Design of Weft Detection System in The Stenter Machine

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Abstract. In order to build an effective automatic weft-straightening system, it is important for the sensing device to detect most of the possible fabric styles, designs, colours and structures, an optical sensing system that detects the angular orientation of weft threads in a moving web of a textile has been built. It contains an adjustable light source, two lens systems and photodiode sensor array. The sensor array includes 13 radial pattern of photosensitive areas that each generate an electrical signal proportional to the total intensity of the light incident on the area. The moving shadow of a weft thread passing over the area will modulate the output signal. A signal processed circuit was built to do the I/V conversion, amplifying, hardware filtering. An embed micro control system then deals with the information of these signals, calculates the angle of the weft drew. Finally, the experiments were done, the results showed that the weft detection system can deal with the fabric weft skew up to 30° and has achieved good results in the application.

1. Introduction

In dyeing and finishing process, when the fabric has different force in the warp/weft interweave point size during the movement, the speed will be different, the weft will not perpendicular to the warp, weft skew is formed [1]. It greatly affect the quality of the fabric and need to be corrected.

The existing weft detection system mainly has two methods: image processing and photoelectric detection approach. At present, there are quite a few research literatures on the image processing[2-3], for example, the literature [4] using characters of Fourier amplitude spectrum and statistical analysis method to realize the weft fabric image texture recognition. Literature [5] using Hough transform method to detect the fabric tilt, taking image gradient as the direction information of weft. Paper [6] using the Fourier transform to extract the line signal from fabric image, and choosing the maximum linear information used to judge the position of yarn. The common defaults are: 1) the fabric structure has great influence on the recognition effect, and a large numbers of the fabrics cannot be recognized; 2) The image recognition equipment is still not suitable for high-speed operation; 3) It needs to buy the high-speed camera, the cost of system is high.

In the practical application, photoelectric detection method[7-8] is still the mainstream, such as Bicanco in Italy, Mahio in Germany, and the other companies in China and Japan. There are two ways of photoelectric detection, one is that using rotating sensors and the other is using fixed sensor. Mahio, Bicanco utilize a rotating scanning head with a single slot. Correlation between the angular position of the head and the signal generated by the light passing from the fabric through the slot gives an indication of the weft thread orientation. While this system may provide more precise information and wide range,
it has maintenance and cost disadvantages associated with rotating elements and the necessity of measuring and correlating the position of the rotating member with the output signal, also it not suit for the low speed application; Others adopt fixed head systems, an sensor array with 13 Photodiode slots or more was adopt, it was distributed with a fix angle. This method has compact structure and good adaptability to different speed, but the detection range is restricted.

The fabric type is numerous in the heat setting process, so, a optical sensing system for determining the angular orientation of weft was set. This paper investigated the detection principle, and built the optical and electronic system. The designed system has been developed to calculate the angle of the weft and communicate with CAN bus to the weft straightener.

2. Detection Principle
In the direction of the weft, 2 to 4 devices are deployed. Each device has a light source and a sensor part, they are located on the opposite sides of a moving web of a textile. The light source, which includes an optical focusing element, directs a converging light to be homogeneous parallel beam of generally uniform intensity onto the fabric. The sensor part includes an optical system which focuses the light transmitted through the fabric onto a sensor. The fabric weft image will be projected on to the sensor array which has a pattern of photosensitive areas formed by photodiodes. The number of the photodiodes is 13 in this paper. They are in a radial array with the central area of the array generally aligned perpendicular to the direction of advance of the web. The signal processing circuit is used to magnify the photoelectric information of the photodiode slots with noise filtering, an embed processor will do the compensation and calculation the slope of the weft line. The detection principle diagram is shown in figure 1:

![Figure 1. Schematic of the weft detection](image)

The light source includes a lamp that produces a generally uniform, high intensity light. The light intensity can be adjusted by the feed back system with the aid of the micro controller. The lamp can use different light source, in order to reduce scattering, it was suggested to adapt the lamp which produces light having maximum output at a wavelength in the range of 700 to 900 nm, because these range are more sensitive to the photodiode.

