurement system. The system using continuous laser beams is innovative for road quality measurement. However, the lenses needed for such applications, no matter the quality, can still have up to 3% distortion of the resulting images. This problem is solved via a series of calculations, leading to the distortion correction.

Keywords: transversal measurement system, distortions

1. Introduction

The transversal road profile measurement system allows automatic sampling of the road surface based on the innovative combination between an area scan type video camera and continuously emitting laser sources [1]. Furthermore, in contrast with existing equipment [2, 3], all components can be mounted in a fixed assembly - not involving any rotational or oscillatory movement, results in a more robust, reliable and cost-effective measurement system [2, 3]. The eventual irregularities of the pavement will be detected through the numerical data extracted by post processing of the images [4, 5].

Deformations such as grooves, cracks and crevices, are indicators of the structural integrity of the pavement and have a significant impact on the safety of road users. They are represented by differences in vertical direction which exist between the theoretical surface defined by the designer and the real surface of the road. The method used determines the maximum perpendicular distance measured between the lower surfaces of the reference calculated as "control line" and the contact of the lasers beam with the pavement in a specific location.

The aim of this paper was to improve the efficiency of this innovative method used for road safety analysis, by improving the quality of distorted images acquired with such system, through the mathematical post processing.

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2. Results and discussion

The transversal road profile measurement system is made up of a camera with lens and two lasers, as described in Fig. 1 (cross view) and Fig. 2 (longitudinal view). The camera has a CCD sensor with Hm pixels (horizontal), Vm pixels (vertical), dp - pixel size and a lens with a focal length f. The camera is placed at a height Z_0 above the reference line (determined by the tires bottoms). The lasers are placed at a height h above the reference line and generate a laser line which covers a 90° angle.

