VELOCITY MEASUREMENT BASED ON IMAGE BLUR

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Abstract. This work gathers elements for the study and analysis of the main problems and difficulties inherent to the implementation of a device for inspection of a speedometer of automotive vehicles, in order to meet the foreseen Brazilian legislation which defines the maximum allowed error for speed-meters of ± 5km/h for speeds up to 100km/h and ± 5% for speeds above 100km/h. From this study, a new non contact method based on image analysis, specifically the blur effect, is proposed. In the method, the speed of the target surface is determined by analyzing the characteristics and regularities contained in a single blurred image. Using a device that simulates the soil movement, a CCD camera and a frame grabber, images of the moving asphalt surface are acquired. The information of speed is then determined, through the analysis of the regularities contained in the dynamic image due to the blur effect. The necessary results for the inspection are achieved successfully, with precision below 5%. The developed and evaluated technique demonstrates, through a device that simulates the asphalt in movement, a precision of 0,8% in a range of speeds from 0 to 20km/h, 1,5% in a range of speeds from 20km/h to 60km/h and 2,5% in a range of speeds from 60km/h to 80km/h. Finally, it was investigated the preponderant factors which have limited the errors in this order of magnitude.

Keywords: Speed-meter, velocity measurement, non-contact measurement, image processing

1. INTRODUCTION

This work concerns the development of an image-based method, therefore, a non-contact method for inspection of vehicular speed-meters. This inspection is necessary in order to satisfy Brazilian regulations (INMETRO, 115, 1998) legislation that establishes the maximum allowed error for vehicular speed-meters, of ± 5km/h for speeds up to 100km/h and ± 5% for speeds above 100km/h. Despite other known, contact or non-contact methods for speed-meter inspection, the image-based method is considered for study due to increasing offer in the market, for cameras and computers of lower cost and higher capacity.

Many image-based methods for speed measurement have been proposed. Most of them employ the concept of optical flow. As illustrated in Fig.1, the optical flow is defined as the appearing movement of the brightness standards in a sequence of images (see for example, Jain, 1995 or Anandan, 1989 or Enkelmann, 1986). It describes the direction and the speed of a relative movement between the observer and the scene, through vectors represented by directional arrows. The optical flow is the velocity distribution, relative to an observer, over the points of an image, carrying information to the dynamic analysis of the scene in movement. The bi-dimensional optical flow is defined as the velocity field at the plan of the image, due to the movement of the observer, relative to the objects and the scene, or the apparent movement, which occurs due to the change of intensity of the image between successive frames that mimic movements of the observer or the object. The optical flow is determined by the speed vector of each pixel in a image. The optical flow determination methods, which are aborted in the literature, base on the space temporal analysis of a sequence of images or following frames. In Fig. 2, frame 1 represents the original image, which was displaced of *dx* and *dy* after a determined interval of time. The real movement, registered starting from a sequence of images results of a complex process involving several factors as the illumination of the scene, the form and the roughness of the surface in movement, the formation of shades and reflex, and also of characteristics of the sensor used for acquisition of images. Though, it is necessary to distinguish among real movement, or bi-dimensional field of speeds, and the apparent move, or optical flow. The optical flow can be composed, starting from the space-temporal observation of variations of the
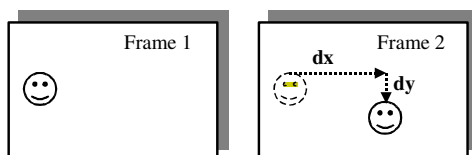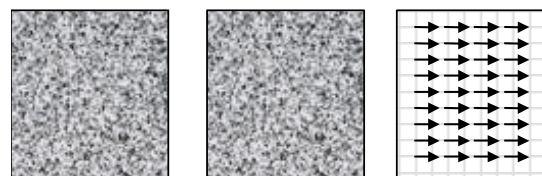

Figure 1. Optical flow of a moving image

a) image1   b) image 1 displaced   c) optical flow

Figure 2. Images registered in consecutive frames

intensities between two consecutive frames (Tiziritas, 1994). Classically, a vector of optical flow is represented by its horizontal and vertical components, $v_x(x,y)$ and $v_y(x,y)$. In order to calculate the optical flow, one should meet the corresponding points between two consecutive frames. For such task, the used information is that, areas in the neighborhood of the corresponding points possess similar intensity patterns.

Followings are the principal techniques of image processing, which extract local estimates of the translation of an image. They are four the principal methods for measurement of the optical flow of a surface in movement (Fleet, 1992):

- Differential method or point based methods (see for example, Fennema *et al*, 1979, Nagel, 1983, Barnard *et al*, 1980, Glazer, 1987, Kobayashi *et al*, 2003, Casarosa *et al*, 2005)
- Comparative methods or region based methods (Glazer *et al*, 1983, Pumrin *et al*, 2002);
- Methods based on contours (see for example, Hildreth, 1984, Waxman *et al*, 1984, Xiao *et al*, 2007);
- Methods based on energy (see for example, Adelson, 1985, Hegger, 1987).

