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Research on Misalignment Detection of Paper Machine Clothing Based on Computer Vision

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Abstract: Paper machine clothing (PMC) is a specialized material essential to the paper industry, forming an integral part of paper-making equipment. Deviations in the net carpet, in particular, can lead to pleats along the edge or in the middle of the net carpet, making it challenging to spread and often resulting in broken pleats. These pleats contribute to increased paper-making costs. To address this issue of paper machine clothing misalignment, this study proposes a monitoring approach based on computer vision. Initially, image filtering and edge enhancement are applied to the video images obtained from the complex manufacturing environment of a paper mill. The Canny operator is then utilized for edge detection to obtain a binary image of the edges. Subsequently, Hough transform is employed to detect the edges of the net blanket based on the straight-line characteristics of paper machine clothing. Additionally, regions of interest (ROI) are established to enhance processing speed and reliability. If broken straight line segments are observed at the edge of the mesh blanket, these are combined using least squares fitting to form a complete straight line. Finally, deviation in the paper machine clothing is monitored by analyzing the slope value of the fitted edge straight line and its distance from the x-axis of the outer roller edge. Test results demonstrate that using the method proposed in this study, it is possible to determine both the angle of net blanket deviation and its distance from the rollers' edges. Through validation using laboratory and mill data, the algorithm presented in this study effectively reflects these parameters.

Keywords: Paper machine clothing, Computer vision, Misalignment detection, Hough linear detection.

1. Introduction

The paper machine clothing serves a crucial function in supporting and transmitting pulp, paper blanks, and paper sheets, while also playing an important role in the forming, pressing, dewatering, and drying of paper sheets. With the acceleration of automation in the paper-making industry and the increase in the speed of paper machines, a series of issues affecting the normal operation of equipment have emerged, with misalignment of the paper machine clothing being a notable example[1, 2] .These cloths can be categorized into forming net, press felt, and drying net based on their location within the paper-making machine [3]. As the paper net blanket is in direct contact with the paper surface throughout the papermaking process, its condition has a direct impact on the quality of the paper products, as well as on the productivity and production costs of the papermaking machine [4, 5].

The causes of paper machine clothing misalignment are complex, the difference in tension on the transverse direction of the web, the rolls are not fully centered, the difference in the parallelism of each roll, the difference in roundness, all of which can cause the web to run out of shape. The misalignment of the net carpet will cause head breakage or paper diseases such as embossing and crimping, and when the misalignment is serious, it will tear the net carpet, affecting the normal operation of the paper machine, and causing great losses to the production of the production plant's output and quality of paper copying.

Existing mesh blanket calibrators can be divided into constant contact, intermittent contact and non-contact according to the detection equipment, and non-contact calibrators can be divided into pneumatic and electric calibrators according to the actuators[6].

The contact calibrator installs a detecting device, the touch palm, on one side of the net blanket, and uses the direct contact between the touch palm and the edge of the net blanket to follow the movement of the net blanket to detect the change of air pressure, and changes the position of the guide rollers by adjusting the air bladder to keep the net blanket running in a certain position. The characteristics of the palm of the material requirements are relatively high, and wear and tear on the edge of the net carpet; intermittent contact calibrator on both sides of a palm to drive a mechanical-pneumatic reversing valve action, to achieve the air circuit switching, will be compressed air to the corresponding air spring, to achieve the automatic correction of the net carpet, the edge of the net carpet wear and tear is relatively small. In addition, the contact calibration system of the airbag, spring, air source failure caused by dislocation misalignment and other reasons is gradually eliminated, and non-contact calibration device can effectively overcome these problems gradually promote the application. Among them, the non-contact pneumatic calibrator consists of infrared detector, solenoid valve and so on [7]. Through the infrared detector will signal feedback to the solenoid valve, so as to control the actuator movement, but the infrared detector performance sometimes detects the signal is not stable. Non-contact electric correction device, two sets of optical measuring heads is installed on one side of the net blanket to detect the position of the net blanket, and the controller controls the electric correction device through the frequency converter. No damage to the edge of the net blanket, high adjustment accuracy, but the investment is relatively large.

Most of the above correction methods require the installation of various types of sensors on the paper machine, for the paper machine clothing in the copying process of the misalignment problem, the use of image processing methods can be more intuitive to solve. At present, currently, closed-circuit television monitoring systems (CCTV) act as an intuitive visual monitoring tool for industrial production, benefiting from a broad application scope, mature technology, and relatively low costs [8]. At the same time, the level of development of computer technology, high-speed digital image acquisition and processing technology have made it possible to monitor the misalignment of paper machine clothing through computer vision technology, but the misalignment recognition algorithm is the detection of the research difficulties.

