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Rapid non-contact visual measurement method for key dimensions of revolving workpieces

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Abstract. Aimed at the rapid non-contact measurement problem of a revolving workpiece's radial and axial dimensions, a fast and high-precision visual inspection method has been presented in this paper. For the workpiece with large axial size, the proposed method established the measurement transformation chain using the object-image and object-object transformations, thus realizing the rapid axial dimensional measurements. For the workpiece with large radial size, this method determined the measurement transformation model based on two-dimensional target and measurement correspondence relationship, and further achieved rapid radial dimensional measurements. The experimental results have shown that the method is effective and can be applied to in situ dimensional measurement of revolving workpieces on high quality production lines.

Keywords: Computer vision / revolving workpiece / real-time / non-contact measurement

1 Introduction

Visual measurement technology is widely used in the field of geometric measurement. For the revolving workpieces with small radial or axial size, such as saw blade, ratchet wheel and chip pin, the non-contact measurement methods mainly include image measurement method, laser triangulation method and three-dimensional reconstruction method. Image measurement method is represented by image measuring instrument, which can realize high-precision measurement for some workpieces with small size or thin thickness. However, for large or thick workpieces such as precision shafts, the measurement task is realized step by step based on the combination of image and guide rail, which shows image measurement method is not suitable for real-time applications [1–3]. Laser triangulation method is more mature in surface measurement applications and often integrated in some complex measuring equipment, but it cannot fully meet the requirements of real-time dimensional measurement because of its scanning measurement mode [4–6]. The 3D reconstruction method can obtain the 3D point cloud information. However, the grating fringe information cannot be fully obtained when measuring the reflective metal surface which can easily result in incomplete measurement data [7,8]. This paper presents against the above background a rapid non-contact visual measurement method for key dimensions of revolving workpieces and discusses the key issues of using this method to realize the in situ rapid measurement when the workpiece has large radial and axial dimensions. This method can be applied in situations where the production line has high quality requirements for workpiece inspection [9,10].

2 In situ measurement of key axial dimensions

2.1 Topological structures description of measured objects

The topological structure of the measured objects can be described as radial divergent topological structure, axial parallel arrangement topological structure and spatial expansion topological structure which combines the first two topological structures. As shown in Figure 1, the measured geometric elements include point, line and surface.

2.2 Configurations of visual sensors

According to the different features and spatial positions of the axial elements to be measured, the configuration of the visual sensors can be different. These configurations

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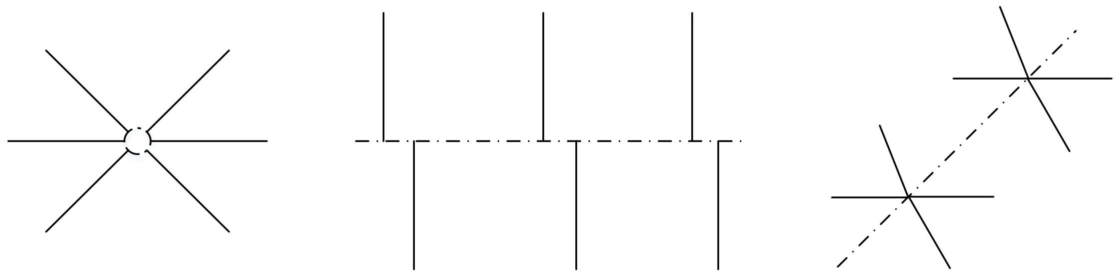


Fig. 1. Topological structures of measured objects.

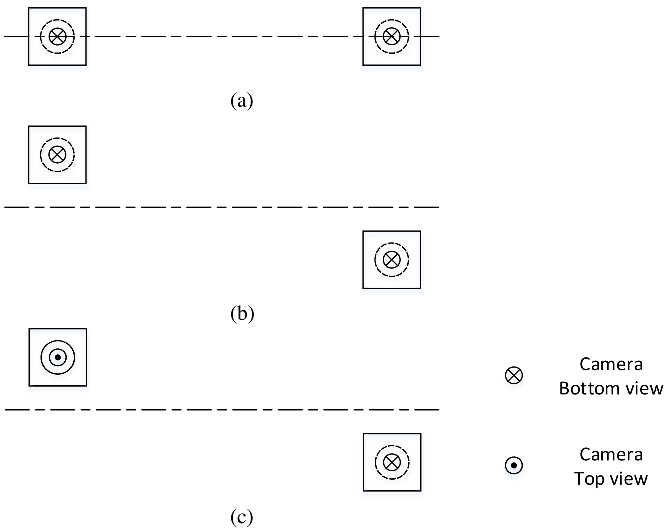


Fig. 2. Layouts of visual sensors. (a) linear. (b) diagonal. (c) mirror.