These methods have the following requirements:

- It is desirable to works with the minimum blur of the registered image, or ideally to with frozen images.
- It is necessary that the time between successive frames be well defined and regular.
- It is necessary that an image segment registered in a frame, be also registered in a consecutive frame.

Although based on solids theoretical fundamentals, all of above-mentioned methods require that a same portion of the image appear in successive frames, with an interval of a well-defined time between them. Such techniques cannot be applied in the approach of this work, being considered conventional cameras of low speed, that do not work in speeds above 50Km/h, as explained next. As described in Fig.3, the vehicle speed can be determined fixing a CCD (charge coupled device) type camera on the body of a vehicle and applying image processing. Being considered the distance between the camera and the soil of 60cm, an image of 45cm size is obtained, determined by the field of view of the camera. Considering the NTSC standard, 30 frames per second are registered. Thus, consecutive frames are gathered at time intervals of 1/30s or 33.3ms. Therefore, for example, at the speed of 100km/h, the displacement of the camera in 33.3ms is of 93cm. In such situation, images registered in the frames 1 and 2 are completely different, which disables the application of the current techniques presented in the literature for speeds of this order of magnitude.
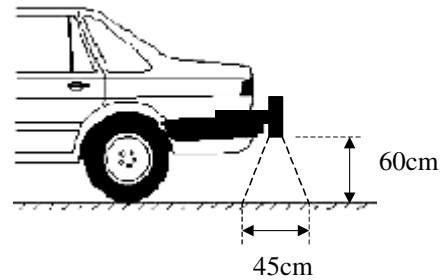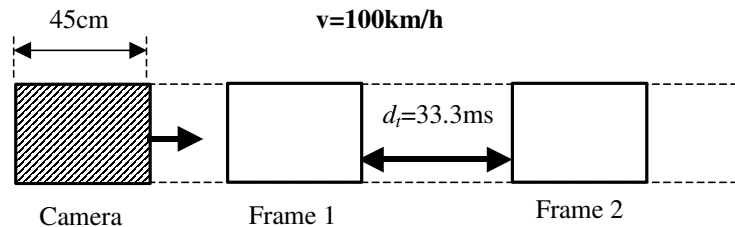

Figure 3. Set-up for speed measurement

Figure 4. Interval between consecutive frames

2. PROPOSAL OF THE BLUR METHOD

2.1 Shutter Speed

In the video camera, the shutter is the device that controls the time that the CCD (the sensor where the images are formed) should receive a certain amount of light. In a video or in a picture, the main function of the shutter, besides regulating the light exposition, is to control a larger or smaller freezing effect of the image in moving scenes. As the speed of the shutter is decreased, larger is the time that the image is projected on the CCD. Unlike the traditional cameras, where the shutter is a mechanical device with movable parts, that open up and close quickly, exposing the film to the light, in the video camera, the shutter is an electronic device. In fact, what makes the shutter to work in the video camera it is an electronic function of fade, a current denominated electric purge current (to turn off), that travels the lines of the CCD a little before the point in that the same is being read. The variation of this distance is that allows a minor control or larger exposition of CCD. As this control is electronic it is possible to obtain high speeds of filling (1/10.000s for instance), allowing freezing of the image in a fast movement. The method proposed in this work, is based on the registration of images containing the blur, produced by the acquisition of images to different exposition times of a CCD, i.e., shutter speeds.

2.2 The blur effect

   The blur effect is the result of the registration of an image in movement, while the shutter of the camera remains opened (see for example, Ben-Ezra *et al*, 2003 or Favaro *et al*, 2004). Considering an image $f(x,y)$ which moves on a know plane at the speed with a component $x_0(t)$ and a component $y_0(t)$, the total exposition in any point of a CCD matrix (or film of a photographic camera) is obtained through the integration of the instantaneous exhibition by an interval of time, during which, the shutter or shutter is opened. Then, if T is the time of duration of the exhibition and assuming that the shutter opens and closes instantaneously, following is obtained.

$$g(x,y) = \int_0^T f[x - x_0(t), y - y_0(t)]dt \qquad (1)$$

Where $g(x,y)$ is the blurred image (González, 1993). To illustrate the blur effect, images are shown in Fig. 5. The first (Fig.5(a)), without blur effect and the second (Fig.5(b)), simulating the blur effect, overlapping 50 images, simulating a parallel speed to the axis *x*, to the right.

