실시간 3 차원 링클 측정 시스템

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Development of Online 3D Wrinkle Measurement System

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Key Words : roll to roll(롤투롤), wrinkle (링클), area scan camera(영역 스캔 카메라).

Abstract

Roll to roll (R2R) system, known as 'web processing', is the process of producing these electronic devices on a roll of flexible plastic. With the need of improved performance and productivity in R2R industry, effective control and on-line supervision for web quality is essential. In this report, we present a system for on-line measurement of wrinkles, one of defects incurring due to compressive stresses developed in the web. This system is able to capture an image generated when a well defined line shape laser beam passes through a transparent web. The system calculates 3D shape information, including the height of the wrinkle on the web, and displays the images for the shape information of the web in real time. By using area scan camera and machine vision laser, this system takes more advantages of setting up as a simple and low cost system compared to the line scan camera systems that widely used in web manufacturing. Specific calibration method and analysis on the achievable accuracy will be discussed.

1. Introduction

The promising R2R fabrication of electronic devices on continuous plastic webs offers the possibility of great cost reduction. However, critical technical challenge for R2R also arises as how sub-micron features can be embossed on a large web having poorly controlled thickness and flatness. Research on modeling, control for web handling applications and the use of digital images for supervising the quality of the R2R process is being emerged. Many commercial machine vision systems are already developed, however as far as we've known, they are more focus on detection and reporting of the web's surface defects: dirt, spots and coating streaks… Meanwhile, other process defects such as wrinkle, web vibration, web break or fold are paid less attention as they're also hard to be inspected fully. In fact, *wrinkling* (Fig. 1) is a complex phenomenon that may be induced by misalignment between rollers, anisotropic materials, variations in web tension across the web width or along the web length…and is difficult to be prevented [1].

Obviously, wrinkles do not all react in the same way to deformations, varying according to their shape and their alignment with the directions of elongation. Therefore, an effective measurement method is required as a mean of gathering information on wrinkle geometry to provide feedback to the web control center.

Many problems were confronted due to the transparency of the web (which is of 80% in our case). Triangulation laser sensors lose their intensity for most of the beam will go through the web. High velocity of web movement, ranging from 200 to 1000 mpm, also limit the use of these point sensors, which were previously reported in off-line wrinkle measurement in textile processing [2]. When using a line scan camera with front light illumination, it is possible to detect the occurrence of wrinkles, however the captured shape is not correct since it is based on shading when web surface is deformed. It's also difficult to distinguish with other

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features on the web surface in case it's already printed.

The purpose of this paper is introducing a novel measurement method for wrinkling based on structured light vision. We will describe measurement system including a measurement software, calibration method, experimental evaluation and conclude the paper.

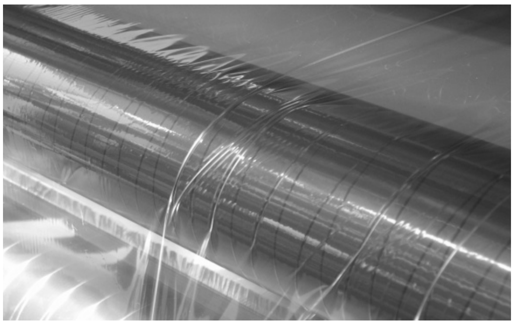

Fig. 1 Wrinkle on the web

2. Wrinkle measurement system

Wrinkle measurement System. The measurement system which consists of a camera and a diode laser that used as the structure light source projecting onto the web (Fig. 2). A Basler Scout camera with resolution of 659 x 494 pixels, sensor size is of 10 µm is used. The camera has the maximum frame rate of 79 monochrome images per second at full resolution and connects to the computer via Intel Gigabit LAN card. The laser generates a plane of light, which in turn creates a light stripe when intersects the web surface. Though most of the laser penetrates the transparent web, the reflectance data from this light stripe can be used to reconstruct the shape of the wrinkles. In case of no wrinkle, the light stripe is a straight line. However, when wrinkles occur, the distortion of the light stripe reflects the wrinkle shape (Fig. 3). We set-up a cover behind the transparent web that curtain off all unnecessary information to reduce the work of image processing. Therefore, the captured image is clear with bright pixels of the laser stripe on a dark background