In recent years, a lot of research has been carried out on paper machine clothing, mainly focusing on the development of a new type of net carpet design, felt chemical cleaning and net carpet dewatering laboratory model, to prevent dehairing, and to improve the performance of the net carpet itself, etc. [9] [10] [11] [12]. The research on the monitoring of the overall operating condition of the felt in the actual working environment is very limited, which in turn greatly restricts the development of modern large-scale high-speed paper machines.

This paper aims at study a high-efficiency method for detecting the misalignment of the paper machine clothing, and at the same time, It can detect abnormal situations with the net blanket in a timely and accurate manner and send out alarm signals accordingly., which can effectively prevent the occurrence of paper disease, and provide a theoretical basis for the design and development of the net blanket condition monitoring system with practical value [13].

2. Paper Machine Clothing Misalignment Detection Method

The flow of the misalignment detection method for paper machine clothing proposed in this paper is shown in Fig. 1. Firstly, preprocess the collected images in the computer, including grayscale processing, noise removal, and enhancing image features. Then the canny operator is used to extract the edge features of the mesh carpet, filtering the useless information and retaining the important edge structure features. And then through the Region of Interest (ROI) selection the part of the image that needs to be detected in the mesh carpet edge line is extracted, while the other parts of the image are not further processed in order to reduce the processing of redundant image data. The Hough linear transformation algorithm is utilized, with an angular filter employed to eliminate interfering straight lines. Subsequently, the least squares method is utilized to fit the discontinuous mesh carpet edge straight lines. This approach facilitates the accurate extraction of the positional coordinates of the mesh carpet edge straight lines [14]. Finally, through the angle of inclination of the paper machine clothing and the distance between the two sides of the stick according to the net carpet, comprehensively determine whether the net carpet has misalignment faults and fault level, and carry out the corresponding fault alarm.

2.1. Image acquisition

The acquisition hardware of the computer vision-based paper machine clothing misalignment detection system includes, light source, industrial camera, lens, computer, data transmission equipment, etc. [15]. The structure of the image acquisition system is shown in Fig. 2, which adopts the LED ring lighting technology and image acquisition on the surface of the paper machine clothing through the CMOS surface array industrial camera, and then the image data is transmitted to the PC through the gigabit network cable, and the PC realizes the misalignment detection according to the image processing technology.