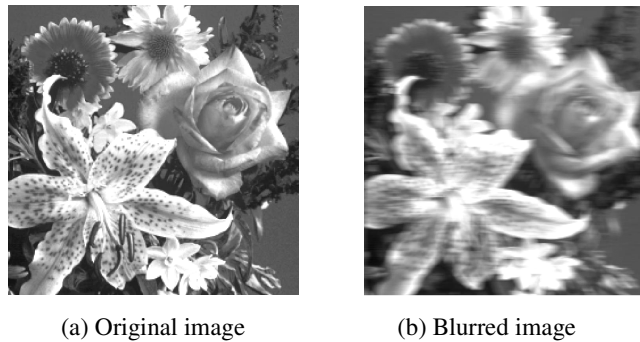(a) Original image   (b) Blurred image

Figure 5. Illustration of blur effect

The blurred image above was simulated through a specific function of MATLAB® (software of implementation of computer calculations, visualization and programming), that simulates the blur effect of an image.

2.3 The blur method

   This work proposes a technique based on image processing, capable to determine the speed of the moving asphalt surface based on blur effect. The speed is obtained by counting the amount of bright segments contained in a single blurred image. The main idea of this approach is that the bright segments contained in a blurred image can be counted and these segments have a size proportional to the speed of the object surface, at the instant in which the image was gathered. Fig. 6 shows a blurred image of an object

Figure 6. Identification of segments in a dynamic photo

moving at a certain speed. One can clearly identify the presence of segments of a same size (marked in the image by white rectangles). Moreover, as demonstrated later, the size of segments is proportional to the speed of the moving surface.
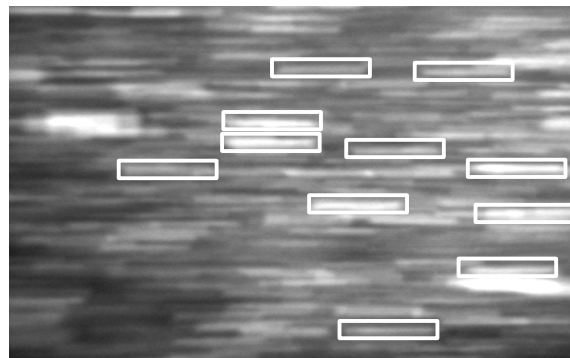
2.4 Modeling the blur effect

   Consider an image $f(x,y)$ that moves in a known plane at a speed with a component $x_0(t)$ and a component $y_0(t)$. The image registered with blur effect $g(x,y)$ occurs due to a point spread function, given as follows.

$$g(x,y) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} h(x - \alpha, y - \beta) f(\alpha, \beta)d\alpha d\beta + n(x,y) \qquad (2)$$

Where, $h(x,y)$ the point spread function and $n(x,y)$ the term of random noise (Lin, 2004). In Eq. 2, if the motion is linear, the point spread function is given as follows.

$$h(x,y) = \begin{cases} \dfrac{1}{R}, |x| \le \dfrac{R}{2}\cos\theta, y = \tan\theta \\ 0, |x| > \dfrac{R}{2}\cos\theta \end{cases} \quad (3)$$

(a) Original image $f(x,y)$ (b) Blurred image $g(x,y)$

Figure7. Blur effect with one point on a dark background

Where, θ is the motion direction and R, the length in pixels of the blur effect. In the case of this work, it is assumed that the motion is parallel to the horizontal axis of the image, i.e., $\theta = 0$. Thus, Eq.(3) is simplified as follows.

$$h(x,y) = \begin{cases} \dfrac{1}{R}, |x| \le \dfrac{R}{2}, y = 0 \\ 0, |x| > \dfrac{R}{2} \end{cases} \quad (4)$$

Once θ is known ($\theta = 0$) and not considering the effect of $n(x,y)$, Eq.(2) is reduced to an one-dimensional equation.

$$g(x) = \frac{1}{R}\int_0^R f(x-\alpha)d\alpha \quad (5)$$

Figure 7 illustrates the application of the formulation of the blur effect by means of a white point over a black background, represented by $f(x,y)$. Applying Eq. (5), adopting $R=4$, following is obtained.

$$g(x) = \frac{1}{4}\int_0^R f(x-\alpha)d\alpha \quad (6)$$

The mathematical model of an isolated white point applied under a dark background, defined as original image $f(x,y)$, has as blurred image, $g(x,y)$, defined as a straight line segment, has the size proportional to the period of time of exhibition in that the shutter remained open. In this way, it is reasonable to consider that, counting the number of segments of same length contained in a blurred image, one can estimate the speed of the figure in movement at this specific instant, since the size of the straight line segments contained in the image, are proportional to the speed of the object in movement.

Being considered now an original image (Fig. 8(a)), where for hypothesis there is no overlap, the blurred image formed (Fig.8(b)), will be composed by segments of same size, proportional to the speed of the image in movement at that instant.

In this example, all the segments of the image with blur have the same size, proportional to the speed of the object in movement. In a real image, it is reasonable to presume that one will obtain segments with several sizes, but it prevails the idea that, the incidence of segments of a same size, proportional to the speed in study, should be the predominant.

