

TRANSVERSAL LASER ROAD PROFILER

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ABSTRACT: The article presents a practical application of lasers, for reconstruction of the road transversal profiles in dynamic regime. The method uses a laser source and a video area scan camera placed at a determined distance behind the laser for the contactless measurement of the height above the pavement surface. The laser source projects a planar beam which is perpendicular on a road horizontal plane and oriented on its transversal direction to cover an entire road transversal section. The intersection of the planar beam with pavement surface represents the road profile. The main advantage of the proposed method is that it is cheaper than ultrasonic or laser sensors methods.

KEY WORDS: Laser, scan, road profiler, area scan, video camera.

1. INTRODUCTION

The rapid development of the optoelectronics field has led to the improvement of laser sources and to the diversification of their range of uses. One of the many areas of laser application is the testing of road quality [1 - 3]. Differences in vertical direction, between the theoretical surface defined by the designer and the real surface of the road, can often appear. These irregularities affect the uniformity of a road, which is one of the main functional characteristics of the road structures. The studies concerning the comfort, circulation safety and the dynamic action of the loadings with which the vehicles stress the running surfaces with uniformity defects, revealed the necessity to identify the irregularities whose wavelengths are situated between 0.5 m and 50 m [4].

Road surface uniformity measuring equipment can be classified as “response” or “profilometer” type devices. The “response” type devices deliver a “uniformity note”, characterizing the dynamic behaviour on vertical direction of a vehicle or part of it, which is moving along the tested road. The response type devices do not permit the road profile reconstruction and their response varies with the nature, load and wear of the vehicle on which they are mounted. Also, the response type equipment need frequent calibration [5]. “Profilometer” type devices permit the direct or indirect reconstitution of the tested road longitudinal profile [6].

The ruts (tracks) represent permanent deformations of the pavement structure. These are an indicator of the pavement structural integrity and in the same time, have an important impact on the safety of the

road users. For these reasons, most of the road monitoring agencies performs regularly a control of the rut depth levels from their pavements.

In a traditional way, the rut depths were manually measured by using of a “rod-and-level” static survey in where the level provides the elevation reference, the readings from the rod provides the height relative to the reference, by using a sliding straightedge method known as “Viagraph” which measures the road irregularities by recording the deviation at the centre point of the straightedge or by resorting to a dipstick method which uses a stationary inclinometer originally developed to measure the flatness of concrete floors. Although simple to apply these methods deliver results without congruity for the measurements performed at large time intervals and, moreover, the manual sampling of an entire network of roads is not practicable. The emergence of new contactless measurement equipment using ultrasonic or laser sensors made the manual method become in many countries obsolete. The new methods are based on the measurement of the pavement transversal profile and afterwards on the processing of the acquisitioned data in order to calculate the depth of the ruts under a straight edge which is simulated by computing.

The rutting is performed according to ASTM E 1703/E 1703M. The processing operation simulates the straight-edge method to determine the maximum perpendicular distance measured between the inner surface of the reference which is computed as a straight edge and the contact zone of the lasers with the pavement in a specific location. According to this standard the rutting is defined as the length of

individual wheel path in meters where rutting (wheel tracking) exceeds 30 mm in depth measured from a 2 meter straight-edge laid transversally across the wheel path. Only the length where rutting exceeds 30 mm is measured.

The ultrasonic technology: A large number (usually about 30) of ultrasonic sensors are disposed in line, at intervals of 100 mm one from the other. In order to eliminate the possibility of any interference between the acoustic signals of the adjacent sensors these sensors are not simultaneously triggered but in a sequential procedure. A common feature of the ultrasonic equipment is that they use the “progressive sampling”, taking into account that when the ultrasonic sensors are not placed at intervals of minimum 300 – 500 mm interferences from the sonic signals of the adjacent sensors will occur. The effect of the progressive sampling is that the transversal profile which is used in analyses is a “composite” profile which is built on measurements performed by individual sensors in successive sequences of time. At the same time it should be mentioned that the acquired profile is influenced by both the speed with which the sensors are triggered and the lab vehicle speed. In a typical way, for the transversal profile this means distances of 3-5 meters at 70 km/h and up to 10 meters at higher speeds.

The laser point sensor technology: Like the ultrasonic sensors, the “point” type laser determines the value of the distance downwards to the pavement point located in front of it in that moment. Because of their high cost, the number of the laser sensors of this type is much more reduced than that used by the ultrasonic profilometers, usually only 13-16. Hence, because the reduced number of the sensors, these profilometers cannot provide a sufficient resolution to detect ruts with smaller dimensions.

