Problem analysis of image processing in two-axis autocollimator

A Nogin, I Konyakhin

Chair of Optical-Electronic Devices and Systems, ITMO University, 49 Kronverksky Pr. St. Petersburg, 197101, Russia

E-mail: rujusted@gmail.com

Abstract. The article deals with image processing algorithms in the analysis plane of an angle measuring two-axis autocollimator, which uses a reflector in the form of a quadrangular pyramid. This algorithm uses Hough transform and the method of weighted summation. The proposed algorithm can reduce the area of nonoperability and open up new possibilities for this class of devices.

1. Collimation scheme as the angle measuring system

Angle measurement is widely used in enterprises of mechanical engineering and optical industry to measure the deviations from the straightness guide, deviation from planarity faceplate and surface plate, configuration tools and machines, the analysis of vibration and temperature changes, as well as measuring of angles of optical wedges. Optoelectronic systems allow non-contact, quickly and high-precision solution of the given tasks. There are two schemes of constructing angle measuring systems - collimation and autocollimation.

To use the first scheme, the collimation, it is necessary to place the collimator on base object, and the registration system of spatial position the beam emitted from the collimator on the controlled object.

In the second scheme, autocollimation, the controlled object is a passive reflector, and on the base object is located autocollimator. The autocollimator is both a collimator with an eyepiece attached to it for lighting grid and registering its reflection from the reflector on the object. This system is the most preferred because it does not require a power supply at the control point. It simplifies and reduce the cost of installation the entire system.

![Autocollimation scheme](image)

**Figure 1.** Autocollimation scheme.
2. Analysis of the image plane

Autocollimator consists of emitting optic-electronics channel and a receiver with a microprocessor. Emitting channel generates an optical beam that falls on the reflector. Optical electronic receiver meant for registration of optical radiation from the control element and measuring its parameters, which determine rotation angles of the object. When the reflector element rotates on angles $\Theta_1$ and $\Theta_2$, the reflected beam has deviated from the original direction. As a result the image shifts on the matrix photo-receiver of the autocollimator. The microprocessor calculates video frames from the matrix photo-receiver and determines the shift of the image. Angular coordinates $\Theta_1$ and $\Theta_2$, of the reflector, are determined as a result of this processing.

In the process of selecting a base object, some of the key parameters are the size of the autocollimator and the distance to the control object. One way to solve this problem is to use a special reflective element instead of an ordinary flat mirror. The reflector in the form of quadrangular pyramids can be used as the special reflective element. This control element allows to increase the working distance angle measuring system and reduce the diameter of the objective to receive the beam.

A characteristic feature is that the opposed faces comprise a single working surface, and for this reason, the parallel beam incident on the refractive face at the reflection, is divided into two beams, each of which is formed a corresponding equivalent prism BR-180. By rotating the pyramid relative to one axis, each reflected beam in the plane of the aperture the objective will move only along this axis while the other coordinates of its position will not change.

The initial stage of the calculation of the angles $\Theta_1$ and $\Theta_2$ is to determine the center of the marks registered by the system. Using the control elements different from flat mirror creates a situation when in the image plane will mark overlap with each other. In this connection, the question arises what should be the distance between the centers of the marks in order to save serviceability and accuracy of the measurement system.

![Figure 2](image)

**Figure 2.** The images on the photodetector matrix: 1, 2 – before the rotation of the reflector, 1' and 2' - after the rotation.

3. Algorithm for measurement of coordinates in the overlapping marks

To study the possible solution of this problem has been developed and implemented a model for the processing of overlapping arrays of irradiance in technology MatLab. This model has allowed to investigate the influence marks overlapping on the measuring accuracy of the coordinates.
In general, the idea of the algorithm consists in preliminary finding the most probable centers of marks and their subsequent clarification by the weighted summation method. To minimize the effect of marks overlapping, it is decided to use one of the key features of the control element, namely the fact that each mark can move only along one axis.

Table 1. The model parameters.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| The size of the matrix     | 128*128 pixels         |
| The radius of the mark     | 12 pixels              |
| Signal-To-Noise Ratio      | 17                     |
| The law of distribution of noise | Normal                |

3.1. The preparatory stage of the algorithm

The first stage is to prepare the image to be processed. At this stage, the image processing by the circular averaging filter with a window size equal to the diameter of a circle plus one pixel. Then apply a threshold filtering that allows to cut noise. After filtering threshold is necessary to apply a Gaussian filter as the image becomes unusable for processing by a weighted summation method.

