Design of automatic system of lead sheet roll for fishing gear industry

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Abstract. In this paper, we report an automatic system which combines machine design and machine vision to promote the automatic lead sheet roll production. In terms of the key problem identifying and locating millimetre-level slit in motion, the rotating module and the slit recognition module are designed based on the geometric characteristics of the lead sheet roll hub, and machine vision technology is used to extract the features of slit images. The automatic system enhances the production efficiency of lead sheet roll by nearly 8 times and lowers the production cost.

1. Introduction

With the comprehensive promotion of the strategy of "made in China 2025", China's manufacturing industry as a whole has developed rapidly in terms of independent innovation capacity, resource utilization efficiency and informatization level. The development of fishing gear industry shows that most designs of fishing gear have got rid of the traditional mode, and it is being continuously optimized in the direction of combining modern advanced technology [1][2]. However, the production of some fishing gear is still in the traditional manual production mode, such as lead sheet roll, shown in figure 1. The function is that users can cut a certain length of lead according to their needs to increase the weight of the fish pendant. The production process of lead sheet roll is to insert the calibrated lead sheet into the slit of the hub and wrap the lead tightly around the hub along the hub axis, and the manual efficiency is about 1.5/min, which is inefficient and expensive to produce. And it doesn’t meet the market demands of China as a big producer and consumer of fishing gear. So, a novel automation equipment which can improve the production efficiency and reduce the cost of lead sheet roll needs to be designed urgently. Specially, we need to address the following difficulties:

Tip1: How to quickly and accurately identify and locate the slit that is only 1mm wide and in rotational motion.

Tip2: How to design an automatic mechanical system with low noise and low energy consumption which can improve the production efficiency of lead sheet roll.

For slit detection, ultrasonic testing, visual detection and infrared testing can be selected. However, because of the small size and complex structure of the lead hub, the resolution of ultrasonic and infrared detection is not applicable. And the shape, size and position of the millimetre-level slit cannot be determined. But visual detection, due to its high efficiency, objective results, non-contact measurement and easy extraction of micro-contour feature information, has been widely used in the detection of mechanical manufacturing process [3][4][5][6] and defect detection [7][8][9][10] in recent
years. Combined the geometric features of the lead sheet roll hub with the machine vision technology, we proposed a method to solve the millimetre-level slit’s recognition and positioning in motion, and made an automatic system based on the method.

2. Mechanical System Design

The mechanical system is mainly composed of three parts: feeding device, visual identification device and lead sheet supply device. The working process of the system is as follows: Firstly, the feeding device feeds the hub into the visual identification device through the sweep plate. Secondly the rotating module in the visual identification device identifies the front and back of the hub, and then the positioning hole on the hub rotates to the same direction as the fixed axis to complete the clamping of the hub. Furthermore, in the slit recognition module, CCD obtains slit information and the system conducts coarse and precise positioning. After the process, the lead sheet is fed into the system to finish the winding. The flow chart of the system is shown in figure 4.

2.1. Feeding device design

Feeding device needs to be transported the hub which is used for visual recognition and the process should avoid bumping and scratching the hub. Considering this, the traditional feeding device based on mechanical vibration principle is not applicable. We put forward a novel feeding device, the design scheme is as follows: there is a circular hopper with an open top and the inside of the hopper is a guide plate that spirals upward along the bottom surface of the hopper. The guide plate forms the conveying
channel of the hub. The width of the guide plate is slightly small than the diameter of the disk at both ends of the hub so that there is only the hub which is stand can pass while others which fall or lean on other hubs are screened out.

It’s worth mentioning that there is a problem that hubs will overlap each other at the end of the guide plate, that will cause a blockage. To solve it, we set a section of arc guide plate with gradual thickness above the guide plate end as shown in figure2-a. Through this way, once the hub overlaps with each other, the rear hub cannot pass because its height is higher than the arc guide plate, and the front hub can move forward under the action of the sweep plate whose design includes a motor under the hopper which drives the horizontal plate in the center of the hopper to rotate. Finally, a rotary disk with a notch diameter slightly larger than the diameter of the hub axis is set at the outlet to adjust the relative position of the hubs again, so the hub can be transported in an orderly manner.