(a) Original image   (b) Blurred image

Figure 8. Blur with various points

From here, the work assumes the use of the asphalt surface that is the usual object in a vehicular speed meter inspection. The asphalt surface contains white or clear rocks, applied under a dark asphalt background (Fig.10). This gives desirable contrast to the application of the blur method. The sum of the effect generated by several rocks, generates an image containing several straight segments, with proportional length to the speed of the surface in study, as illustrated in Fig. 9.

The method proposed in this work is based on the assumption that, on counting the incidence of straight segments contained in a blurred image of an asphalt surface, a great number of segments with a size proportional to the asphalt speed is obtained. Based on this strategy, an algorithm is developed for counting the number of clear segments contained in the blurred image. The
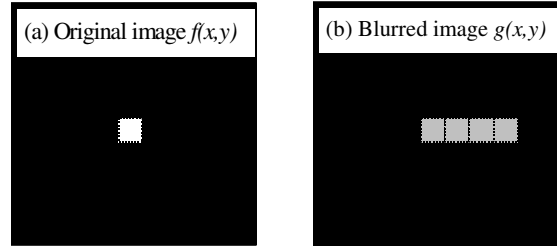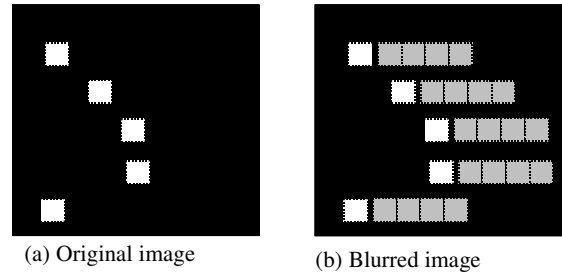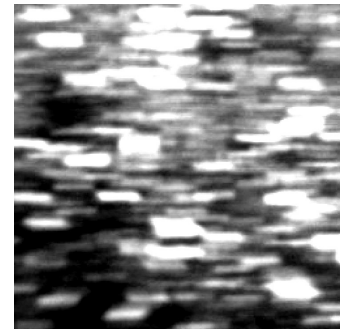

Figure 9. Blurred image of asphalt surface

obtained result is registered in a graph that has, in the horizontal axis, the size of the found segment, and in the vertical axis, the number of segments with a given size, found in the blurred image.
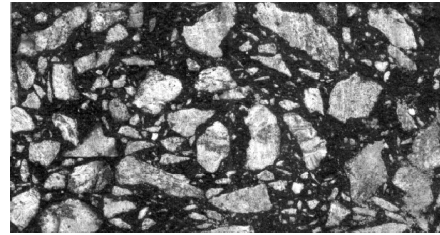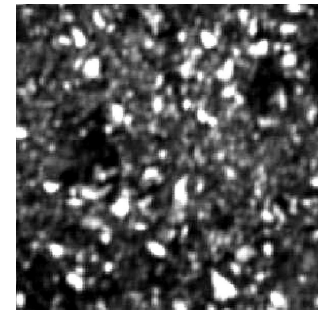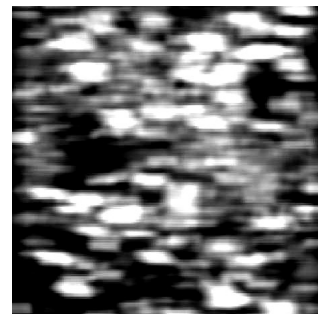
2.5 The blur effect of an asphalt surface

In the previous item it was decided to study the regularities contained in a blurred image, in order to determinate the speed of the background in movement. Starting from this point, the asphalt surface is defined as a standard surface, which speed will be determined. Therefore this surface has white-gray rocks in contrast to a dark background.

Figure 10. Typical asphalt mixtures

The asphalt is an agglutinative material, of dark color, constituted by complex mixtures of non-volatile hydrocarbons of high molecular mass. It is extracted from the petroleum, or found in deposits in the terrestrial surface (natural asphalts) (DNER-EM 204/95). As per the DNER-ES 313/97, the asphalt mixture or bituminous concrete is the mixture executed in an appropriate plant, with specific characteristics, composed of graduate mineral (rocks, sands and stone powder), filler, bituminous and fibers (as addictive stabilizers), dispersed and hot compressed. According with the DNER-EM 37/97, the big rocks is the rolled pebble, the gravel, the broken stone, the scum of high oven or other proven inert granular materials and of similar characteristics, of superior maximum diameter to 4.8mm. The DNER-EM 38/97, defines as small rocks the quartz sand, the artificial sand resultant of the stone-breaking of stable rocks or, since approved, any other inert materials with similar characteristics, of diameter same or inferior to 4.8mm.

