Flat spiral spring dimension inspection based on machine vision

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Abstract. Dimension inspection plays a vital role in spring quality control. Human inspection is a traditional way to classify the good pieces and not good pieces, which is instable and time consuming. In this paper, a machine vision based inspection system for flat spiral spring dimension inspection is proposed, which can inspect various sizes of flat spiral springs. A robust algorithm is developed to measure the flat spiral spring dimension. Four sets of testing samples are collected to evaluate and compare precision and efficiency between proposed vision system and human inspector. Experimental results show that precision of the proposed machine vision based system is 100\%, the time consuming is 0.5 s to 0.7 s for one piece.

1. Introduction

Springs are considered as the important and widely applied parts in the industry of machinery \cite{1}. They have been widely used in engines, railway, hydraulic components, cars etc. The quality of springs can directly influence the performance of many machines, such as engine values, isolators, impact damper, and may even cause serious disasters \cite{2}.

Flat spiral spring is one of the typical springs, which is widely used in crane motor stators. As shown in figure 1, the specification of flat spiral spring is determined by $d_{hel}$, $l_{spr}$, $\theta$, where $d_{hel}$ is the diameter of the spring helical line, $l_{spr}$ is the length of the spring, $\theta$ is the key angle. The fixed position is in the center of the spring helical line, and the force bearing point is in the hook outside of the spring helical line. The useful force is given by $\theta$, which will be strictly controlled. In fact, the only dimension need to be inspected is the key angle. In the spring manufactory, this key angle is inspected by human inspectors with a special tool, as shown in figure 2. The accuracy based on human inspector is only about 1 degree, and the efficiency is about 30-40 pieces per minute.

However, with the development of spring manufacturing technique, the production rate is increased greatly, which results a low price per spring. For more profit, the output of spring is huge. Meanwhile, more and more industry productions are assembled automatically in the downstream customers, therefore the springs are calling for complete inspection to ensure all the springs qualified. But, with the method of human inspection, it is impossible to get rid of all the disqualified springs.
Machine vision has been developed many years. Many researches have been done in this field [3], especially in the basic industry components, such as bearing [4], gear [5], screw [6] etc. However, the inspection of spring based on machine vision is rarely reported. In this paper, we propose a machine vision based inspection system for the flat spiral spring key angle inspection. A high efficiency lighting and image acquisition system is designed, as shown in figure 3. Then, a serious of image processing methods are proposed to calculate the key angle of flat spiral spring. Especially, a robust inspection algorithm is proposed, regardless of any position of the spring, as shown in figure 4.
2. Lighting and image acquisition system

As to meet the requirement of on-line production, the time consuming for the machine vision system should be less than 1 s, including the cost of machine movement, image acquisition, signal transmission and key angle inspection. Considering the property of flat spiral spring, we design a high efficiency lighting and image acquisition system for the key angle inspection. This system, as shown in figure 3, consists of an area-scan camera, a bi-telecentric lens, a ring-shaped glass pane and a red light LED illuminator. The camera is triggered by software, with resolution factor of $2452 \times 2056$. The image acquisition and algorithm implementation are completed on a personal computer with Intel® Core™ i5-4200H CPU@ 2.80 GHz 2.79 GHz.

A special spring vibration feeder will transfer the springs into the ring-shaped glass pane, shown in figure 3, and the ring-shaped glass pane keeps rotating around the center. The image will be acquired when the spring moves into the center of the lens, which will be used to calculate the key angle with our proposed inspection algorithm.

3. Inspection algorithms

In order to get the value of key angle, shown in figure 1, we need to get fixed position and force bearing point first, and then get the inner line equation, at this moment we will get the value of key angle. The algorithm flow chart is shown in figure 5.

![Algorithm flow chart](image)

3.1. Image acquisition

The camera is triggered by software sorted in PC, and then the acquired image will be transferred to PC by Ethernet. The max transfer rate is 15fps with full resolution. The acquired raw image is shown in figure 6(a).
3.2. Binarization
Threshold methods are used to segment springs from background. As shown in Figure 6(a), the difference between foreground and background is obvious, so we use Otsu thresholding method [7] to binarize the acquired image. The color of foreground and background are reversed for the convenience of the following progress, as shown in Figure 6(b).