2. LASER ROAD PROFILER

The proposed method [7] uses a laser source and a video area scan camera placed at a determined distance D behind the laser for the contactless measurement of the height above the pavement surface (see the optical scheme in Figure 1).

The laser source projects a planar beam (yellow in Figure 1) which is perpendicular on a road horizontal plane and oriented on its transversal direction to cover an entire road transversal section (of width L).

The intersection of the planar beam with pavement surface represents the road profile. A camera lens with a focal length f is placed at a distance $C+h$ above the reference level (the plane determined by the contact of the lab vehicle tyres with the road

surface). C is the minimum distance between the lens and the road surface and h is the maximum measurable height or depth of the road surface.

The road profile is a chart of the measured heights z at different points of coordinate x along the road width (x takes values between 0 and L).

The lens forms an image of the intersection of the laser planar beam with the road surface on the area scan sensor.

Each point on this profile of coordinates (x,z) corresponds to a red (the laser radiation is red) pixel on the area scan sensor, of coordinates (p_x,p_y) .

The sensor is n_x pixels in width and n_y pixels in height, the pixel width being Δ .

Simple trigonometry provides the next equations to calculate pixel coordinates (p_x,p_y) :

$$\left(\frac{n_y}{2} - p_y\right) \cdot \frac{\Delta}{f} = \frac{D}{C+h-z} \quad (1)$$

$$\left(\frac{n_x}{2} - p_x\right) \cdot \frac{\Delta}{f} = \frac{x - \frac{L}{2}}{C+h-z} \quad (2)$$

Here above x varies between 0 and L and z between $-h$ and h . The leftmost pixel position ($p_x = 0$) corresponds to $z = h$ and $x = L$, thus giving the value of C :

$$C = \frac{f \cdot L}{\Delta \cdot n_x} \quad (3)$$

Similarly, the uppermost pixel position ($p_y = 0$) corresponds to $z = h$, thus giving the value of D :

$$D = \frac{L \cdot n_y}{2 \cdot n_x} \quad (4)$$

The ratio n_y/n_x is precisely sensor’s aspect ratio, usually $3/4$, so the distance D is uniquely determined for a given road width L . The minimum distance between the lens and the road surface C depends on the lens field of view. The field of view half angle on horizontal direction θ_x is:

$$\theta_x = \arctan\left(\frac{n_x \cdot \Delta}{2 \cdot f}\right) \quad (5)$$

For a chosen sensor (n_x and Δ known) an appropriate lens should be selected: for a small focal length the lens should be wide angle. From (3) C can be derived:

$$C = \frac{L}{2 \cdot \tan(\theta_x)} \quad (6)$$

As for D , C is uniquely determined for a given road width L , because θ_x was previously chosen (when choosing the lens).

The method to determine the road transversal profile consists in finding the brightest red pixels in the image formed on the sensor and then deriving coordinates z and x corresponding to those pixels.

First, z can be derived from (1):

$$z = h - C \cdot \frac{p_y}{\frac{n_y}{2} - p_y} \quad (7)$$

Then, x will be derived from (2), (3) and (7) as:

$$x = \frac{L}{2} \cdot \frac{1 - \frac{p_x}{n_x} - \frac{p_y}{n_y}}{\frac{1}{2} - \frac{p_y}{n_y}} \quad (8)$$

The accuracy of the measurement is given by the derivative $\left| \frac{\partial z}{\partial p_y} \right|$:

$$\left| \frac{\partial z}{\partial p_y} \right| = \left(\frac{2 \cdot C}{n_y} \right) \cdot \left(1 + \frac{h-z}{C} \right)^2 \quad (9)$$

This accuracy will be minimal (best value) for $z = h$, when:

$$\left| \frac{\partial z}{\partial p_y} \right|_{\min} = \left(\frac{2 \cdot C}{n_y} \right) \quad (10)$$

The value of accuracy will be maximal (worst value) for $z = -h$, when:

$$\left| \frac{\partial z}{\partial p_y} \right|_{\min} = \left(\frac{2 \cdot C}{n_y} \right) \cdot \left(1 + \frac{2 \cdot h}{C} \right)^2 \quad (11)$$

Considering (11), h - maximum measurable height or depth of the road surface – will be agreed with the required measurement accuracy.

