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IMPROVED ALGORITHMS OF THE LIGHT-SECTION DETERMINATION OF 3D GEOMETRIES

Abstract: *The light section measurement technique is a method for the optical determination of three dimensional objects. A light source, usually a laser, projects a line onto the surface which is to be measured. The interaction of the light plane and the object which is to be measured is observed by a camera. Using projective geometry the form of the original object can be reconstructed from the shape of the line which is detected in the image. The concept is very simple, however, the accuracy and reliability of the measurement depends to a high degree on the quality of the algorithms being used. The measurement system developed here is used in a plant for the continuous coating of steel strip. The strip being measured is feed continuously. Further, there are many different types of strip with many different optical characteristics. This paper presents new algorithms, where the a priori knowledge of the surface which is to be measured and the physics governing its deformation are used, to achieve high reliability, with high precision and good numerical efficiency. The complete system has been installed and commissioned in an industrial plant under strongly varying light conditions.*

1. Introduction

The light section method is a well known measurement technique for the optical determination of three dimensional objects.

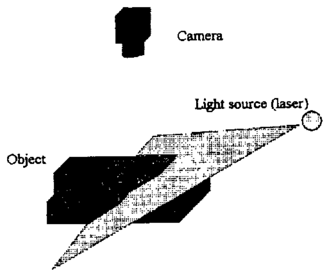

Figure 1: Basic principle of the light section measurement method.

The basic principle is shown in figure 1. A laser beam projects a line onto the surface which is to be measured. The interaction of the light plane and the object which is to be measured is observed by a camera. Using projective geometry the form of the original object can be reconstructed from the shape of the line which is detected in the image. A typical geometry for a measurement system is shown in figure 2 [1].

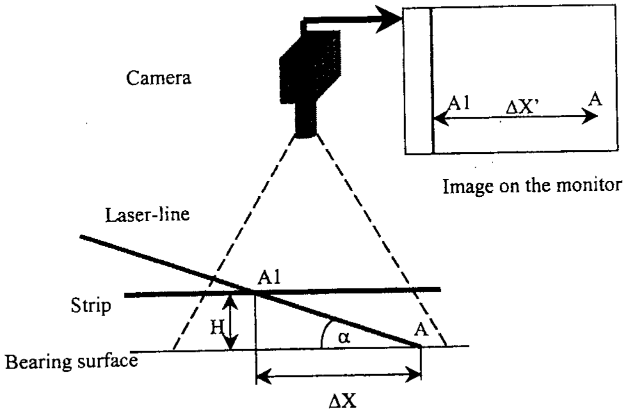

Figure 2: Typical geometry of the light section measurement system.

Where: H is the height and can be calculated as follows: $H = \Delta X * \tan\alpha = \beta * \Delta X' * \tan\alpha$

α is the angle of the laser plane with respect to the reference surface,

β is an enlargement factor of the image (optical gain) and

$\Delta X'$ is the deflection of the laser-line as seen on the monitor.

The measurement concept is very simple, however, the accuracy and reliability of the measurement depends to a high degree on the quality of the algorithms being used. In particular, there are many problems involved in the measurement of metallic objects.

2. Problems involved in measurement of real metallic objects

There are many special problems associated with the measurement of real metallic objects. These effects are demonstrated here with the measurement of the cross section of a turbine blade, see figure 3a and 3b.

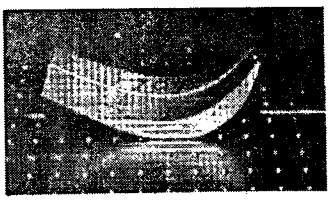

Figure 3a: Cross section of a turbine blade and interaction with the laser plane.

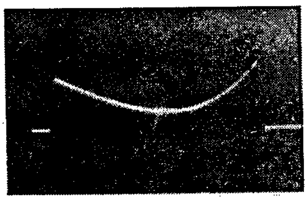

Figure 3b: Resulting image which is used for further processing.

2.1 Speckles

The interaction of the coherent light with the metal surface leads to constructive and destructive interference in the camera. The constructive interference results in artificially bright points, which are known as speckles. Consequently, simply calculating the maximum intensity along a cross section of the laser line will not result in reliable detection of the centre of the line. Further the noise distribution of the speckles is non Gaussian.

2.2 Starring

The surface of the metal may have some facets, particularly common when the metal surface has been ground. These facets result in a directed reflection of the laser light, resulting in a staring in the camera image.

2.3 Strong variations in the image intensity

Strong variations in the image intensity result from the different surface qualities and variations in the cleanliness of the object being measured. This can result in large variations in the apparent line width.

2.4 Non-continuous line

The line from which the surface is to be reconstructed is commonly not continuous. That is, due to poor optical conditions some portion of the laser line can not be detected. This can cause problems in determining control points for the description of the surface.

2.5 Sub pixel resolution is required

The accuracy which is desired requires sub pixel accuracy.

Figure 4: Detailed section of the laser line.

Many of the above problems can be seen in the detailed section of the laser line image shown in figure 4. Finally, it should be noted that a high efficiency of the algorithm is required, to enable an "on line, real time" measurement in industrial environments.

3. Improved algorithm

The image is pre-filtered, using a three by three averaging filter [2] [3]

$$F_{i,j} = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \qquad \text{Eqn. 1}$$

to eliminate spurious points. Then the image is segmented into n subsections, a middle line is constructed approximately perpendicular to the laser line in each section. The co-ordinates x_p, y_p of the maximum intensity along each middle line,

$$x_p, y_p = x, y \;\; where \;\; I(x,y) = \max\{I(x,y)\} \forall \, x = const, \; y = 1..y_{\max}, \qquad \text{Eqn. 2}$$

is then detected as a preliminary construction point. Where *I(x,y)* is the image intensity for the pixel with the address x and y.