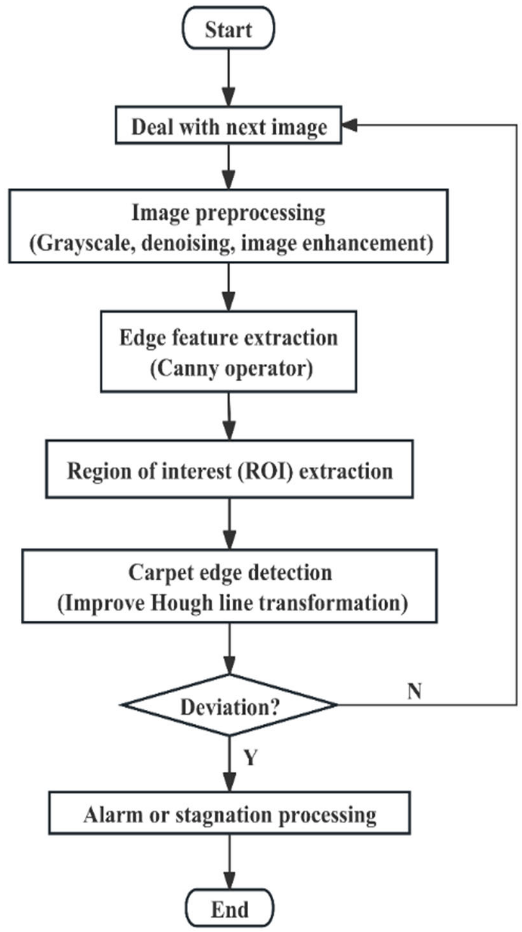


Figure 1. Flowchart of paper machine clothing deviation detection

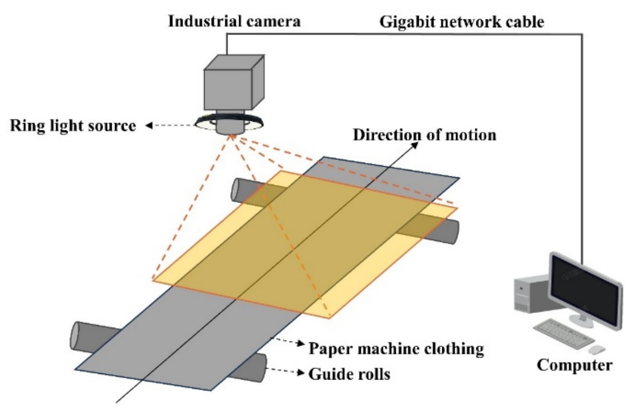
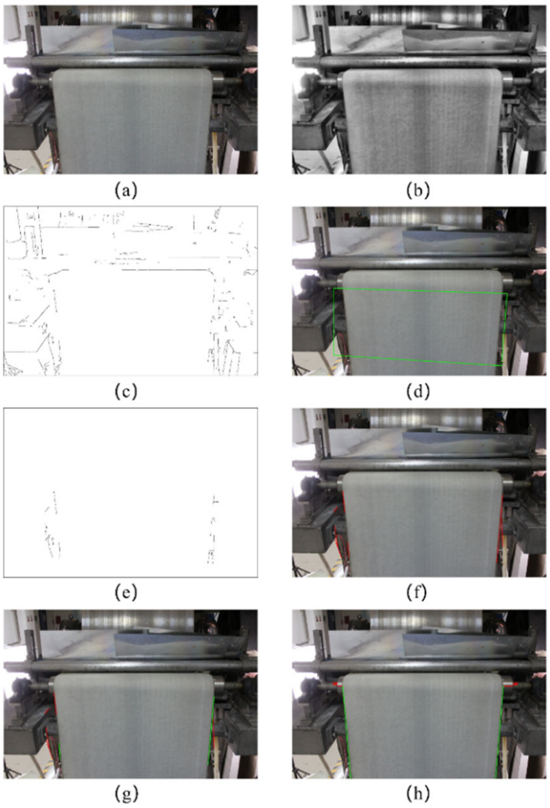


Figure 2. Schematic structure of image acquisition system



(a) Original image (b) Pre-processing(c) Edge feature extraction (d) ROI mask area (inside the green quadrilateral)(e) Region of interest (ROI) (f) Hough linear transformation (g) Edge detection of mesh blanket (h) Graph of deviation detection results

Figure 3. Net blanket image processing results

2.2. Image Preprocessing

(Figure 2a) is an original image of the paper machine clothing collected. Through its analysis, it is known that the original image contains more irrelevant information from other equipment, there are a lot of dust and water vapor in the working environment of the field, and there is uneven brightness. In order to eliminate irrelevant information and suppress noise in the image, it is necessary to preprocess the original image. This paper proposes a simple and efficient image preprocessing algorithm, including grayscale processing, image enhancement, Gaussian blur, and erosion and expansion operations [16]. The preprocessing results are shown in (Fig. 2b).

2.3. Edge Feature Extraction

In digital image processing, the operators that can be used to perform edge detection are usually Robert, Log, Canny, Sobel etc[17]. Following a comparison of various operators, the Canny operator is selected for binarizing the image and detecting edges in this study. The thresholding process used in Canny operator edge detection helps to generate a complete and continuous edge curve, which can eliminate the effect of noise as much as possible and has good detection effect on edge points [18]. The implementation steps of the edge feature extraction algorithm are shown in Fig. 4. The minimum and maximum thresholds set in this paper are 180 and 250, respectively, and the detection detection effect is shown in (Fig. 2c).

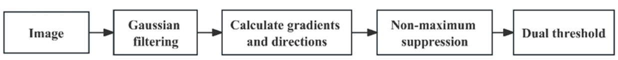


Figure 4. Canny edge detection implementation flow

2.4. Extract Region of Interest (ROI)

Although the image has been preprocessed and Canny edge detection, there are still some other environmental information in the image that affects the accurate recognition of the edge of the mesh carpet, and it is necessary to make the picture contain only the information about the edge of the mesh carpet as far as possible, and also in order to improve the accuracy of the algorithm's detection and reduce the complexity of the algorithm's computation. So a region of interest is designed to include all the information related to the edge of the mesh carpet in the picture. From the image information after Canny edge detection, a quadrilateral region can be used to include all the information about the edge of the mesh carpet. Firstly, a quadrilateral mask is set manually according to the position information of the mesh carpet edges after Canny edge detection, and the mask area set in this paper is shown in the green quadrilateral in Fig. 2(d), and then the mask is used to cover the mesh carpet edges information in the image, and the extraction of the region of interest is finally realized, and the result is shown in Fig. 2(e).