In its surface, the asphalt is composed mainly of small rocks, with inert rocky materials of diameter same or inferior to 4.8mm. Fig. 11 shows photos of a typical asphalt surface. The contrast between the small rocks and the completion mass motivated the study of the image in movement of this surface, because the solids of clearer color, they should generate a blur on the dark background, as illustrated by Fig. 11(b).


(a) Static image

2.6 Identification of a segment in an image

In this work, each pixel of an image has an intensity that varies from 0 to 255. On identifying a segment, the pixel is considered belonging to the segment if its intensity is above a certain threshold value (*Thr*). Otherwise, the pixel is not considered part of the segment. As an example, Fig.11(a) shows a image of a segment composed by pixels and Fig.11(b), the numeric matrix representing this image. The painted cells represent the pixels with intensity above 120. Fig. 12

(b) Dynamic image

Figure 11. Asphalt photos

shows other example in which, a threshold of 100 is considered. Only pixels with intensity above or equal 100 is considered as part of the segments. Thus, in this example, following segments are identified:

- 1 segment of 1 pixel length
- 1 segment of 3 pixels length
- 1 segment of 4 pixels length
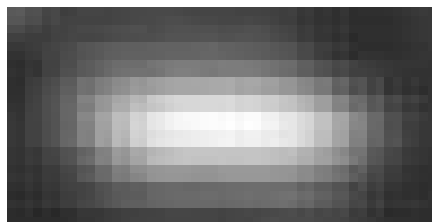
(a) Image of a segment
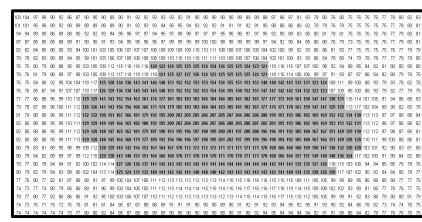
(b) Pixels with intensity above 120

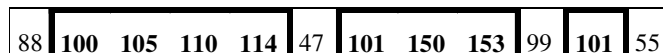Figure 12. Identification of a segment in a image

Figure 12. Identification of segments in a vector of pixels

This way of identifying a segment in an image has a problem. The same image shown in Fig. 12(a) may result in a segment of different length if a different threshold value is adopted. This problem would make this method very sensitive for noise and mainly for luminous changes. Once the method is supposed to be one for outdoor applications, the robustness against luminous changes is a relevant point to be considered. In order to minimize this problem, this work suggests that, on applying the presented method, the shutter speed is adjusted so as to maximize as possible the blur effect in the captured images. Thus, the total length of segments contained in the image will be large and consequently, the influence of the threshold value, luminous condition and noise on the length measurement is minimized. Experiments presented in following items shows that this solution is reasonable.

2.7 Segment histogram

Once the segments are identified in a given blurred image, results are compiled in a graph shown in Fig. 13. In the horizontal axis, the graph shows the length of the segment and, in the vertical axis, the incidence of segments of that length. Interpreting the histogram of Fig.13, one can conclude for example, that:

- Point (1) indicates the existence of 38 segments of 5 pixels length
- Point (2) indicates the existence of 114 segments of 14 pixels length
- Point (3) indicates the existence of 20 segments 24 pixels length

However, the most significant information contained in the histogram is the peak point of the curve. This indicates that the incidence of segments of 14 pixels length is predominant and this peak point will give the speed of the asphalt surface.
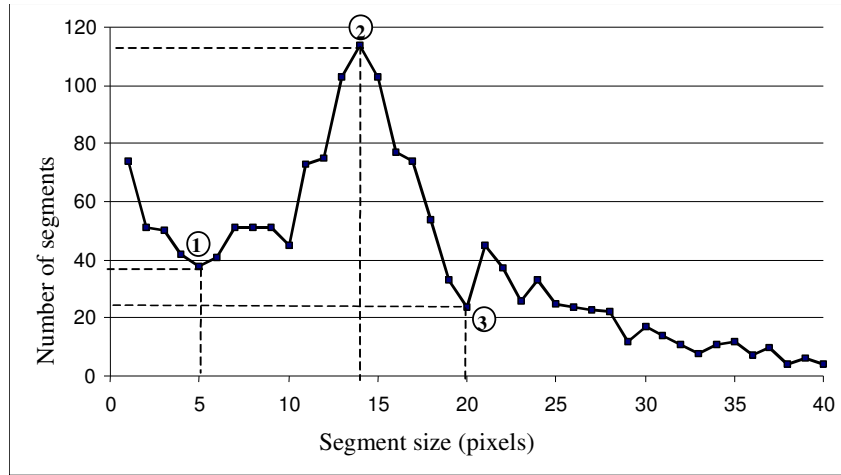

Figure 13. Segment histogram

2.8 Size of the rocks of the asphalt surface

The determination of the maximum mentioned above, is not enough to confirm that this value is exactly equal to the displacement during the interval of time in that the shutter remained open. To determine more accurately this displacement, it is important to take into consideration the size of the rock of the asphalt surface.