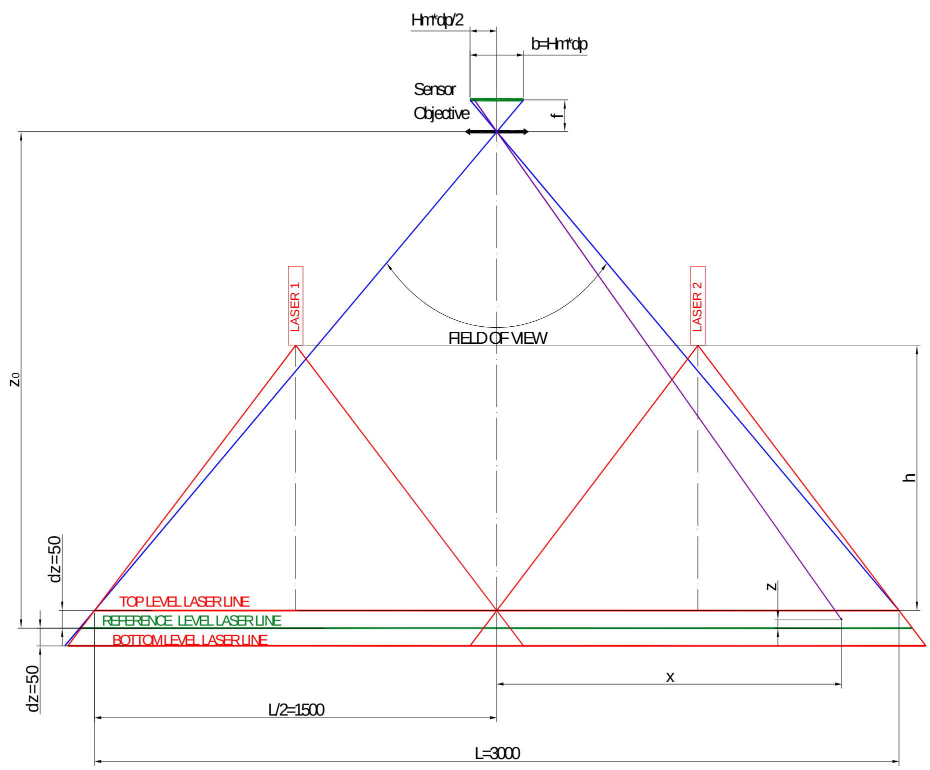


Fig.1. Cross view of the transversal profile measurement system

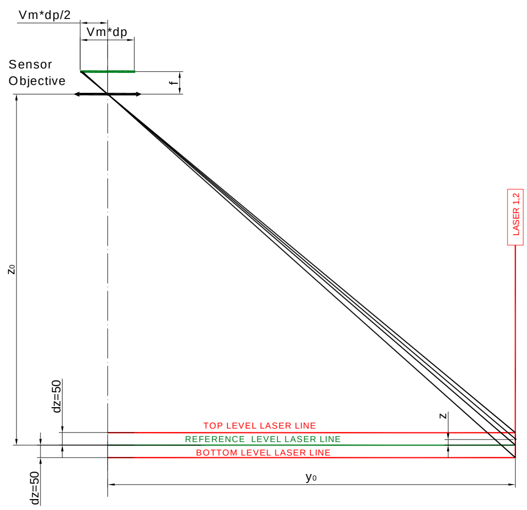


Fig.2. Longitudinal view of the transversal profile measurement

The measuring range is ± dz. The camera is placed at L/2 = 1.5 m apart (L is the road width). In the longitudinal view (Fig. 2) it can be seen that the laser is placed at a distance Y_0 behind the camera axis. If a point illuminated by the laser line has the coordinates X,Y_0,Z and forms an image on the CCD at coordinates in pixels V and H, we can determine the original coordinates Z and X from V and H:

$$Z = Z_0 + \frac{f \cdot Y_0}{dp \cdot (V - V_m / 2)}$$
$$X = Y_0 \frac{H - H_m / 2}{V - V_m / 2} \tag{1}$$

The problem with the lenses used is that distortion can appear in the collected image [6, 7]. These distortions can be corrected at post processing.

The focal length *f* of the lens is calculated using the formula [8]:

$$f = \frac{\varepsilon_z \cdot dp \cdot V_m \cdot H_m}{L} \tag{2}$$

where ε_z is the smallest value of the precision of height measurement, *dp* represents the pixel size, V_m / H_m is number of vertical/horizontal pixels, and *L* is the road width. The *dp*, V_m and H_m parameters are specific for each type of camera. Considering ε_z=1.1 and L=3000 mm, for a camera with *dp*=3.75µm, V_m= 964 and H_m=1292, the calculated value of *f* is 1.27 mm.

Another problem is the field of view angle of the lens. The field of view angle requires calculation of N, the ratio of lens focal f to sensor width (Wdt):

$$N = \frac{f}{dp \cdot H_m} = \frac{\varepsilon_z \cdot V_m}{L} \qquad (3)$$

By using the formula and values mentioned above, the resulting necessary field of view is quite large, 132-135º. The problem is that only fisheye lenses can provide such field of view, and these lenses are usually not or very low distortion corrected. Distortion transforms the image of a square into a barrel. This fact makes difficult the retrieval of the Z coordinates from the sensor image.

An important discussion should be done on the distortion: even if we chose a distortion-corrected lens this doesn't mean that it will be no more distortion in the image formed on the sensor [6]. A residual distortion of maximum 3% at the image edges still persists. A straight line will be imaged as a curve, as in Fig.3. If this distortion if remains uncompensated can cause significant errors in the calculation of height Z using the coordinates in pixels of the camera sensor plane.

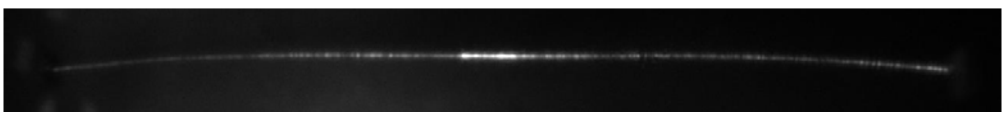


Fig.3. Distorted image of the laser line

To define the distortion we consider the coordinates of a pixel from the centre of the sensor, H and V. Next, we will pass to a system of polar coordinates:

$$\begin{aligned} R &= \sqrt{H^2 + V^2} \\ \theta &= arctg(H/V) \end{aligned} \qquad (4)$$

Distortion is manifested by a change (increase or decrease) of the radius R while keeping unchanged the angle θ. It is also calculated maximum radius R_m:

$$Rm = \frac{\sqrt{Hm^2 + Vm^2}}{2} \qquad (5)$$

We calculate a relative radius $r = \frac{R}{Rm} = 2 \cdot \sqrt{\frac{H^2 + V^2}{Hm^2 + Vm^2}}$. We denote by $q = \frac{H}{V} = \tan(\theta)$ the tangent of the azimuth angle, value that is not affected by distortion. Distortion transforms r to r' by using a third degree polynomial law [7]:

$$r' = a_3 \cdot r_3 + a_2 \cdot r_2 + a_1 \cdot r + a_0 \qquad (6)$$

where the coefficients a_3, a_2, a_1, a_0 are determined experimentally.