2.5. Mesh Blanket Edge Detection

2.5.1. Hough Linear Transform

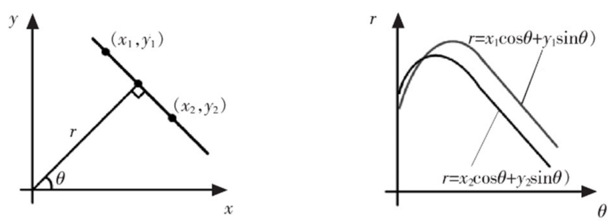
The mesh carpet edge detection is a straight line detection of the edge features extracted from the region of interest (ROI). The principle of the Hough transform is to use the one-to-one correspondence between the straight line in the Cartesian coordinate system and the point in the parameter space to convert a straight line or a curve from the image space to the parameter space, and the transformed straight line maps into a peak point in the parameter space. The problem of determining the presence or absence of a straight line in the image space of a detected Cartesian coordinate system is converted into the problem of counting the number of times a peak point appears in the parameter space [19]. On a planar image, the distance from any point on a straight line in the coordinate system to the origin:

$$r = x\cos\theta + y\sin\theta \tag{1}$$

θ - the azimuth of the line;

x, y - coordinates of any point on the line.

The image space and parameter space are shown in Fig. 5, for 1 straight line in the image coordinate space, after this transformation, any point on the line can be mapped to 1 sinusoidal curve in the parameter space, and for 2 points on 1 straight line in the image space, their corresponding curves in the parameter space intersect at the same point, so that detecting a straight line in the image space can be changed into finding the maximum number of sinusoids in the polar coordinate parameter space that passes through the point (r,θ) with the maximum number of sinusoidal curves.



(a) Image space (b) Parameter space

Figure 5. Image space and parameter space

The flow of Hough straight line detection is shown in Fig. 6, set the accumulator A′ to map every point in the image space to the parameter space, if there is a point that satisfies Eq. (1), add 1 to the value of the accumulator A′, if there is 1 straight line in a region of the image, the accumulator A′ will be extremely large in this region, and by x detecting the maximum value of the A′ in each region, the presence of the straight line segments.

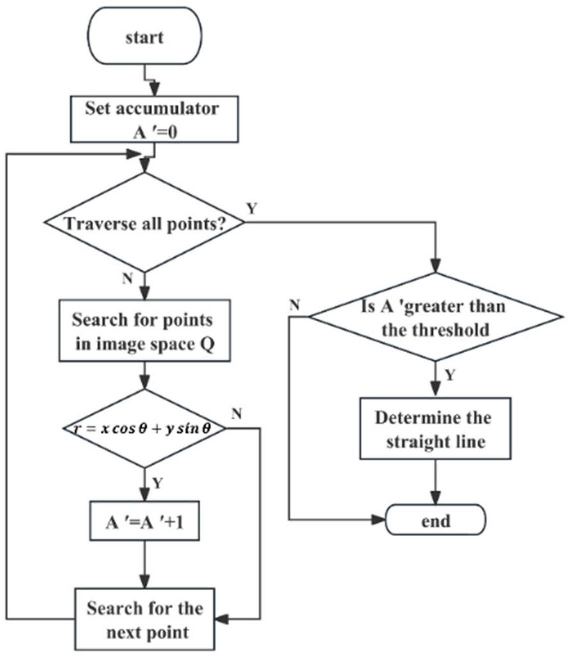


Figure 6. Hough linear detection process

2.5.2. Improved Hough linear transform

Figure 7 shows the straight lines detected by the Hough transform for the edges of the enlarged mesh carpet, and it can be seen that all edges with straight line features will be detected as straight lines, including not only the edges of the mesh carpet, but also the edges of other objects with straight line geometrical features except the edges of the mesh carpet in the captured image, and these straight lines become the noise points that affect the detection results of the mesh carpet.

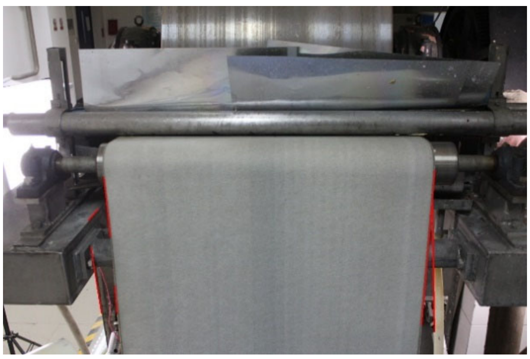


Figure 7. Hough transform detection

In order to quickly find out the edge position of the mesh carpet, reduce the interference of noise, and improve the real-time detection, the Hough transform is improved as follows, taking into account the characteristics of the mesh carpet in the pixel space.