include linear layout, diagonal layout and mirror layout, as shown in Figure 2a–c, respectively. Since the measured features are distributed in the image fields of different vision sensors, it is necessary to study the in situ calibration methods of the sensors with different distributions.

2.3 In situ calibration method

For the calibration problem of visual sensors with spatially separated and non-overlapping image fields, the transformation process of the calibration method is shown in Figure 3, including the projection matrix M1 between visual sensor 1 and target 1, the projection matrix M2 between visual sensor 2 and target 2 and the transformation matrix M′ between M1 and M2. The transformation chain can be established by M1→M′→M2 transformation, as shown in equation (1), which can be applied to realize the scene pose calibration between the visual sensors. For perspective projection model, M1 and M2 can be obtained by accurate pose estimation method; for parallel projection model, M1 and M2 can be obtained by calibration calculation. Therefore, the calibration method only needs to keep the M′ transformation. When the axial dimension is small, the common transformation matrix M′ can be obtained by the conversion of two targets' marked points which are measured through flexible joint manipulator. When the axial dimension is large, the plane coordinate system of the two targets can be aligned by a total station theodolite and M′ can be obtained by using the coordinate transformation.

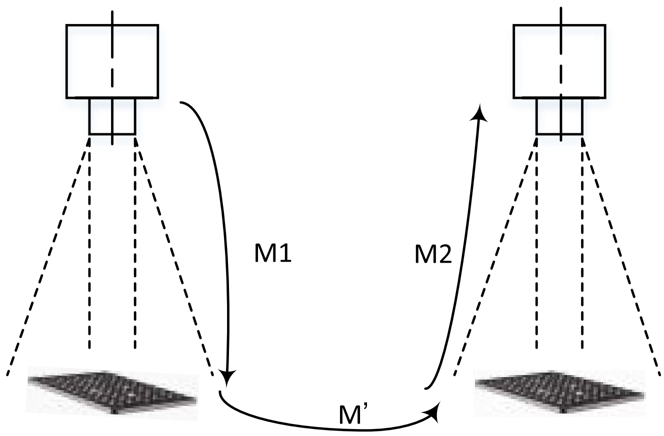


Fig. 3. Illustration of measurement transformation chain.

$$M = M_1(P_1|P_2)\cdot M'(R|T)\cdot M_2(P'_1|P'_2) \qquad (1)$$

In equation (1), P1 (P'_1) and P2 (P'_2) are the internal and external parameter matrices between the camera and the target respectively, which can be obtained by separating the internal and external parameters. R and T are the space transformation matrix and position vector respectively.

2.4 Implementation process

The typical implementation process is as follows:
- The measured workpiece arrives at the measurement station;
- The position status of the workpiece is obtained by externally triggered photoelectric sensors;
- The photoelectric sensors' signal triggers two vision sensors to take photos;
- The visual processing terminal realizes the in situ real-time measurement through the transformation chain relationship and internal parameters obtained from calibration.