An area of interest is then defined around each preliminary construction point, the size of these areas are selected to ensure that the complete x axis range is covered during calculation. The centre of gravity [4] [5],

$$x_c = \frac{\sum_{x=x_p-n}^{x_p+n} \sum_{y=y_p-n}^{y_p+n} x \cdot I(x,y)}{\sum_{x=x_p-n}^{x_p+n} \sum_{y=y_p-n}^{y_p+n} I(x,y)} \quad \text{and} \quad y_c = \frac{\sum_{x=x_p-n}^{x_p+n} \sum_{y=y_p-n}^{y_p+n} y \cdot I(x,y)}{\sum_{x=x_p-n}^{x_p+n} \sum_{y=y_p-n}^{y_p+n} I(x,y)} \qquad \text{Eqn. 3a and 3b}$$

is then calculated for each of these areas of interest. Where: n is one half the width of the area of interest and is a type integer. This results in a two dimensional vector, x_c,y_c of construction points which is n components long. It should be noted that x_c and y_c are real numbers (no longer integers), this gives the desired sub-pixeling resolution.

The two dimensional centre of gravity ensures, that all information in the image relevant to the line is used to determine the construction points. This algorithm is more robust and has a higher accuracy than a one dimensional centre of gravity calculation. Further, this algorithm also produces a result for lines which are not continuous. This calculation can be regarded as a nonlinear filter, which is convoluted with the original image. This tends to suppress the effect of speckles assuming that there probability distribution function is symmetric.

It is known, that the calculation of the centre of gravity is sensitive to changes in the ambient lighting i.e. changes in the ambient light result in changes in the position of the centre of gravity. However, this effect is reduced to a minimum by the use of suitable interference filters in front of the camera. This filter is optimised so as to minimise the ambient light while maximising the light detected from the laser.

The above algorithm delivers construction points which can be used to determine a suitable geometric model for the cross section of the surface. The model chosen must be optimised for a given application. Here the a priori information which is available should be used. The first industrial application described here, deals with the measurement of rolled steel strip. In this case we know that the surface is most probably a minimum energy surface and as such is well described by a spline [6]. Other applications will require other geometric forms, e.g. nurbs [7] etc.

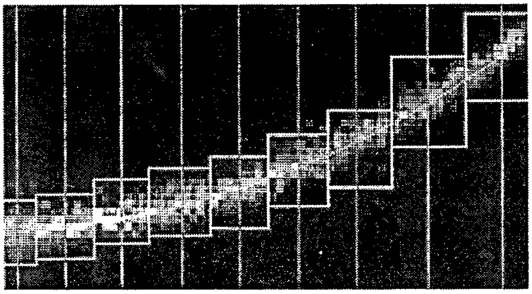

Figure 5: Schematic representation of the algorithm to reconstruct the surface (this is artificially drawn with the aim of visualising the procedure).

4. Industrial Application

The above basic algorithm has been implemented in a complete measurement system which is used to measure the flatness of rolled steel strip. The strip being measured is 1,2 m wide and is feed continuously. One of the main problems in this application is that the steel strip has a very strongly varying surface property. Some strips are electroplated, some sintered, others are raw. This leads to large variations in the quality of the acquired image (a typical image can be seen in figure 6).

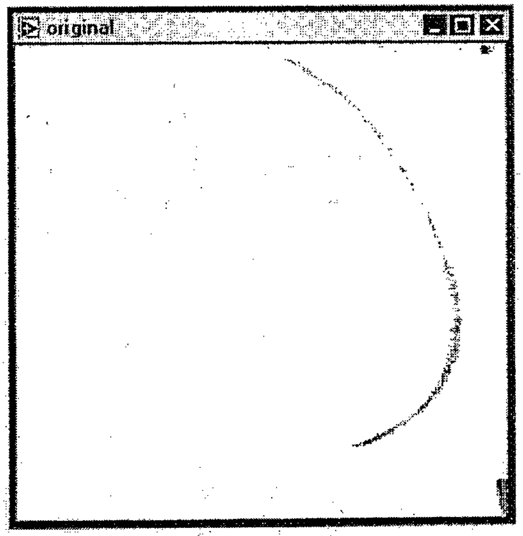

Figure 6: Typical digital image from the measurement of the steel strip.

The complete measurement system has been installed and commissioned for the continuous measurement in the industrial environment. The flatness [8] of the strip orthogonal to the direction of flow is measured from a single image and the waves along the length of the strip are determined from 24 sequential images. Presently an accuracy of 0.1 mm over the width of

1.2 m has been verified. The complete system consists of a supervisor interface, measurement system and protocol portability via SQL(structured query language).

5. Future improvements to the algorithm

Work is presently being carried out to improve the above algorithm, whereby the robustness and numerical efficiency are of vital importance for the application in industry. The basic concept is to extend the system by a predictor corrector algorithm in the following manner:

- The above algorithm is used to calculate the predictor.
- Then the areas of interest are modified to reflect the rate of curvature of the line being measured. This will give the optimal compromise between accuracy and numerical efficiency in the remaining processing.
- The control points will be determined using an algorithm which is calculated perpendicular to the curve.

6. Acknowledgements

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