1) Limit the range of the slope variation of the left and right edge lines. This paper takes the image captured by the camera at the location as the processing sample, and through a large number of image analysis, it is known that the clip angle of the edge of the mesh carpet is not random, and these clip angles are generally distributed in a range. Generally speaking, the angle between the left and right edge lines of the mesh carpet and the horizontal direction in the image ranges from 60°<θ<90°. Based on this characteristic of the mesh carpet edges, a linear screening method based on linear angle constraints is used. The edge lines that are not within the angle constraints are eliminated, and the mesh carpet edges that are within the angle constraints are retained. As a result, the slopes of all discrete small straight line segments of the mesh blanket edges also exist in a certain range.

$$\theta = \arctan\frac{y_2-y_1}{x_2-x_1}$$

$$\begin{cases} 60° < \theta < 90° & \text{Recognized as paper machine clothing edge line} \\ Other & Exclusion \end{cases} \quad (2)$$

Where x_1, x_2, y_1, y_2 are the endpoint coordinates of the line segments detected by Hough. By comparing the angles of the line segments, those line segments whose angles are not within the set range are eliminated.

2) Remove straight line segments that deviate significantly from the average slope value. Considering the slope constraint, all discrete line segments may not be the edge lines of the mesh blanket. Calculate the average slope of the remaining set of line segments. Based on a large number of experiments, setting the threshold for slope deviation to 0.3, the final set of left and right edge lines of the mesh blanket is:

$$L_{left} = \{L_i/L_{li} \in (k_{Llift} - 0.3, k_{Llift} + 0.3), i = 0,1,2,3 \cdots\} \quad (3)$$

$$L_{right} = \{L_j/L_{lj} \in (k_{Lright} - 0.3, k_{Lright} + 0.3), j = 0,1,2,3 \cdots\} \quad (4)$$

Where: k_{Llift} represents the average slope of the straight line segments in the collection L_{left} of the left lift paper machine clothing. k_{Lright} represents the average slope of the straight line segments in the collection L_{right} of the right lift paper machine clothing.

2.5.3. Edge line fitting

Since the edge of the mesh carpet detected by the Hough straight line may be a continuous line segment, it can be seen from Fig. 7 that the detected straight lines of the edge of the mesh carpet are 2, that is, the whole edge is not detected as 1 complete straight line, but it can be seen from Fig. 7 that the 2 straight lines are trending on a straight line. In order to merge the 2 straight lines into 1 straight line, the 2 straight lines are fitted using least squares, and the principle of least squares is shown in Fig. 8. According to a given set of data points P (xi, yi) consisting of n points, i = 0, 1, 2, ⋯, n, seeks a straight line or curve that minimizes the sum of the squares of the distances of the given n points, so as to minimize the sum of the squares of the distances of these n points to the straight line or curve. Least square are a mathematical approximation and optimization method that does not require that the curve in question passes through all n points.

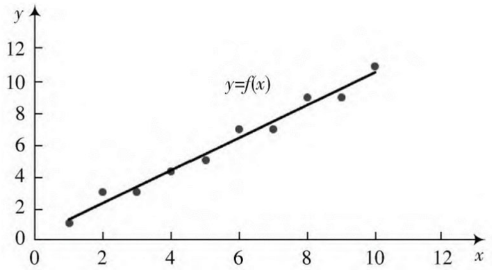
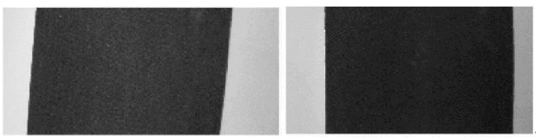


Figure 8. Principle of least squares fitting

Because the algorithm program gets 2 endpoints of each straight line, 2 straight lines that is, 4 endpoints, using least squares fitting for these 4 points, the slope of the straight line and the intercept of the straight line on the y-axis can be obtained, so that the parameters of the straight line are obtained, and the corresponding equation of the straight line can be obtained. The final edge-fitted straight line is obtained as in (Fig. 3f). It can be seen that the fitted straight line is completely close to the edge of the paper machine clothing, the effect is more satisfactory.

2.6. Determination of Misalignment

Paper machine clothing misalignment failure is usually manifested in two forms: ① edge of the net carpet deflection, as shown in (Fig 9a), ② net carpet overall misalignment, as shown in (Fig 9b).



a) Edge deflection b) Overall deflection

Figure 9. Two types of misalignment

(1) Paper machine clothing edge deflection

Edge straight line features extracted using the improved Hough algorithm, the results will retain the starting coordinates of the detected edge straight line, assuming that the starting coordinates of the straight line are (x_1,y_1), the ending coordinates are (x_2,y_2) and the angle of the net carpet running direction clip angle is θ_0, then the edge straight line corresponding to the angle of the misalignment of the running angle θ_p is:

$$\theta_p = \left|\arctan\left|\frac{y_2-y_1}{x_2-x_1}\right| - \theta_0\right| \quad (5)$$

When the paper machine clothing misalignment occurs, the angle between the detected straight line and the original web running direction is the misalignment angle θ_p, and two angle thresholds θ_1 and θ_2 are set simultaneously and $\theta_1 < \theta_2$.