It is assumed that the real displacement d while the shutter remains open, be same to the distance among the centers of mass (CM) of the initial image and of the final image of the rock, as shown in Fig. 14. Thus, the distance d (real displacement) is equal to the total displacement D determined by the blur (segment length measured in the image), minus the diameter of the rock d_{rock}, as follows.
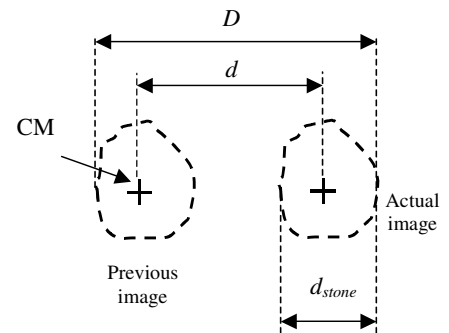

Figure 14. Center of mass of stones

$$d = D - d_{rock} \qquad (7)$$

The diameter of the rocks is determined by determining the size of the segments for a static image, as illustraded by the segment histogram in Fig. 15. In this case, the peak point indicates that the medium size of the rocks is of 3 pixels.

3   IMPLEMENTATION OF THE SYSTEM, EXPERIMENT AND ANALYSIS

3.1 Schematics of the experimental set-up

Figure 16 describes schematically the set-up used to test the blur method proposed in this work to measure speed of asphalt surface. The set-up has in its center, a motor driven belt with images of asphalt printed in it. The speed can be

adjusted through a speed selector and measured by a set composed of a toothed wheel, a hall type proximity sensor and an oscilloscope. A CCD camera (Costar, black and white camera) is set at the top oh the belt that is lightened by a filament type lamp. Images are transferred to the PC type computer through a frame grabber.
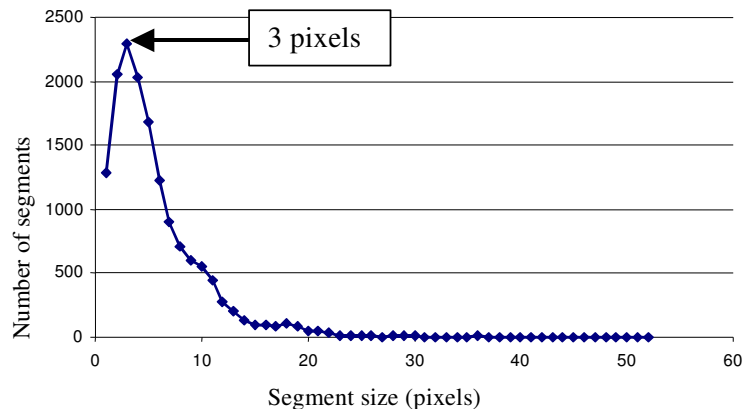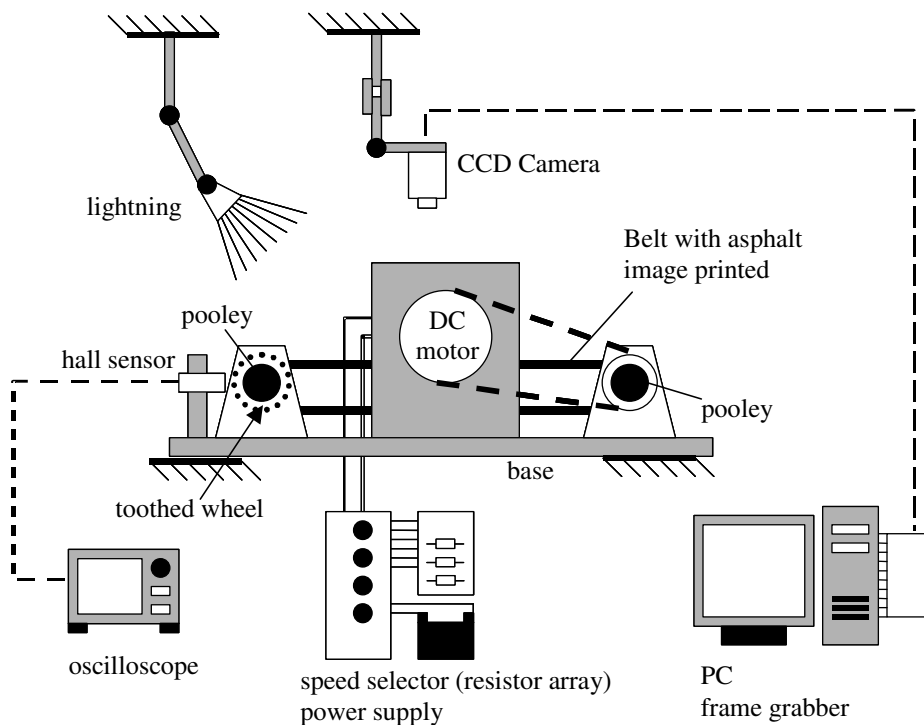

Figure 15. Segment histogram of static image

Figure 16. Schematics of the experimental set-up

3.2 Results under different speeds

A sequence of five images is registered asynchronously for each speed. From the images, five segment histograms are obtained as shown in Fig. 17.