2.2. Visual identification device design

Visual identification device includes a rotating module and a slit recognition module. The rotating module consists of a rotating motor, a CCD and a cylinder, as shown in figure2-b. When the hub is in the rotating module, the cylinder pushes the hub to the CCD recognition area at a certain time interval. After the positive and negative side features of the hub are recognized, the positive side rotates counterclockwise while the negative side rotates clockwise. The purpose is to align the central hole on the positive side of the hub with the fixed axis in the slit recognition module to clamp the hub.

The slit recognition module is composed of a rotating motor, a cylinder, a CCD, two notched disks, a motor that drives the disk and a sleeve, as shown in figure2-c. By adjusting the position of the hub through the rotating module, the hub will fall into the gap between the disks under the effect of gravity. At this time, both ends of the hub will get stuck on the disks, restricting the lateral freedom of the hub. After that, the lateral movement of the cylinder drives the sleeve matched with the motor1 so that the motor1’s axis can be extended to finish clamping and locating the hub.

By the way, after many experiments, we found that if the location between the CCD and the hub is spatially fixed at 15°, a better light and shade area could be obtained on the hub, which was conducive to image pre-processing.

2.3 lead sheet supply device design

Lead sheet supply device consists of several square frames for storing the lead sheet, a synchronous belt and wheel for moving the frames, a motor for driving the synchronous wheel, a conveying wheel set at the exit, a motor for driving the conveying wheel, and a guide part matched with the entrance of the slit recognition module, as shown in figure2-e. First of all, the synchronous belt wheels on both sides of the lead sheet supply device are driven by motor1 to move the square frames to the outlet and align with the groove set in the middle of the device, the lead sheet can fall into the groove. Moreover, the motor6 drives the conveying wheel to rotate, the lead sheet moves forward under the force of friction and enters the entrance of the slit recognition module through the guide part. Specially, there is an entrance’s design that import is wide and export is narrow and the export is aimed at the slit, as shown in figure2-f.

In order to ensure that the entrance will not shift easily caused by mechanical vibration, a spring press block is set above it to limit its degree of freedom up and down. In a word, the design of the entrance is to enable the lead sheet to enter the slit recognition module smoothly and insert the slit accurately.

3. Image Detection

3.1 Image pre-processing

In the process of image acquisition, there are a lot of noises in the collected images due to the objective factors such as light interference and mechanical vibration. Therefore, the image should be pre-processed before slit recognition. The image pre-processing techniques we adopted include: gray-
conversion, filtering and edge extraction, the process of image acquisition is shown in figure 3. Some of the important points are as follows: 1. average filtering is used and the kernel is 4×4. 2. canny edge extraction is employed and the pixel thresholds are set to 100 and 80.

Figure 3. Image pre-processing. (a) Filtering processing. (b) Gray transformation. (c) Canny edge extraction. (d) Target baseline identification.

3.2 Slit recognition and location
In the program design, we adopt the combination of coarse location and precise location to detect the slit, in order to ensure the accurate location of the slit. Firstly, after adjusting the position of the hub and finishing positioning and clamping, the hub rotates at a certain speed under the drive of the motor. At the same time, CCD obtains the hub’s image of each frame and the slit contour information further. After that there is a coordinate value of the midpoint of the contour, if the value is consistent with the pre-set coordinate value, the slit coarse location is completed, the motor will slow down.

However, because of the pixel level error, further optimization is required. After the coarse location is completed, the motor is adjusted by PID repeatedly, and the positioning angle value θ is output according to the mathematical model in the hub rotation process. The mathematical model is shown in figure 5. The precise positioning of the hub is completed until the difference between value θ and the true value obtained through many experiments is within the allowable error range. At this point, the motor stops. The formula for Value-θ is as follows:

$$\theta = \arcsin \frac{KV}{r \cos \alpha}$$  \hspace{1cm} (1)

Where K is the empirical parameter, and V is the difference between the central line of the slit projected into the CCD plane and the reference line in the CCD plane, r is the radius of the hub, and α is the angle value from the geometric relationship, which is 22.95°. The true value is 46.5°.

Figure 4. System flow chart.
4. Experimental Process and Result Analysis

4.1 System efficiency estimation

The 57BYG250B step motor is selected as the system motor, the basic parameters and control parameters are shown in Table 1 and 2. According to the production process of lead sheet roll and the above parameters, the time of single lead sheet roll produced by system is as follows:

$$T_i = \frac{SR}{f} \quad i = 1, 2, 3, 4$$  \(\text{(2)}\)

Where \(T\) is the time required for each module to complete the action, \(S\) is the subdivision of step motor, \(f\) is pulse frequency. \(R\) is the turning laps of each module’s motor and the calculation is based on the following:

Tip1: Based on the design of feeding device, the motor needs to rotate 3 times to transport the hub from the bottom to the exit.