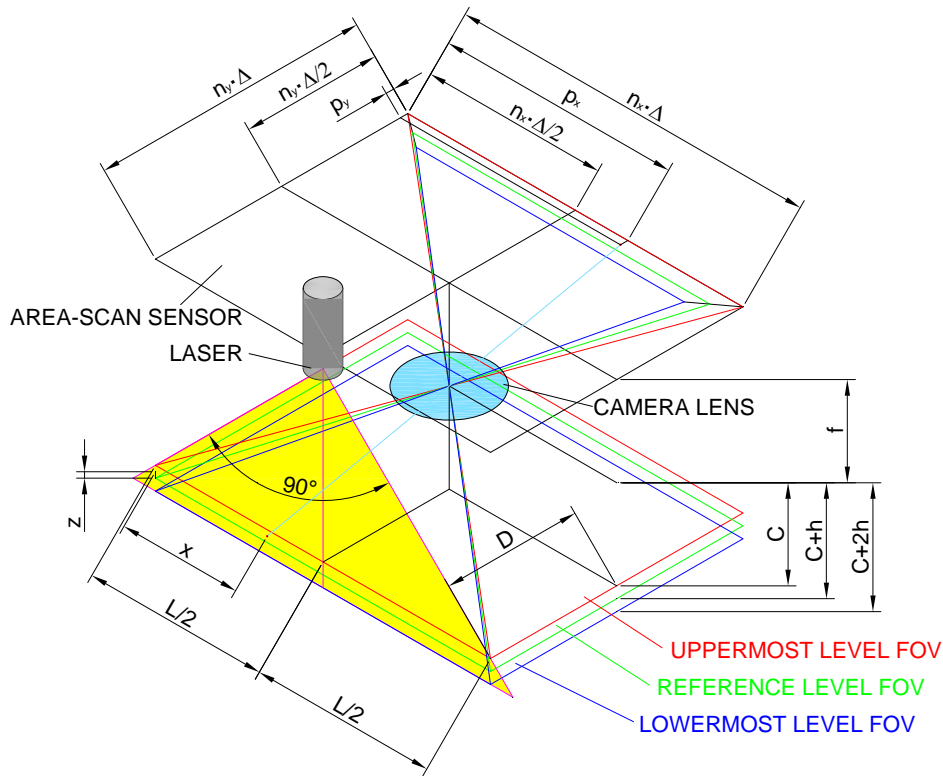


Figure 1. The optical scheme of the transversal laser road profiler.

3. RESULTS AND CONCLUSIONS

The area scan camera acquires an image like in Figure 2.

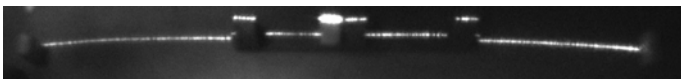


Figure 2. Example of an acquired image.

In the above example the acquired image is in grey tones. A better solution is to use a colour camera. This makes easier the recognition of the laser path (which is red), as can be easily seen in Figures 3, 4 and 5. Bright pixels may be artefacts, but red bright pixels are surely from the laser.