3.3. Center of helical line
In order to get the center of spring helical line, we are first to get the gravity center of foreground in the binarized image as follows:

\[
\text{Row}_{\text{gra}} = \frac{\sum \sum B(i, j) * j}{\sum \sum B(i, j)}, i = 1, 2, \ldots, 2452, j = 1, 2, \ldots, 2056
\]

(1)

\[
\text{Col}_{\text{gra}} = \frac{\sum \sum B(i, j) * i}{\sum \sum B(i, j)}, i = 1, 2, \ldots, 2452, j = 1, 2, \ldots, 2056
\]

(2)

where Row_{\text{gra}} and Col_{\text{gra}} are the row position of the gravity center and col position of the gravity center, respectively; B(i, j) is the gray value of the binarized image at the location (i, j).

And then, the center of helical line is acquired by following equations:

\[
\text{Row}_{\text{hel}} = \frac{\sum \sum B(i, j) * j}{\sum \sum B(i, j)}, (i^2 + j^2 \leq r^2)
\]

(3)
\[ Col_{hel} = \sum \sum B(i, j) \cdot i \leq (i^2 + j^2) \leq r^2 \]  

(4)

Where Row_{hel} and Col_{hel} are the row position of the center of helical line and col position of the center of helical line, respectively; \( r \) is the radius of a virtual circle, which is just a little bigger than the helical line with (Col_{hel}, Row_{hel}) as center of the virtual circle, as shown in figure 6(c).

3.4. Fit inner line

Here, a 100×100 ROI with (Col_{hel}, Row_{hel}) as center is gotten, as shown in figure 6(d), then among all of the profile points of the spring in this ROI, these layed on the inner line will be gotten. The inner line equation is acquired by these profile points with least square method [8]. The inner line equation is as follow:

\[ y_{inn} = k_{inn} x + b_{inn} \]  

(5)

Where \( k_{inn} \) is the slope of inner line; \( b_{inn} \) is the intercept of inner line.

3.5. Fixed position

Drawing a straight line across (Col_{hel}, Row_{hel}), center of the helical line, perpendicular to the inner line, the intersection point is considered as the fixed position, (Col_{fix}, Row_{fix}), as shown in figure 6 (e).

3.6. Longest point

The longest point is acquired by following equations:

\[ B(i, j) \cdot ((Row_{log} - Row_{hel})^2 + (Col_{log} - Col_{hel})^2) = \max \{ B(i, j) \cdot ((j - Row_{hel})^2 + (i - Col_{hel})^2) \}, \]

\[ i = 1, 2, \ldots, 2452; \quad j = 1, 2, \ldots, 2056; \quad Row_{log} \in j; \quad Col_{log} \in i \]  

(6)

Where (Col_{log}, Row_{log}) is the longest point location, as shown in figure 6 (e).

3.7. Force bearing point

Drawing a line between the longest point and center of the helical line, known as linelongest, there will be an intersection point (Col_{r2}, Row_{r2}), as shown in figure 6 (e).

The force bearing point is acquired by following equations:

\[ B(i, j) \cdot dist((Col_{for}, Row_{for}), line_{longest}) \geq \max \{ B(i, j) \cdot dist((j, i), line_{longest}) \}, \]

\[ (i - Col_{hel})^2 + (j - Row_{hel})^2 \geq (Col_{r2} - Col_{hel})^2 + (Row_{r2} - Row_{hel})^2; \]  

\[ Row_{for} \in j; \quad Col_{for} \in i; \]  

(7)

Where (Col_{for}, Row_{for}) is the force bearing point location, as shown in figure 6 (e); dist((Col_{for}, Row_{for}), line_{longest}) and dist((i, j), line_{longest}) are the distance between point (Col_{for}, Row_{for}) and line_{longest} and distance between point (j, i) and line_{longest}, respectively.