Most fabrics have 36 to 120 lines per inch, it means the thickness of the weft line is between 0.13mm to 0.42mm,and the width of the weft line is between 0.71 mm to 0.21 mm. The width of each Photodiode slot which is roughly comparable to the width of one of the weft threads is selected. In this paper it was selected to 0.3mm. In order to acquire a good signal-to-noise ratio, the length of the sensors were set form 13 to 15 mm. The processing fabric weft slope is generally not more than ±15°, thus the sensors are in a radial array with angle: 15°, 12°, 9°, 6°, 4°, 2°, 0°, -2°, -4°, -6°, -9°, -12°, -15°.

The key point of designing the optical system is to ensure that the weft can be well imaged through a array of sensors. The distance between the fabric and the light source, and that between the convex lens to the sensors needs to be well adjusted. The sensor part should confirm the vertical magnification of the lens will be proportional to the appropriate ratio, and the enlarged yarn slightly smaller than the width of the photodiode slot.

The basically work principle is as follow. Each sensor produces an electrical signal which is proportional to the total intensity of the light incident on that area. The signal is also modulated by the
shadow of the weft thread. This modulation is very strong when a weft thread is generally aligned with a sensor while others are weak. The output signal was shown as Figure 2.

![Figure 2. Schematic of the weft detection principle](image)

For example, when the fifth sensor has the maximum amplitude, it indicated that fabric weft is moving at an angle of $4^\circ$; When the fabric has no inclination, the output value of the seventh sensor is the strongest.

### 3. Signal processing

The signal processing of photodiode is very important in the fabric weft detection, which directly affects the accuracy and speed of the measurement. The photodiode can be considered as a high impedance current sensor, and the signal processing circuit needs to solve the impedance transformation and dc amplification, stability compensation and noise elimination.

#### 3.1 Photodiode Amplifier

There are two operation modes for the photodiode\(^{(9)}\), the photovoltaic mode and the photoconductive mode. In photovoltaic mode, there has zero voltage potential across the photodiode. No dark current flows through the photodiode, the linearity and sensitivity are maximized, and the noise level is relatively low, which makes it well suited for weft detection. The current of the photodiode needs to change into the voltage, and the signal should be amplified. The following circuit as shown as Figure 3 was designed.

![Figure 3. Photodiode amplifier circuit](image)

Here the DC output voltage $V_{\text{out}}$ due to the source current can be written as $V_{\text{out}} = I_S * R_F$. The value of the feedback resistor ($R_F$) should be set as large as possible to give a high transimpedance gain to the photocurrent. Here, this gain is high enough to use most of the op amp’s output voltage swing when the photocurrent is at its maximum value. The op amp will contribute a DC offset voltage to the output, so we needs to choose op amp with lower $V_{\text{OS}}$ and $I_B$.

The gain peaking and step output ringing are typical phenomena, which produces high noise, may severely degrade the integrity of the output signal and make the photodiode amplifier unstable. A compensation capacitor can be added in the feedback loop to eliminate the problem. Figure 4 shows the noise gain bode plot of the photodiode amplifier in log-log scale. The stability of the system is...
determined by the net slope between the noise gain ($G_N$) and the open loop gain ($A_{OL}$) at the frequency where they cross over.

Here,

$$f_1 = \frac{1}{2\pi R_J|R_F|(C_J+C_{OP}+C_F)}$$

$$f_2 = \frac{1}{2\pi R_F C_F \cdot GBWP}$$

$$f_3 = \frac{1}{G_N}$$

Here, $R_J$ is the junction shunt resistance, $C_J$ is the junction capacitance, $C_{OP}$ is the op amp input capacitance, $GBWP$ is the op amp gain bandwidth. $f_1$ is the location of $G_N$’s first zero, $f_2$ is the signal gain bandwidth, $f_3$ is the noise gain bandwidth.