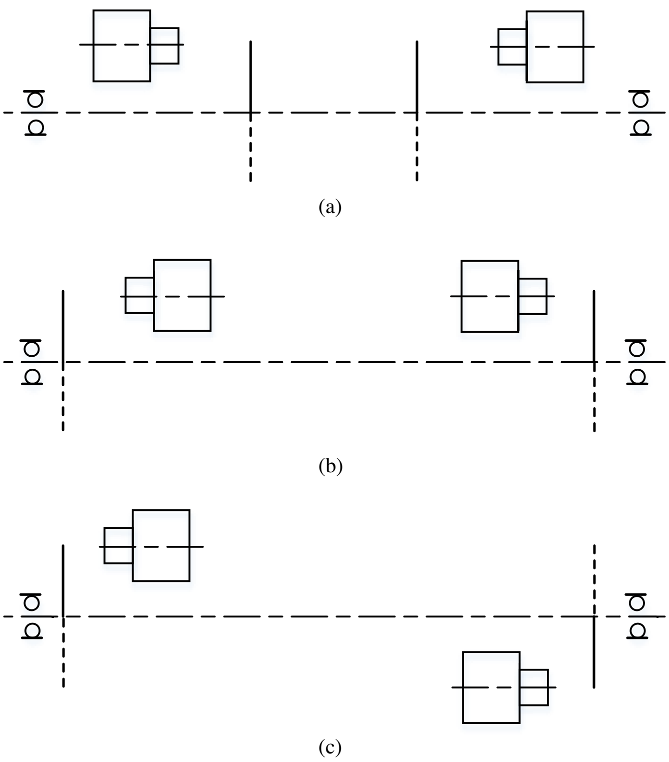


Fig. 4. Layouts of vision sensor. (a) face-to-face. (b) back-to-back. (c) parallel.

3 In situ measurement of key radial dimensions

3.1 Configuration of visual sensors

According to the different shapes and spatial positions of the radial elements to be measured, different configurations of visual sensors may be used, including monocular visual sensing and multi-view sensing. The multi-view sensing may be further divided into face-to-face layout, back-to-back layout and parallel layout, as shown in Figure 4a–c, respectively. Different from the key axial dimensional measurement, the measurement area of the visual sensor only sees part of the geometry. The other part of the geometry is the revolving center of the workpiece outside the field of view. Therefore, it is necessary to establish the transformation measurement model and design the in situ calibration method to realize the rapid measurement.

3.2 In situ calibration method

The transformation measurement model of a single visual sensor is shown in Figure 5. How to establish the transformation relationship between the target and the revolving center is the key to accomplish the measurement task. The transformation relationship is shown in equation (2). In the case of small radial sizes, the 3D target with known parameters can be designed to determine the rigid transformation relationship between the two. In the case of larger radial sizes, the separation calibration method can be used. The coordinate data of the

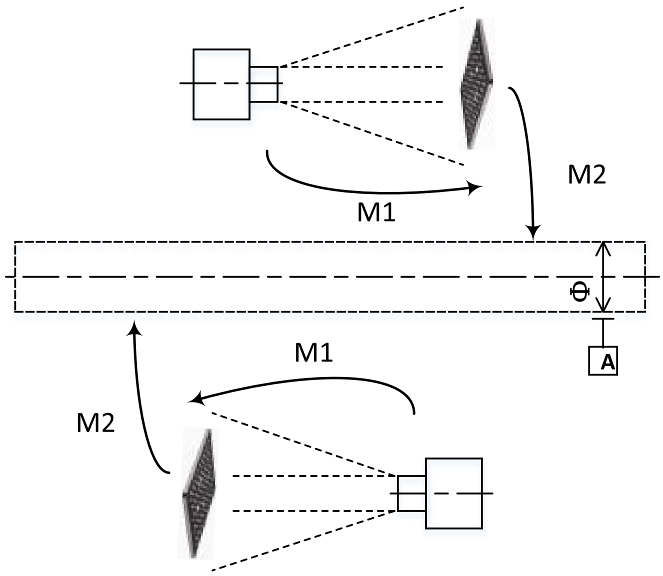


Fig. 5. Schematic diagram of measurement transformation chain.

revolving center line is fitted by the measurement of flexible joint manipulator. Then the marked hole position of the target is measured. The spatial transformation matrix between the two is obtained through coordinate transformation and pose calculation. Combined with the internal and external calibration parameters between the visual sensor and the target, the fast in situ radial measurement of the workpiece can be realized.

$$\mathrm{M} = \mathrm{M}_1(\mathrm{P}_1|\mathrm{P}_2)\cdot\mathrm{M}_2(\mathrm{R}|\mathrm{T}) \tag{2}$$

In equation (2), P1 and P2 are the internal and external parameter matrices between the camera and the target respectively. The two matrices can be obtained by internal and external separate parameter calculations. R and T are the spatial transformation matrix and position vector respectively. The point cloud data of the reference axis A is obtained by center fitting method.