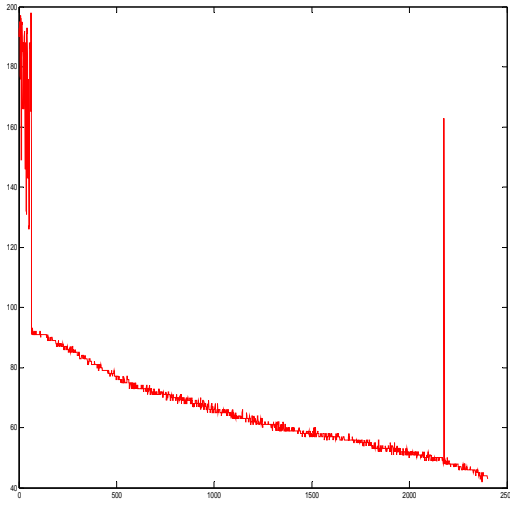


Figure 3. Brightest pixels. Red channel

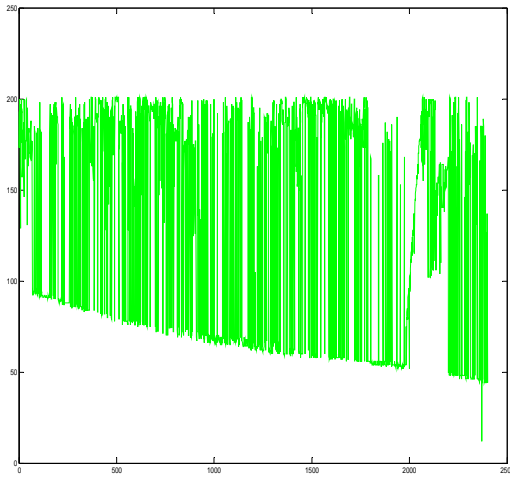


Figure 4. Brightest pixels. Green channel

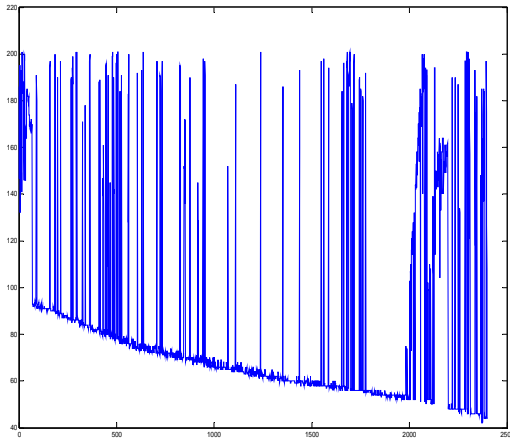


Figure 5. Brightest pixels. Blue channel

The artefacts appear only in green (Figure 4) and blue (Figure 5) channels.

Another problem is the distortion. The wide angle of the camera lens requires a good correction of the distortion. Still, there is a residual distortion (less than 3% at image margins), that spoils the required accuracy. Fortunately, this may be corrected by software.

Considering polar coordinates for a pixel (r, θ) , where r is the relative radius and θ is the polar angle, measured from the centre of the sensor, we get:

$$r = 2 \cdot \sqrt{\frac{p_x^2 + p_y^2}{n_x^2 + n_y^2}} \quad (12)$$

$$q = \tan(\theta) = \frac{p_x}{p_y}$$

Since distortion alters only the relative radius, in a polynomial way (of 3rd degree) we can recover the original pixel positions. In polar coordinates:

$$r_c = 2 \cdot \sqrt{\frac{p_{xc}^2 + p_{yc}^2}{n_{xc}^2 + n_{yc}^2}} \quad (13)$$

$$q = \tan(\theta) = \frac{p_x}{p_y} = \frac{p_{xc}}{p_{yc}}$$

The corrected relative radius r_c is:

$$r_c = a_3 \cdot r^3 + a_2 \cdot r^2 + a_1 \cdot r + a_0 \quad (14)$$

Coefficients a_3 to a_0 are obtained from experimental curve fitting.

Figure 6 displays such an image used to calibrate (eliminate the distortion) the camera lens. Some markers (diamond shape) were placed on the floor to provide a scaling of the image.

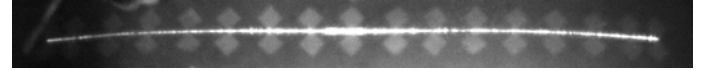


Figure 6. Test measurement for distortion correction

The calibration should be done just once for a given lens, when coefficients a_3 to a_0 are determined. Thereafter these coefficients will be used to correct each acquired image.

Corrected pixel positions will be:

$$p_{yc} = \frac{r_c}{2} \cdot \sqrt{\frac{n_x^2 + n_y^2}{1 + q^2}} \quad (15)$$

$$p_{xc} = p_{yc} \cdot q$$

q and r_c being calculated for each brightest pixel of the image.

An example of distortion correction of a transversal profile is presented in Figure 7. The red curve represents the original (distorted) profile, while the blue one represents the corrected (distortion free) profile.