Tip2: The disk at the outlet of the feeding device adopts the design of five notches equidistant distribution, therefore moving a single hub requires only 0.2 turn.

Tip3: The design is same as the tip2

Tip4: Depends on the length(\(L=27cm\)) of lead sheet roll and hub diameter(\(D=0.8cm\)), the number of turns needed to complete the wrapping is \(R = \frac{L}{\pi D}\).

Tip5: Depends on the length(\(L = 27cm\)) of lead sheet roll and conveying wheel diameter(\(D=5cm\)), the number of turns needed to complete the wrapping is \(R = \frac{L}{\pi D}\).

To sum up, the time of completing a lead sheet roll is estimated as: \(T = \sum_{i=1}^{4} T_i = 5.02s\). The efficiency is about 12 per minute. It’s 8 times higher than the 1.5 per minute manual.

**Table 1. Motor parameters.**

| Motor Type       | Output Torque(Nm) | Electricity(A) | Actuator      | Subdivision |
|------------------|-------------------|----------------|---------------|-------------|
| 57BYG250B        | 1.2               | 3              | TB6600        | 6400        |

**Table 2. Motor control parameters of main mechanism.**

| Module Motor       | Subdivision(S) | Pulse frequency (p/s) | Turning Laps (r/min) | Time(s) |
|--------------------|----------------|-----------------------|----------------------|---------|
| Feeding Device     | 1000           | 1875.                 | 3.00                 | 1.65    |
| Rotary Disk        | 1600           | 500.                  | 0.20                 | 0.64    |
| Disk               | 3200           | 3472.                 | 0.20                 | 0.18    |
| Slit Recognition   | 6400           | 35000.                | 11.00                | 2.00    |
| Supply Device      | 1600           | 5787.                 | 2.00                 | 0.55    |
4.2 Experimentation

The experimentation of the system is shown in figure 6. After making sure the raw material is sufficient to start the system, the system is initialized firstly. Then, starting each subsystem according to the working flow chart of the system as shown in figure 4. It’s worth noting that users can observe the working process in real time at the interface of detection system, such as the process of front and back recognition and slit recognition, it is shown in figure 6-a and figure 6-b. In addition, user can know the status of each subsystem and adjust relevant parameters, such as motor parameters and CCD frame rate and so on, according to the real-time monitoring image, and the number of finished lead sheet rolls can be obtained from the top right corner in real time, which can be used to calculate the efficiency of the equipment. Finally, the prototype and finished product are shown in figure 6-c and figure 6-d.

5. Conclusion

In order to solve the problem of lead sheet roll’ production, we report an automatic system and design a novel feeding device which can avoid hub damage, because the damaged hubs can make visual recognition difficult. For millimetre-level slit’s location and identification, we mechanically design the rotating module and slit recognition module to complete the hub positioning and clamping, and the combination of coarse location and precise location is designed in the program, then based on the mathematical model of rotating hub, the positioning angle is output, so that the motor can repeatedly change its position by adjusting the PID to realize the accurate positioning of the slit; indeed it displays quite a remarkable performance considering its low-cost, easy control, and high efficiency. Since the equipment can increase the efficiency of production of lead sheet significantly, it has shed light on the application of fishing gear production automation.

Figure 6. Prototype experiment process. (a) Slit detection process. (b) Canny edge extraction. (c)Prototype. (d)Finished product.

In the process of design and production, we also found some problems. For example, in mechanical design, because of the influence of manufacturing accuracy and installation accuracy, some unnecessary jitters were increased during the working process, which brought certain errors to the visual recognition unit. As for the system itself, due to the delay of information transmission and processing, the designed mathematical model and PID parameters may not be the ideal optimal parameters, so we believe that the efficiency of the system for the fast and high-precision positioning of the slit can be further improved. Our next step is to consider adding Deep-Reinforcement-Learning into the program design, and adopt PPO algorithm to compensate the speed and position of motor output, so that the slot can be positioned more quickly and accurately. We estimate that the positioning time is optimized by about 30%.
6. Acknowledgments
We’d like to thank the Robot Team of Southwest University of Science and Technology for providing the experimental equipment and site.

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