These histograms are obtained using a shutter speed adjusted to 2ms and the threshold, to 120. Also, 25 frames are gathered to obtain each histogram. Although the proposed method is based in the analysis of a single blurred image, this is done in order to improve accuracy of results minimizing effects of noise over the measurement results. Since images can be acquired without any kind of synchronization, this does not affect the advantage of this method over others that, as mentioned before, requires the use of high-speed cameras and the capturing of successive images in a very precise time interval. In each histogram of Fig.17, the measured speed is estimated from the peak point and all measured results are grouped in only one graph, in which, the measured speed is compared to the reference speed, measured by set composed by the toothed wheel, the hall sensor and the oscilloscope.

It is observed that, as the peak point moves to the right, the peak point becomes smaller or less prominent. This is clearly observed in Fig.18 and it happens due to the overlapping of segments. Many segments are in a same height of an image. As the speed increases, the length of these segments increases, so that, above a certain speed, one segment overlaps other near segment. As higher the speed, the incidence of overlapping increases, increasing the measurement error. This problem is solved once the shutter speed is decreased.

Table 1 shows results of measurement tests using different values of shutter speed. For each range of speed, the shutter speed was adjusted so as to obtain acceptable values of error in accordance with Brazilian regulations. Although the shutter speed is selected experimentally in these tests, the shutter speed can be adjusted automatically, observing the height of the peak. This will be a theme for future improvements in the method. In Tab.1, the measured speed is compared to the reference speed and the error computed. Errors stay below 1% in speeds up to 40Km/h and 3% for speeds around 70km/h. Tests are limited to speeds around 70Km/h since higher speed could not be achieved in the experimental set-up. However, this method has potential for measurements for higher speeds. Results of Tab.1 are plotted in a graph "measured speed" by "reference speed", showing the good linearity of results.
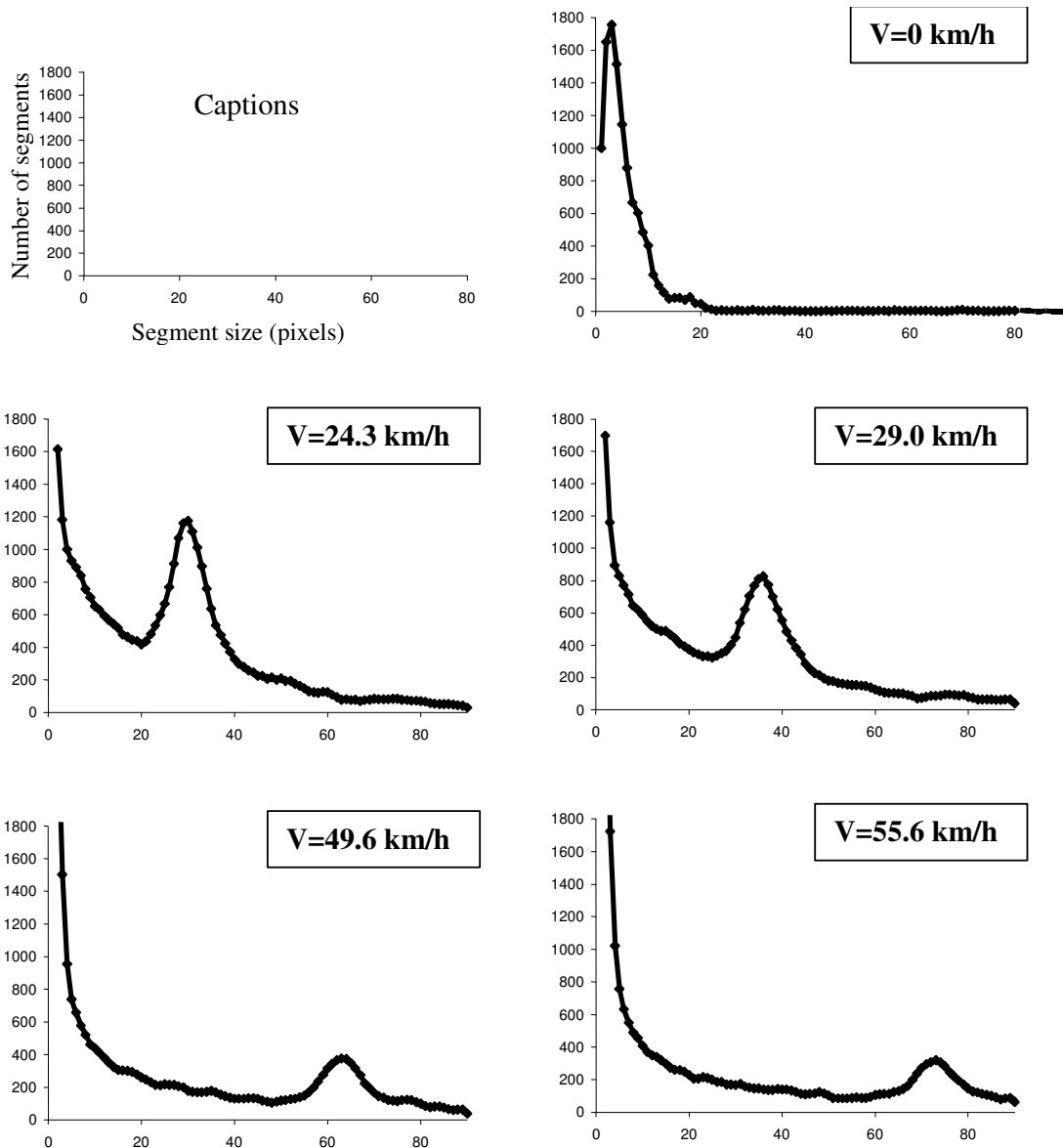