A net blanket is considered not to have undergone misalignment when there is a range of slight controllable misalignments that are allowed to occur during normal operation, i.e., $\theta_p < \theta_1$;

When $\theta_1 \le \theta_p \le \theta_2$, it is considered that the mesh carpet has a slight misalignment fault; when $\theta_p > \theta_2$, it is considered that the mesh carpet has a serious misalignment fault.At this time, the system automatically in the host computer detection interface pop-up grading alarm prompts, and on-site paper machine equipment issued sound and light alarms, to remind the relevant personnel to the scene in a timely manner for maintenance and repair.

(2) Overall misalignment of paper machine clothing

When the entire mesh carpet experiences deviation, assuming that the average value of the transverse coordinates of the right edge line of the mesh carpet is x_r and the average value of the transverse coordinates of the left edge line is x_l, then the transverse coordinate of the center line of the mesh carpet, d_m=($|x_r - x_l|$)/2. Typically, when the net blanket as a whole undergoes misalignment, the difference in the transverse coordinates of the centerline relative to the transverse coordinates of the misalignment exceeds 5% of the bandwidth.

$$|d_m - d_n| > 0.05w \quad (6)$$

(where d_n represents the coordinates of the center position of the two edges in the image of the paper machine clothing, and w represents the width of the paper machine clothing).

In summary, the judgment formula of whether the conveyor belt misalignment:

$$\theta_p = \arctan\left|\frac{y_2 - y_1}{x_2 - x_1}\right| - \theta_0$$

$$|d_m - d_n| > 0.05w$$

When any one of the above 2 situations is met, it can be judged that the net carpet misalignment, and the corresponding warning or alarm processing can be carried out.

3. Experimental Results

In order to verify the accuracy and robustness of the implementation of the algorithm in this paper, we evaluate the misalignment detection method in the paper through two parts of experiments, static acquisition and dynamic acquisition, the static acquisition is the image of the web carpet in non-operational state in the laboratory, and the dynamic acquisition is the image of the web carpet monitoring video frames in operation at a real industrial site. Since the press section of a paper machine is subjected to continuous mechanical stresses and will undergo roll pressing, wear, compaction and contamination with the highest risk of misalignment [20], we used the Press felt in the press section of a paper machine as an example for experimental validation.

Build an experimental platform according to the structure shown in Figure 1, and the algorithms were compiled in the PyCharm environment, written in Python 3.8 and implemented using OpenCV 4.5.1, using a computer with the following hard environments: an Intel Core i5 11400H processor, 16 GB of RAM, an NVIDIA GeForce RTX 3050, and a 4 GB RAM graphics card.

3.1. Laboratory experiments

Press felt data for the laboratory experiments were obtained from a medium-sized inclined long web test paper machine at the College of Light Industry Science and Engineering, Shaanxi University of Science and Technology, with a design speed of 35 m/min. 5-megapixel 2/3" CMOS Gigabit Ethernet industrial face-mounted camera from Hikvision, model number MV-CA050-10GC, was used for the laboratory experiments. The resolution of the paper machine Press felt is 2445*2048, in order to meet the experimental needs, the collected images are cropped by AOI area [21], and the final resolution of the processed image is 1296*864, the experimental scene is shot with a variety of interference situations, such as the interference of other equipment in the surrounding and the linear features in the experimental environment, and so on.

After the algorithm proposed in this paper, the tilt angle of the net blanket, the distance between the left and right sides of the net blanket near the stick, and the running time of the algorithm can be obtained, as shown in Table 1. By artificially creating misalignment, the images of four groups of paper machines with different positions were detected and analyzed. Firstly, based on the position and tilt angle of the normal operation of the paper machine net blanket, the analysis and calculation of the unmisaligned pressing net images was performed. At the pixel coordinate system, the distance between the left and right sides of the net blanket near the stick was found to be 35 pixels, and the standard pressing net operation angle was 85.5 degrees. Then, the maximum misalignment angle and maximum offset were set (in this experiment, the maximum offset is 2.5% of the bandwidth, the maximum offset angle is 2.5 degrees, i.e., the threshold for the lateral offset of the net blanket is 5 pixels, and if the tilt angle exceeds 2.5 degrees, it is considered to be misaligned). This paper analyzes the angle at the pixel level, and through the correspondence relationship between pixels and actual distance [22], can effectively detect the real size.