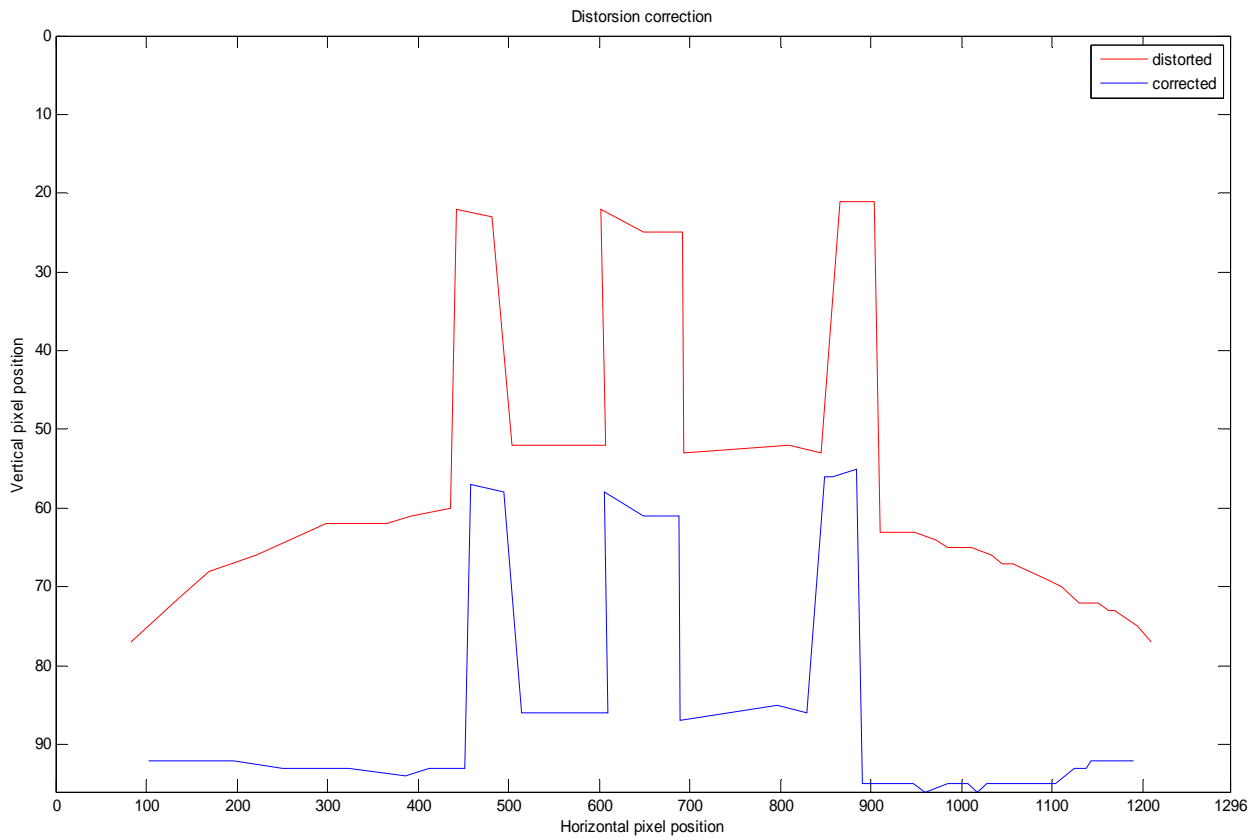


Figure 7. Distorted (red) and corrected (blue) transversal profile.

Once pixel positions are corrected of distortion, the true profile can be retrieved from pixel positions, using (7) and (8). A plot of the retrieved road profile is presented in Figure 8.