Coordinates H_c and V_c of the transformed point are calculated as:

$$\begin{aligned} V_c &= round\left(\frac{r' \cdot Rm}{\sqrt{1+q^2}}\right) \\ H_c &= round(V_c \cdot q) \end{aligned} \qquad (7)$$

We acquire an image of a line along which particular marks have been made (as shown in Fig.4) in order to determine the coefficients a_3, a_2, a_1, a_0. The next experiment was done for a 3.1 m – wide laser line just to prove the method.

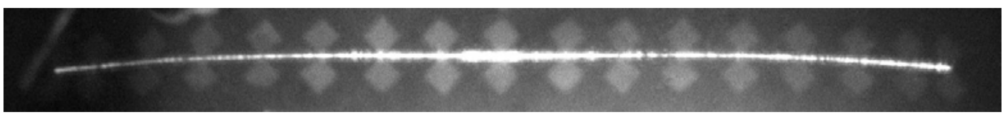


Fig.4. The image of the test line for determining distortion coefficients

Marks were set at several distances from the center of the line, as follows: -1550, -1400, -1200, -1000, -800, -600, -400, -200, 0, +200, +400, +600, +800, +1000, +1200, +1400 and +1550 mm. Marking diamond peaks describe two lines parallel to the laser line, located at 125 mm away from it.

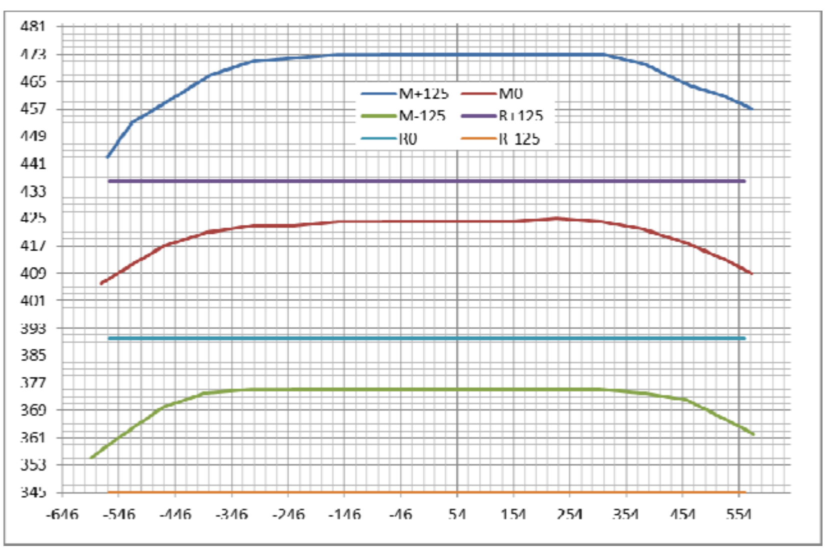


Fig.5. Measured (M+125, M0 and M-125) and undistorted (R+125, R0 and R-125) lines

Using the formulas above, we determine *H* and *V* coordinates in the image and calculate the theoretical H_c and V_c for all these points, listed in Table I.

From these data we can calculate the *r* and *r′* parameters, using curve fitting coefficients. The results are: $\boldsymbol{a_3}$=-0.5361, $\boldsymbol{a_2}$=+0.6476, $\boldsymbol{a_1}$=+0.8300 and $\boldsymbol{a_0}$=+0.0330. For the next curve distortion coefficients are obtained by fitting the curve: $\boldsymbol{a_3}$=+0.9934, $\boldsymbol{a_2}$=-1.6025, $\boldsymbol{a_1}$=+1.7918 and $\boldsymbol{a_0}$=-0.1590.