Table 1. Results of laboratory experiments

Group	Left tilt angle/°	Right tilt angle/°	Left distance/pixel value	Right distance/pixel value	Detection time/s	result
1	-85.00	83.50	18	52	0.715	Misalignment
2	-85.07	83.65	14	56	0.814	Misalignment
3	-85.11	85.99	31	38	0.697	normal
4	-85.08	83.17	26	44	0.688	Misalignment

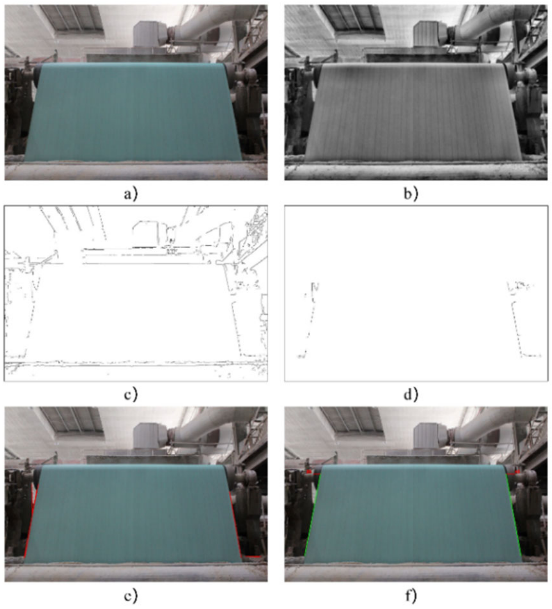
According to the experimental results, it can be seen that for a single static paper machine clothing image, the algorithm can accurately measure the angle of the two edge straight lines and the pixel distance from the edge of the roll, and can quantitatively and truly reflect the misalignment of the value netting at the pixel level through the set threshold. In addition, the average running time of the algorithm described in this paper is 0.728s in four groups of experiments, which has good real-time processing efficiency, and if it is transplanted to a digital signal processor (DSP, Digital signal processing) [22], its running time will be further shortened.

3.2. Industrial field experiment

In order to verify the effectiveness of this paper's algorithm in real industrial scenarios, we further use the data of paper machine Press felt from industrial site for experimental analysis. And to determine whether the paper machine felt at this moment has a misalignment fault. The experimental samples for the industrial field experiments are from the crescent-type tissue machine designed by Dingchang Paper Making Machinery of the Famensi Paper Industry in Shaanxi Province, which reaches a speed of 520 m/min and a width of 2600 mm.

The final field test results of net run deviation detection are shown in Figure 10. (Fig 10a) are the original image obtained from pressing net, which undergoes preprocessing to obtain Figure 10(b). Figure 10(c) shows the result of edge feature extraction using the Canny operator. Figure 10(d) shows the image containing the net edge after setting the ROI. Figure 10(e) is the result of Hough line transformation. The final display of edge pixel values and edge position is shown in Figure 10(f), where the green lines on both sides are the detected net edges, and the red numbers are the calculated pixel offsets. It can be seen that the detected net edges coincide with the actual edge positions.

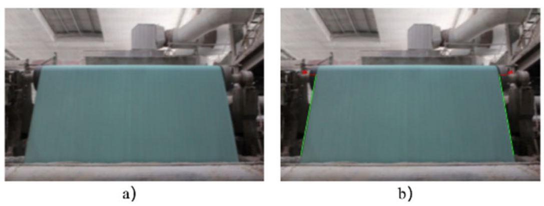
The images collected during high-speed operation in the factory may be blurry, and this algorithm can also recognize them well. As shown in Figure 11, the image with added filtering blur can still accurately extract the edge of the mesh blanket, which has good robustness.



a) Original image b) Preprocessing c) Edge feature extraction d) Region of interest (ROI) e) Mesh blanket edge detection f) misalignment diagram

Figure 10. Field test of net blanket misalignment detection

Due to the development of large-scale and wide format paper machines, the shooting field of view is large, and multiple cameras need to be installed to see the entire paper machine mesh blanket image. According to the results in Tables 1 and 2, it can be seen that when the mesh blanket deviates, both the left and right edges of the deviated mesh will undergo angle and position changes. Therefore, it is feasible to only capture images of one side of the mesh blanket to determine the deviation.



a) Blurred image b) Experimental results of blurred images

Figure 11. Experimental results of blurred images

3 Conclusion

The proposed computer vision-based improved Hough straight line detection method for paper machine clothing misalignment detection is able to accurately identify the mesh area and realize the extraction of straight line features of the mesh edge;A method for determining the net carpet misalignment of paper machine clothing is given, and the position coordinates of the extracted straight lines at the edge of the net carpet are used to comprehensively determine whether the net carpet misalignment occurs through the tilting angle of the net carpet of the paper machine clothing and the distance of the net carpet according to the two sides of the stick;Through the laboratory and factory experiments, the algorithm in this paper can effectively identify the misalignment, and provides an effective method for the correction of paper machine clothing. This technology opens up a new way for continuous online inspection in paper-making industry.