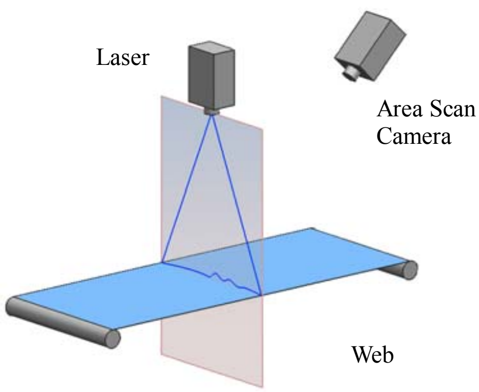

Fig. 2 Layout of the wrinkle measurement system

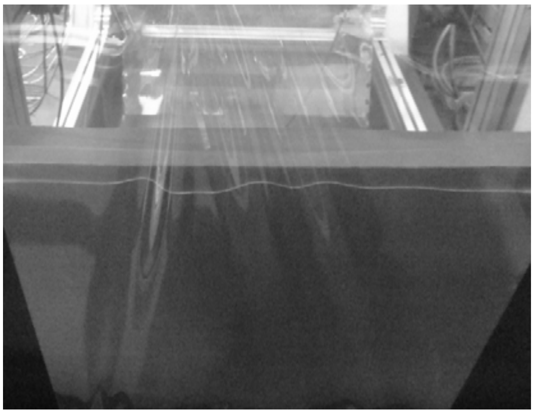

Fig. 3 Image of a laser stripe on the rolling web

3. Calibration

A structured light unit consists basically of a light projector and a camera. The light projector throws a plane of light in the direction of the scene. The intersection of this plane with an object creates a stripe of illuminated points on the object surface, the stripe being recorded in the camera image plane. If the unit is properly calibrated, the world coordinates of the illuminated points can be calculated by using triangulation formulas [3].

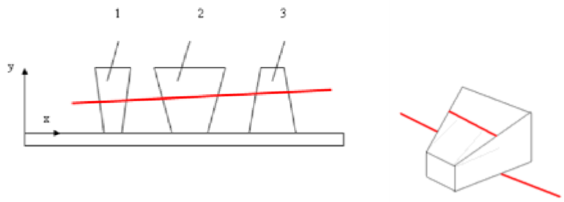

Fig. 4 Fig. 4 Calibration objects

We will now propose a procedure for calibration. A trapezoidal object, calibration objects, is located permanently in the work area. The object is shaped in such a manner that no two edges of the top surface are parallel to each other (Fig. 4). Therefore, one might say that the equations that define the lines corresponding to these edges are known [4]. Consider one such line: Since a line can be defined as the intersection of two planes, it is described by the following two equations corresponding to the two planes.

$$\begin{cases} a_1x + b_1y + c_1z = d_1 \\ a_2x + b_2y + c_2z = d_2 \end{cases} \quad (1)$$

The relation between world coordinate of object and camera image plane U is described by following equation in which ρ is a free variable account for the non-uniqueness of homogeneous coordinate expression, and T is a 4x3 conversion matrix.

$$\rho\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \\ t_{41} & t_{42} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}$$

rewrite as

$$\rho\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{bmatrix} .U \qquad (2)$$

By eliminating the free variable, we have

$$\begin{aligned} x &= T1.U / T4.U \\ y &= T2.U / T4.U \\ z &= T3.U / T4.U \end{aligned} \qquad (3)$$

or equivalently

$$\begin{aligned} T1.U - x\,T4.U &= 0 \\ T2.U - y\,T4.U &= 0 \end{aligned}$$

The intersection between laser stripe and calibration line will generate illuminated points which can be recorded in image coordinate U, and its world coordinates are unknown. Then, equation (eq. 1) can be substituted by right hand side of equation (eq. 3) in view of the fact that we have no need for the world coordinates of the illuminated point on the calibration line.

$$\begin{cases} a_1 T_1.U + b_1 T_2.U + c_1 T_3.U = d_1 T_4.U \\ a_2 T_1.U + b_2 T_2.U + c_2 T_3.U = d_2 T_4.U \end{cases} \qquad (4)$$

Of course, each calibration line is capable of producing a set of two equations (eq. 4) in terms of the 11 coefficients of conversion matrix T . Therefore, if we use at least six calibration lines or 3 different calibration objects, we will have a system of over-determined linear equation to estimate the conversion matrix.