Figure 17. Measurement of different speeds

Table 1. Measured speed using different shutter speeds

Shutter speed (ms)	Measured speed (Km/h)	Error (%)
4.0	9.1	0.8
	11.9	0.6
	16.5	0.7
	20.4	1.0
2.0	24.0	0.5
	27.8	0.6
	35.2	0.6
1.0	44.4	1.3
	55.6	1.2
	65.6	2.2
0.5	70.1	2.8
	72.6	3.2

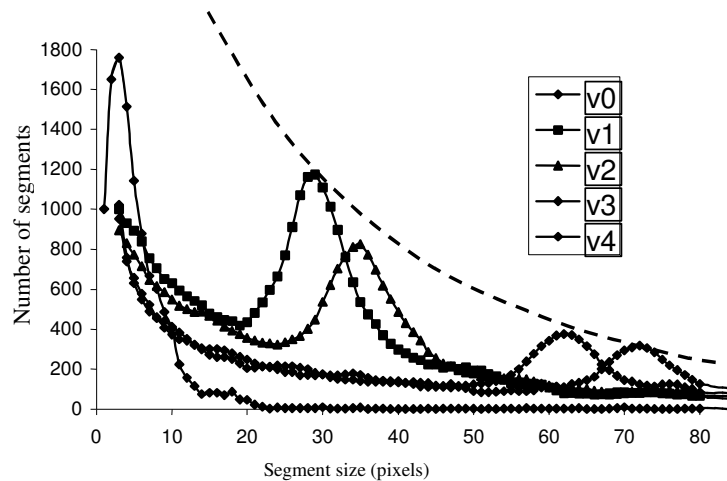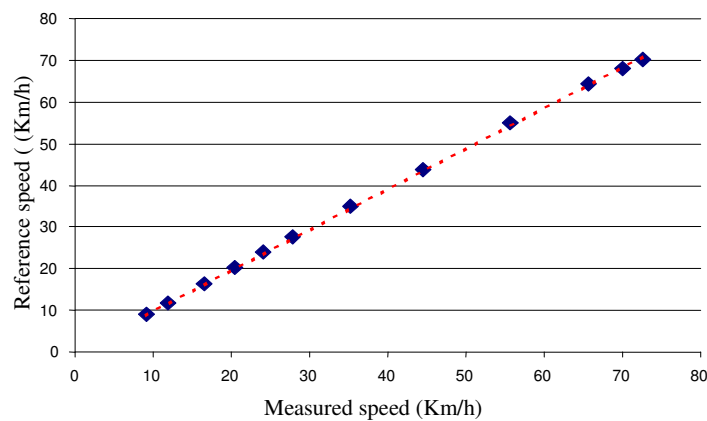Figure 18. Comparison of different speeds

Figure 19. Measured speed x reference speed

4. CONCLUSIONS

The speed measurement method proposed in this work, the blur method is tested and results demonstrate that the method is effective to measure speeds in a one-dimensional movement in a satisfactory way. The proposed method is innovative in comparison with known techniques because, differently of the approaches that consider a space-temporal sequence, the blur method is based on the analysis of an only one image with the blur effect.

The proposed method does not require images captured in a very precise time interval. Even capturing various images in order to improve the measurement accuracy, the image captured in one instant can be totally different of that captured in other instant, enabling the measurement of high speeds without using a high speed camera.

Experimental results show that the involved precision are quite satisfactory for a vehicular speed-meter inspection, staying below 1% in speeds of up to 40Km/h and of 3% for speeds in the order of 70Km/h.

Future works consider improvements in the method, considering development of strategies for automatically adjusting the shutter speed so as to minimize the error caused by change in the measured speed and by changes in the luminous condition.

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