Hough transform is used to find the most probable centres of marks. This method is based on an assessment of the normal orientation of the voting contour points.

The first step of the process is finding edge pixels surrounding the perimeter of the object. For this purpose, used evaluation of the amplitude and direction of the gradient vector. Voting contour point is considered in terms of high modulus gradient.

The second step for each edge pixel is used position estimate and the orientation of the circuit in order to evaluate the center of a circular object of radius $R$ by the movement over a distance $R$ from the edge of the pixel in the direction normal to the contour (i.e. in the direction of the gradient vector).

If this operation is repeated for each edge pixel, a variety of positions alleged points of the center, which can be averaged to determine the exact location of the center.

It should be noted that the coordinates of the center of the marks obtained by Hough transform has a strong dependence on the degree of marks overlapping and signal-to-noise ratio.

![Figure 3. Accumulation array (inverted colour).](image1)

![Figure 4. 3D view of the accumulation array (inverted colour).](image2)
3.2. The main stage of the algorithm
On the main stage, the definition of so-called "zones of interest" i.e. in what quarters mark do not overlap. The definition of "zones of interest" based on the approximate coordinates of the center. After determining the zone of interest, there are an allocation disjoint parts of each mark into its own array. This array is restored and then use the weighted summation method for determining the centers of marks. Since the mark is moved along only one of its coordinate axes, one already known and the problem reduces to the determination of only the second coordinate.

The result of the program is to display the result in the image plane with an indication of the measured centers of coordinates and the distance between the centers.

Figure 5. The result of the program. (Inverted colour).

4. Capabilities of the algorithm and the results of research its usage
4.1. Estimation of measurement error
During research of the algorithm using the model was evaluated errors. An analysis of the data determined that positioning accuracy is dependent only on the distance between the centers of the marks and the degree of the image overlapping. Parameters such as the size of the matrix, the size of marks and other factors on the accuracy of coordinate measurement is not affected. This algorithm is unusable when the distance between the centers of marks less than half the radius of the marks.
To estimate the errors were constructing graphs below. From this graph, it is clear that takes place to be a large error in the interval 1.1-1.6 radii in the deviation of the measured $X$ coordinate from the real.

![Graph showing measurement errors for overlapping marks.](image)

**Figure 6.** Measurement errors for overlapping marks.

The research also found that when the distance between the marks more than two radii error does not exceed half a pixel.

![Graph showing measurement errors for nonoverlapping marks.](image)

**Figure 7.** Measurement errors for nonoverlapping marks.

4.2. **Functional testing of the algorithm**

The algorithm was tested for functional three-axis autocollimator with the tetrahedral reflector. Despite the fact that the algorithm is not optimized for a given reflector were detected correct marks.
and measured their centers. The algorithm has also been able to ignore the parasitic image. When we crossing marks algorithm also retained its capacity for work and was able to detect the mark and measure their position and ignore the parasitic image. The experiment was to evaluate the accuracy of the algorithm will be held in subsequent experiments.

5. Summary
In conclusion, it is necessary to highlight the main advantages of the algorithm: a small area of malfunction, an error less than half a pixel at a distance least two radii and less than 1 pixel in the other cases. Also, worth noting is the possibility of the algorithm to work with any number of marks and high noise immunity.

The algorithm allows to use autocollimation scheme where it was previously not possible. The algorithm after improvement can use not only in the angle measuring systems but also in medicine and biology.

6. Acknowledgments
This work was financially supported by Government of Russian Federation, Grant 074-U01.

References
[1] T Turgalieva, I Konyakhin, 2013, Research of autocollimating angular deformation measurement system for large-size objects control, Proc. SPIE 8788, 878832
[2] I Konyakhin, T Kopylova, A Konyakhin, 2012 Optic-electronic autocollimation sensor for measurement of the three-axis angular deformation of industry objects, Proc. SPIE 8439, 84391N
[3] I Konyakhin, T Kopylova, A Konyakhin and A Smekhov, 2013, Optic-electronic systems for measurement the three-dimension angular deformation of axles at the millimeter wave range radiotelescope, Proc. SPIE 8759, 87593E
[4] D.H. Ballard, 1981, Generalizing the Hough transform to detect arbitrary shapes, 13(2), pp.111-112,
[5] L.A.F Fernandes, M.M. Oliveira, Real-time line detection through an improved Hough transform voting scheme, №41, pp.299-314, (2008).
[6] R. Gonzalez, R. Woods, S. Eddins, 2010, Digital Image Processing Using MATLAB