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References

[1] Wang Guodong, Z.Y., *Forming Fabrics for Modern Paper Machines.* China Pulp & Paper Industry, 2022. **43**(22): p. 12-28.

[2] Xiao, S., W. Lei, and Z. Weimin, *Empirical Discussion on Abnormal Application Analysis of Paper Machine Felt.* China Pulp & Paper 2022. **41**(002): p. 041.

[3] Adanur, S., *Paper Machine Clothing*. 1997, Technomic Publishing Company, Inc.: USA.

[4] Paulapuro, H., *Papermaking Part 1, Stock Preparation and Wet End*. 2000, Finland: Finnish Paper Engineers' Association.

[5] Holmberg, H., M. Tuomaala, and P. Ahtila, *Papermaking Part 2, Drying Book 9*. 2010, Finland: Finnish Paper Engineers' Association.

[6] LIU, Q. *Principle application and maintenance of high speed paper machine clothing corrector*. in *Proceedings of the 2019 China Pulp and Paper Automation Technology and Intelligent Manufacturing Symposium*. 2019.

[7] WEI Guo-hua, et al., *Application of contactless correction device for dry fabric in high-speed paper machines.* China Pulp & Paper Industry, 2019. **40**(8): p. 42-45.

[8] Cheng, J.C.P. and M.Z. Wang, *Automated detection of sewer pipe defects in closed-circuit television images using deep learning techniques.* Automation in Construction, 2018. **95**: p. 155-171.

[9] Hakala, T., P.J.F. Heikkilä, and T.i.E. Europe, *Press felts coated with electrospun nanofibres.* 2011. **19**(1): p. 84.

[10] Reczulski, M., *Intensification of Press Felt Dewatering for Tissue Machines.* Fibres and Textiles in Eastern Europe, 2021. **29**(1(145)): p. 92-97.

[11] Frischmon, C., J. Xu, and S. Ramaswamy. *Three dimensional visualization and characterization of paper machine fabrics and their relationship to their properties and dewatering performance*. in *TAPPICon Virtual 2021*. 2021. TAPPI Press.

[12] Reczulski, M., *Intensification of Press Felt Dewatering for Tissue Machines.* Fibres & Textiles in Eastern Europe, 2021. **29**(1): p. 92-97.

[13] Kumar, R., S. Rani, and M.A. Awadh, *Exploring the Application Sphere of the Internet of Things in Industry 4.0: A Review, Bibliometric and Content Analysis.* Sensors, 2022. **22**(11).

[14] Wu, X., et al., *Research on Belt Deviation Fault Detection Technology of Belt Conveyors Based on Machine Vision.* Machines, 2023. **11**(12): p. 5.

[15] Yang, Y., et al., *On-line conveyor belts inspection based on machine vision.* Optik, 2014. **125**(19): p. 5803-5807.

[16] Yu, B.C., et al., *Dual band infrared detection method based on mid-infrared and long infrared vision for conveyor belts longitudinal tear.* Measurement, 2018. **120**: p. 140-149.

[17] Jing, J., et al., *Recent advances on image edge detection: A comprehensive review.* Neurocomputing, 2022. **503**(2): p. 259-271.

[18] Marzougui, M., et al., *A Lane Tracking Method Based on Progressive Probabilistic Hough Transform.* IEEE Access, 2020. **8**(7): p. 84893-84905.

[19] Zheng, F., et al., *Improved Lane Line Detection Algorithm Based on Hough Transform.* Pattern Recognition and Image Analysis, 2018. **28**(2): p. 254-260.

[20] Choi, K.-H., et al., *Methods to Detect Road Features for Video-Based In-Vehicle Navigation Systems.* Journal of Intelligent Transportation Systems, 2010. **14**(1): p. 13-26.

[21] Poczekajło, P. and R. Suszyński, *Modern computing methods for digital signal processing engineering systems.* Procedia Computer Science, 2021. **192**: p. 3534-3541.

[22] Karanam, M., et al. *Object and it's dimension detection in real time*. in *E3S Web of Conferences*. 2023. EDP Sciences.