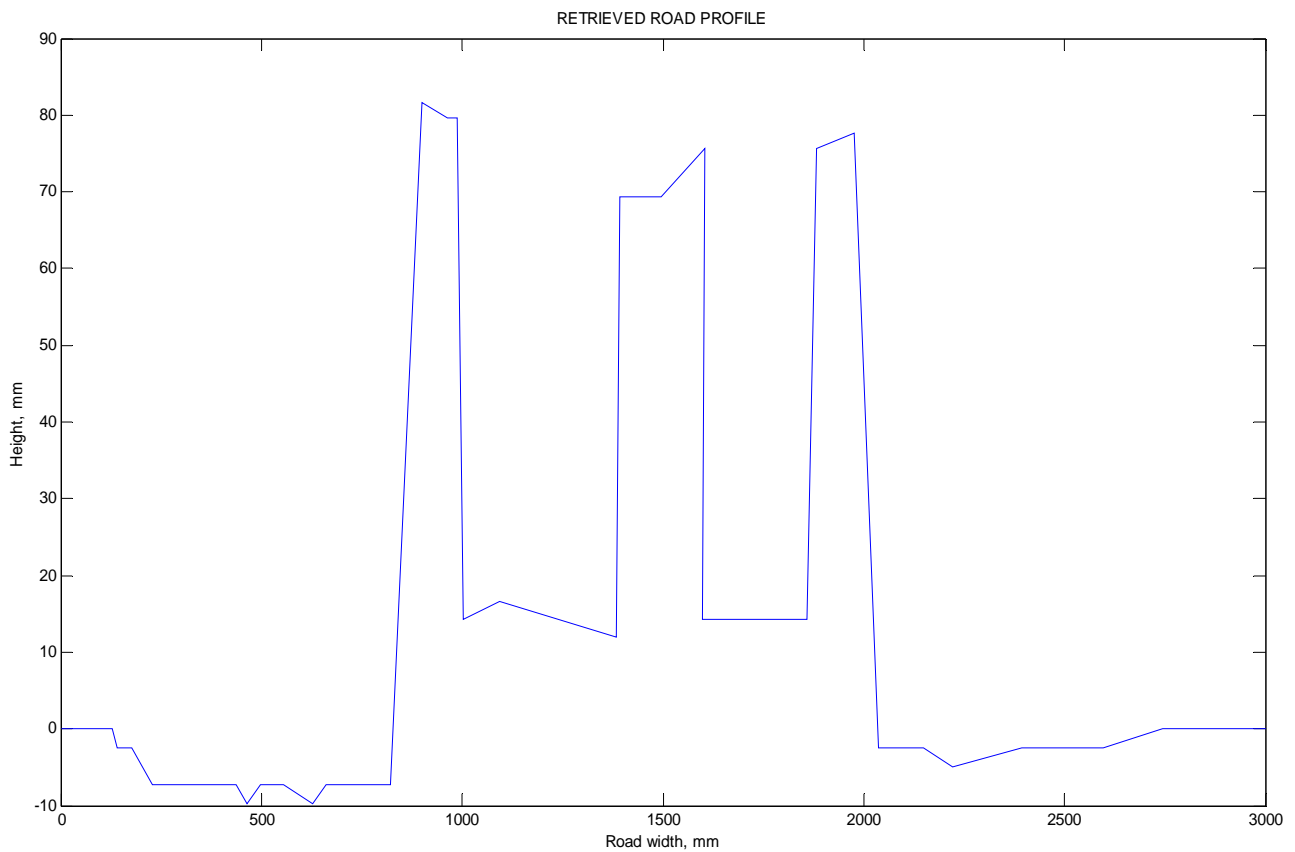


Figure 8. Retrieved road profile.

Determination of the distortion calibration coefficients for a given camera lens raises some problems to be solved.

Usually we don't know the exact position of the principal plane of the camera lens. To solve this problem there are necessary two measurements.

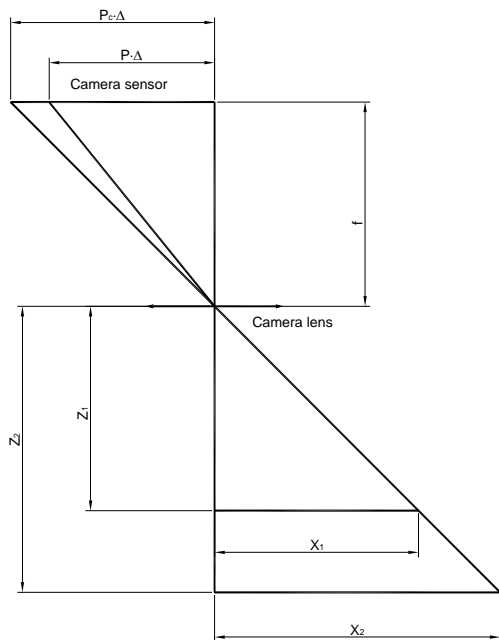


Figure 9. Determination of the distortion calibration coefficients

As can be seen in Figure 9, two measurements are performed at two different heights (Z_1 and Z_2). First measurement is taken at height Z_1 and for a horizontal ruler with regular ticks. For a point at a distance X_1 the image on camera will be at P_c pixel position in absence of distortion and P considering distortion. The second measurement will be done rising the camera with a determined height $\Delta Z = Z_2 - Z_1$. It will be measured the distance X_2 which forms the image at the same pixel position P .

Corrected pixel position P_c will be determined from:

$$P_c = \frac{f}{\Delta} \cdot \frac{X_2 - X_1}{Z_2 - Z_1} \quad (16)$$

In this way two sets of measurements (P and P_c) are obtained and the distortion calibration coefficients a_3 to a_0 can be easily determined by a third order polynomial fit.

4. CONCLUSIONS

The new method for transversal road profiling, using a laser source and a video area scan camera placed at a determined distance behind the laser was developed for a contactless measurement of the height above the pavement surface. The method allows accurate determination of road profile on both height and width directions, at a low cost of components.

5. ACKNOWLEDGEMENTS

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