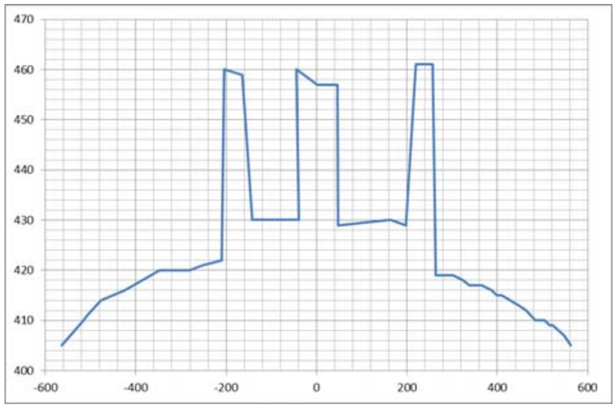
In Fig. 5, the measured (M+125, M0 and M-125) lines and the undistorted (R+125, R0 and R-125) ones are illustrated. Horizontal and vertical axes represent horizontal, respectively vertical position of the pixel on CCD sensor.

Table I

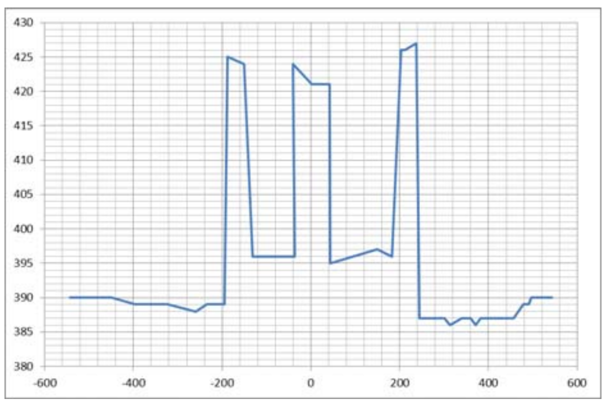
Distorted and Corrected Coordinates of the image

H_{+125}	V_{+125}	H_0	V_0	H_{-125}	V_{-125}	Hc_{+125}	Vc_{+125}	Hc_0	Vc_0	Hc_{-125}	Vc_{-125}
-566	443	-577	406	-596	355	-563	436	-563	390	-563	345
-523	453	-529	411	-536	362	-508	436	-508	390	-508	345
-452	460	-465	417	-467	370	-436	436	-436	390	-436	345
-382	467	-391	421	-392	374	-363	436	-363	390	-363	345
-308	471	-310	423	-311	375	-290	436	-290	390	-290	345
-234	472	-236	423	-239	375	-218	436	-218	390	-218	345
-157	473	-157	424	-155	375	-145	436	-145	390	-145	345
-82	473	-79	424	-76	375	-73	436	-73	390	-73	345
0	473	0	424	0	375	0	436	0	390	0	345
87	473	85	424	80	375	73	436	73	390	73	345
161	473	152	424	156	375	145	436	145	390	145	345
233	473	231	425	232	375	218	436	218	390	218	345
315	473	310	424	307	375	290	436	290	390	290	345
388	470	384	422	380	374	363	436	363	390	363	345
465	464	458	418	460	372	436	436	436	390	436	345
525	461	528	413	533	366	508	436	508	390	508	345
577	457	576	409	579	362	563	436	563	390	563	345

An example of a measured profile and its correction are presented in Fig.6. Horizontal and vertical axes represent horizontal, respectively vertical position of the pixel on CCD sensor.



a)



b)

Fig. 6. Example of image of the measured profile a) distortion-affected, and b) distortion-corrected

This procedure of determining curve fitting coefficients should be applied only once, when adjusting the optical system. It is independent of the laser line image on the sensor; the only condition is that the center of the sensor coincides with the center of the lens. During the adjustment of optical system we should align the laser line to be parallel to the horizontal base of the sensor in order to eliminate the contribution of H coordinate when calculating Z.

3. Conclusions

In this paper, mathematical calculations were employed in order to reduce the distortion of images collected using a laser transversal measuring system for road profile. We have successfully managed to correct the standard distortion introduced by all classical lenses. This correction improves the measurements made with the system presented above.

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