3.3 Implementation process

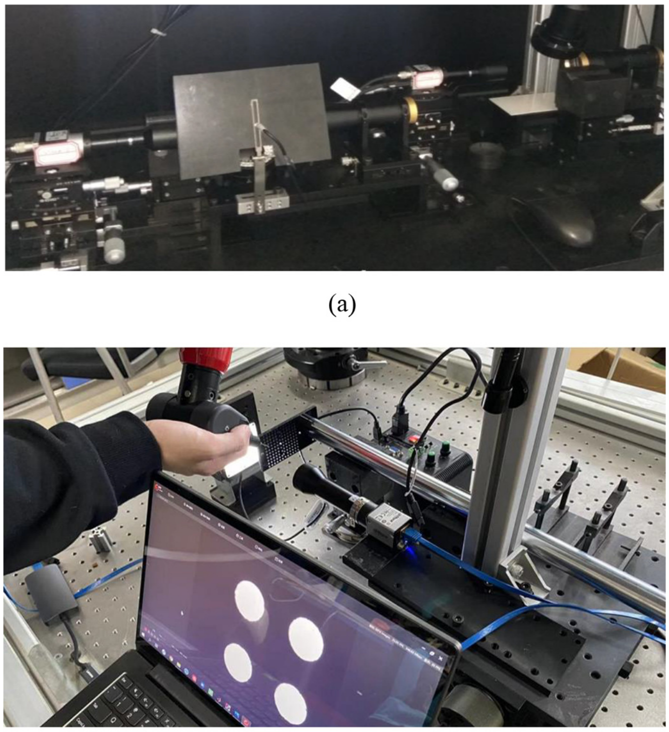
The implementation process is as follows:
- The measurement workpiece arrives at the measurement station;
- The position status of workpiece is obtained by externally triggered photoelectric sensors;
- The photoelectric sensors' signal triggers the monocular or multi-view sensors to take photos;
- The visual processing terminal realizes in situ real-time measurement through the loaded calibration model and its own calibration parameters.

4 Experimental results

In the experimental setup, the high-precision revolving fixture and fine-tuning device are first designed.

Table 1. Experimental results (mm).

Workpiece number	1	2	3	4	5	6	7	8	9	10
Image measuring instrument (truth value)	54.841	54.861	54.840	54.800	54.096	54.011	54.142	54.075	54.063	54.098
Proposed method (measurement)	54.832	54.880	54.837	54.793	54.079	54.009	54.140	54.065	54.059	54.073
Absolute error	−0.009	0.019	−0.003	−0.007	−0.017	−0.002	−0.002	−0.010	−0.004	−0.025
Relative error (%)	−0.016	0.035	−0.005	−0.013	−0.031	−0.004	−0.004	−0.018	−0.007	−0.046
Standard deviation (σ_s)	0.0131									
Mean standard deviation (σ_x)	0.0041									



(a)

(b)

Fig. 6. Experimental setup. (a) Photo of detection device. (b) Measurement accuracy verification experiment.

The parallel projection of bidirectional visual detection device is then established. Finally, the transformation accuracy verification experiment is accomplished. The experimental setup is shown in Figure 6, with the measurement data shown in Table 1. The error distribution curves are shown in Figure 7. The experimental results have verified the effectiveness of the proposed method.

As shown in Figure 7, the absolute error is distributed between 0 and 0.025 mm, indicating that the method has good consistency in the measurement results of the same element. The relative error is less than 0.046%, indicating that the measurement results of different groups have good reliability. The statistical results of standard deviation reflect that the method in this paper has a small random error and can achieve high measurement accuracy.

5 Conclusion

This paper presented a rapid non-contact visual measurement method for key dimensions of revolving workpieces. The proposed method solves the key problems of fast in situ dimensional measurement of revolving workpieces by constructing measurement transformation chain, especially for the situation where the radial and axial dimensions of the workpiece are large and beyond the scope of image field. The method has achieved high measurement accuracy in the designed experiments and has the flexibility in increasing the number of visual sensor nodes. If the nonlinear optimization method of spatial attitude calculation is utilized, the accuracy can be further improved. This method will find applications for the quality control of key dimensions in workpiece inspection.