The value of $C_F$ affects the location of $f_2$, which determines the signal gain bandwidth and the phase margin of the photodiode amplifier. For the photo detection applications, the optimum value of $C_F$ can be chosen as:

$$C_F = 2 \sqrt{\frac{C_J+C_{OP}}{2\pi R_F GBWP}}$$

And a RC low pass filter can follow the photodiode amplifier to eliminate the noise beyond the signal gain bandwidth is added to the circuit, usually the cut-off frequency is 10 times of the normal signal.

3.2 Signal further processing

When fabric is moving, the output of the photodiode amplifier will change like a sine wave which contains a large value of dc component. This signal is not suitable to judge the angular orientation of the weft thread, the following circuit was designed to solve this problem.

![Figure 5. AC signal amplifier and precision rectification circuit.](image)

$V_{out}$ passes through a voltage follower, become the input signal as shown in figure 5. Then the DC part was blocked and the AC value was amplified. Because of the Analogy - Digital Convert in micro processor can not deal with the value above 0, an precision rectification circuit was adopt to Convert the negative voltage to positive.

In general, the micro process can judge the angular orientation of weft threads by the peak of signal, in order to improve the accuracy, this paper using Root-Mean-Square (RMS) instead of the peak value. Finally, the micro processor will output the angular orientation of weft threads by CAN bus.

4. Experiments

Figure 6 shows the designed apparatus used for weft detection. The experiment was done by this machine.
Figure 6. Photo of the weft detection system

Figure 7 shows the signal of the photodiode output value when the fabric move align with the weft thread. It is roughly like a sine wave curve.

Figure 7. Output value of photodiode which move align with weft direction

Figure 7 shows all the 13 output values processed by micro processor when the fabric move align with the weft thread and not.

Here, Part A indicate that the weft thread is not tilting, Part B indicate that the angular orientation of weft threads is 4°. The maximum angle that can be detected exactly is ±15 degrees, and the value larger than that which can also be detected but the angle value can not be achieved. As shown in Figure 7, the value of 6th line and that of 8th line maybe not be equal while the 7th line is the tallest. It means that the actual angular orientation of weft threads is not 0°, this system still has little measure errors, and the deep relationship between those values and angles need to be further studied.

Figure 8. Output value of 13 sensor processed by MCU

5. Conclusion
This article shows that the use of a weft detection system, combined with a optical sensing system and signal processing system, enables the symmetry directions of a fabric to be determined. The range of the angular orientation of weft threads can reach to 30° and the precision is better than 2°. This technique can be used in the weft straighter to correct the weft drew.

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References
[1] Carruthers, W., 1989, The History and Practice of Weft Straightening, Dyers and Colourists, Cheshire, UK.
[2] WU H H, Zhang M M, Pan Z G. Skew Detection and Weft Density Identification for Fabric Images[J]. Journal of Image & Graphics, 2006, 11(5):640-645.
[3] N Khorissi, et al. Application of the wavelet and the Hough transform for detecting the skew angle in Arabic printed documents[C]. 9th International Symposium on Signal Processing and Its Applications, 2007: 1-4.
[4] PAN R R, GAO W D, Automatic skew rectification of image of high density woven fabric [J]. Journal of Textile Research, 2009, 30(10): 58-61.
[5] DONG Y, ZHU Y S, ZHANG X H. Fabric Skew Detection Method Based on DFT and Multi-projection Analysis [J]. Computer Simulation, 2013, 30(8):393-397.
[6] Li JY, DING Y S, ZHANG Z W, et al. Fabric texture image identification method for CCD-based weft-straightening machine [J]. Computer Engineering and Applications, 2007, 43(13): 214-216, 219.
[7] Maddox E L, Pitts T E. Optical sensing system for determining the orientation of weft threads in a wide variety of fabrics: US, US 4656360 A[P]. 1987.
[8] Kofnov O V, Sukharev P A, Shlyakhtenko P G. Method of determining the skewness of the weft thread in fabric[J]. Journal of Optical Technology C/C of Opticheskii Zhurnal, 2014, 81(2):111-113.
[9] Microchip. Using MCP6491 Op Amps for Photodetection Applications [OL]. Site: http://ww1.microchip.com/downloads/en/AppNotes/01494A.pdf.