The computer used for the measurement system is a Pentium IV 2.4GHz, 2GB RAM with 256MB graphics card. The exposure time of the camera is set at a level allowing maximum frame rate of 79 fps can be achieved (with full resolution). The wrinkle measurement program (Fig. 5) is developed for running at multithread to achieve the satisfactory that does not reach the limitation of execution time.

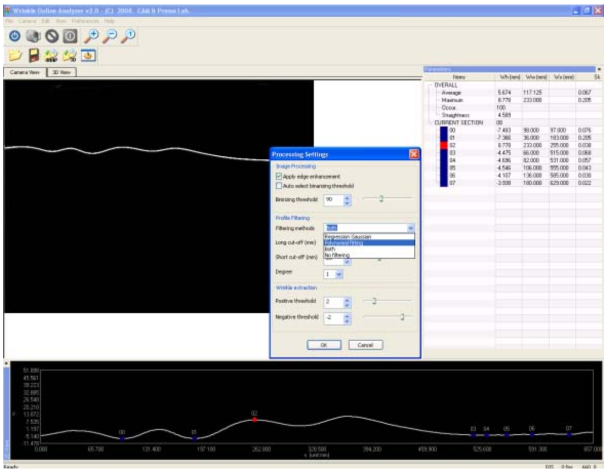

Fig. 5 The measurement software

As the initial step, we consider the procedure to get the conversion matrix T which uses for calibration function. The three isosceles trapezoidal calibration jigs were fabricated in different angle values of inclined plane and side planes (Fig. 6) (from left to right jigs : 30^0 inclined_15^0 side, 15^0 inclined_10^0 side and 30^0 inclined_5^0 side respectively). These objects are used to perform six calibration lines (the edges on the top surface and not parallel to each others) and produce six intersecting points with the laser stripe: U1,..,U6 in camera image coordinate known as camera image plane. By capturing and filtering the stripe (Fig. 6), the value of intersection points were calculated and verified in pixel unit.

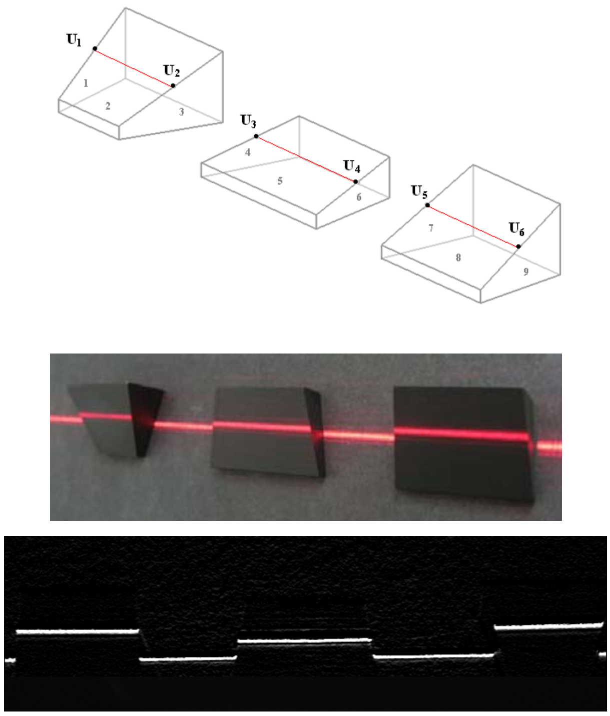

Fig. 6 Project laser tripe on calibration jigs and captured image result

Applying equation (eq. 4) for the described equations of 6 edges and the values of U1,..,U6 we have the system equation of eleven unknowns. Solving this system equation, we get the result of conversion matrix T

$$T = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \\ t_{41} & t_{42} & 1 \end{bmatrix} = \begin{bmatrix} \mathbf{0.0341} & -\mathbf{0.2516} & \mathbf{97.4534} \\ \mathbf{0.0005} & -\mathbf{0.0728} & \mathbf{26.1214} \\ \mathbf{0.0002} & -\mathbf{0.0482} & \mathbf{17.7342} \\ 0.00\mathbf{0} & -\mathbf{0.0023} & \mathbf{1} \end{bmatrix} \quad (5)$$