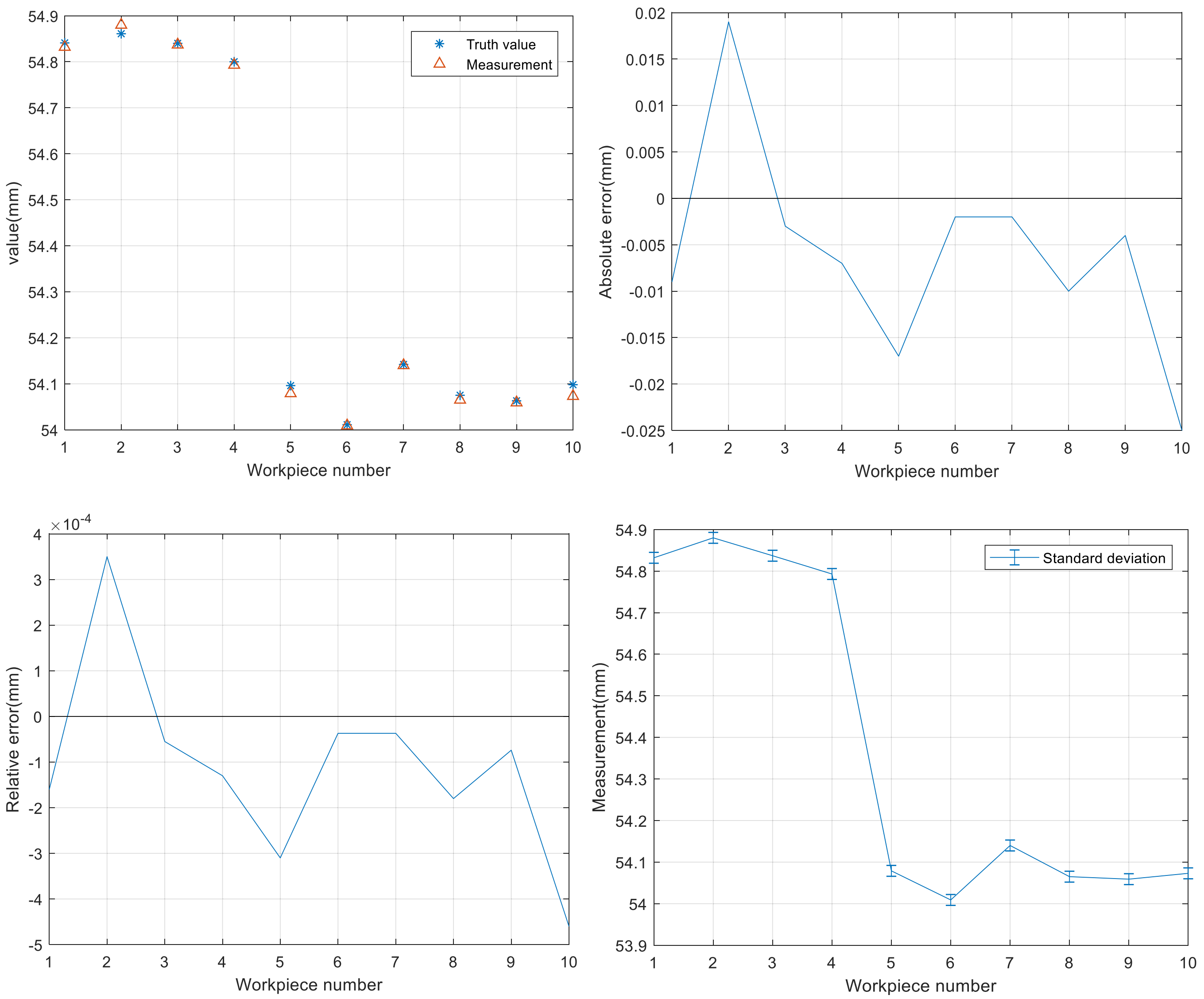


Fig. 7. Error distribution curve.

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