3.8. Key angle

The line across fixed point and force bearing point is acquired by following equation:

\[ y_{ff} = k_{ff} x + b_{ff}, \]

\[ k_{ff} = \frac{Row_{fix} - Row_{for}}{Col_{fix} - Col_{for}}; \quad b_{ff} = \frac{Row_{for} Col_{fix} - Row_{fix} Col_{for}}{Col_{fix} - Col_{for}} \]  

(8)

In fact, the key angle is an acute angle, so the value of the key angle is acquired by following equation:

\[ \theta = \arctan \left( \frac{k_{ff} - k_{inn}}{1 + k_{ff} k_{inn}} \right) \]  

(9)
Where $\theta$ is the value of key angle.

4. Experimental results
The inspection algorithm is programmed with the language of C++. To evaluate the performances of the proposed inspection system, four sets of different size springs are collected, whose features are as shown in figure 7, and the specifications are shown in table 1. Testing set $a$ includes 567 good and 23 not good testing samples; set $b$ includes 426 good and 12 not good testing samples; set $c$ includes 352 good and 1 not good samples; set $d$ include 613 good and 11 not good testing samples. All of the testing samples are carefully collected from a leading flat spiral spring manufacturer in China. And all the testing samples are classified into good and not good samples by a skilled human inspector. After the tests, all the good and not good samples are inspected by several skilled human inspectors many times to ensure the inspection results is correct.

| Set   | $d_{hel}$(mm) | $l_{spr}$(mm) | $\theta$(degree) |
|-------|---------------|---------------|------------------|
| $a$   | 16            | 19            | 20               |
| $b$   | 14            | 17.6          | 70               |
| $c$   | 9.7           | 15.5          | 80               |
| $d$   | 9.6           | 12            | 35               |

We compare the proposed machine vision based inspection system with skilled human inspectors. The results of machine vision system are shown in table 2. The machine vision system classified all the good and not good samples among the 4 testing samples, the precisions of the 4 testing sets are all 100%. The time consuming for inspecting one single spring is between 0.5 s to 0.7 s, which depends on the shapes of springs, for the larger the spring is, the more time it needs to calculate the key angle. The results of human inspection are shown in table 3. The precisions of set $b$ and $d$ are 100% inspected by skilled human inspector. However, the precisions of set $a$ and $c$ are 99.83% and 99.72% inspected by skilled human inspector, respectively. It indicates that the skilled human inspectors are not completely reliable, especially when they are working for a long time. The time consuming of skilled human inspector for inspecting one single spring is between 1.3 s to 2 s. When the spring volume is small, it is hard to hold. Meanwhile, it is hard to distinguish the key angle, when the spring volume is small. Therefore, the smaller spring costs more inspection time.

![Figure 7. Different size of flat spiral springs.](image)

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Table 2. Results of machine vision based inspection.

| Set | Good | Not Good | Sample number | Time consuming (s) | precision |
|-----|------|----------|---------------|-------------------|-----------|
| a   | 567  | 23       | 580           | 391               | 100%      |
| b   | 426  | 12       | 438           | 272               | 100%      |
| c   | 352  | 1        | 353           | 201               | 100%      |
| d   | 613  | 11       | 624           | 351               | 100%      |

Table 3. Results of skilled human inspection.

| Set | Good | Not Good | Sample number | Time consuming (s) | precision |
|-----|------|----------|---------------|-------------------|-----------|
| a   | 566  | 24       | 580           | 773               | 99.83%    |
| b   | 426  | 12       | 438           | 615               | 100%      |
| c   | 353  | 0        | 353           | 557               | 99.72%    |
| d   | 613  | 11       | 624           | 1208              | 100%      |

5. Conclusions

This study develops a machine vision system for inspecting flat spiral spring dimension. In this system a robust algorithm is proposed for inspecting flat spiral spring key angle. Experimental results show that both the inspection precision and inspection efficiency of machine vision based system are superior to that of human inspection.

In fact the machine vision system has been applied to the automatic production line in a flat spiral spring manufactory, replacing the human inspector. Thanks for the support of Research and application of generic technology of national quality foundation (2016YFF0202100).

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