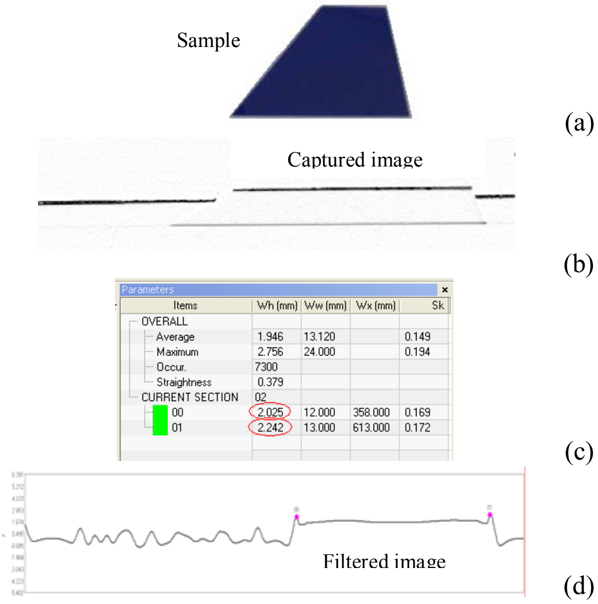

Fig. 7 Testing and evaluating the calibration function

The following test will evaluate the conversion matrix after calibrating. Figure. 7 shows the measurement result of a 2mm thickness dark color sample on a black flat background. As evaluating the height of sample (Fig. 7a), it is considered in the same process to measure wrinkle. Captured image of sample (Fig. 7b) displays the discontinuous of laser stripe image which caused by the different height between the bottom and top surface of sample. By applying the Regression Gaussian profile filtering method for the bitmap image, the measurement program can clearly detect the two edges of sample and show the value of thickness at two sections which the laser stripe broken. However, the height measurement at section 00 and 01 (Fig. 7d) with the value of 2.025 mm and 2.242 mm (Fig. 7c) points that the error happens when setting up the relative position between camera and laser projector (which shows as a small slope of laser stripe in captured image). Due to the experimental result, this kind of error can be fixed by setting up both optical devices in the good manner of position and angle (i.e. installing in the same housing). And actually, the more precise calibration objects will act a role in improving the accuracy of measurement result.

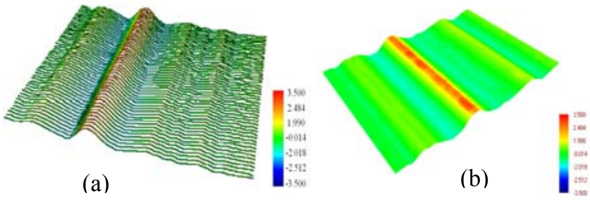

Fig. 8 3D online wrinkle measurement result

The experiment for online 3D wrinkle measurement which shows in Fig. 8a has a good performance. By capturing, processing and accumulated displaying a series of stripes, the software can show an advantage for measuring and performing the complex 3D shape of wrinkle. This will be valuable for online web inspection. To keep the quality of 3D display, rendering function is used as the final measurement result (Fig. 8b) when turning off online camera scanning.

4. Conclusion

In this paper, we presented a machine vision system based on structured light ranging for measurement of wrinkle geometry. The device set-up is simple, low cost comparative to line scan camera systems that widely used in web manufacturing. Another advantage of this method is the capability of measuring the wrinkle height, which is a more useful parameter to feedback to the control center than its projective shape. The measurement software was built on multi-threading technique with image processing and filtering algorithms tailored to meet the requirements of on-line visual inspection. Experimental results showed that the software operated well at the camera's maximum acquisition frame rate and can display good 3D measurement results. However, the system is still in early stage of development and needs to be studied more in details to increase the detection capability and accuracy.

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