DISCUSSING ACCURACY IN AN AUTOMATIC MEASUREMENT SYSTEM USING COMPUTER VISION TECHNIQUES

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Abstract. *A Computer Vision system extracts and analyzes image features in order to recognize and/or measure it. A Computer Vision system for inspection has received considerable industry attention, in the last years. This paper uses some Computer Vision techniques to measure parts and discusses common difficulties of automated inspection. The parts conformity analysis using a non-contact measurement system has been adopted specially to small objects, where accurate instruments are not so simple to be used. In these cases Coordinate Measuring Machine (CMM) can be used. However, in many times it is impossible to move the object to the CMM. In this case an image automated inspection should be a good alternative. The proposed system consists in a CCD camera positioned in the upper viewer of the object. Some considerations must be pointed out: (1) the object should be thin, to reduce the height influence in the measurement; (2) a standard gage must be used to convert pixels units to millimeters units. We present the algorithms developed to make dimensional measurements in industrial parts. A rectangle object with three holes is analyzed. The obtained results are compared with convencional instruments measurements. We highlight the difficults concerned to image automated inspection, discussing accuracy and the relationships among images and measurements.*

Keywords: *Computer vision, Metrology by image, Automated measurement, Automated inspection, Accuracy.*

1. Introduction

Industry needs automated inspection because in the manufacturing processes there are uncertainties, tolerances, defects, relative position and orientation error, which can be solved by vision sensing. The advent of digital images makes it very common to use Computer Vision systems in several fields of the industry, principally in measurement process. Besides, Computer Vision offers consistency, accuracy and repeatability in non-contact measurements. It contrasts to the subjectivity, fatigue, slowness and cost associated with human inspection. The main problem consists in how to match technology to a specific application in an optimal and cost-effective manner. There isn't a unique Computer Vision system to solve all problems; the systems are particular to each application. All visual inspection systems use a priori knowledge to perform inspection, and in this case it is essential to reduce the expertise required in the configuration of am automated inspection system. This is one of the industry difficulties, to choose the satisfactory system. It involves cost to develop vision software with robustness to solve very specific application.

A Computer Vision system involves Image Processing theory. Considering a measurement system by image, we can observe two different approaches; the first consists in the recognition application and the second in the automated inspection (Fig. 1). Recognition systems involve image characteristics extraction and some intelligence to distinguish the object or patterns. In this case it is not fundamental to obtain exact values, in the other hand, inspection systems needs accuracy. We can call an automated inspection/measurement by image, *Metrology based on image*, which uses concepts of Metrology and Computer Vision. It is a dimensional non-contact measurement using computer algorithms.

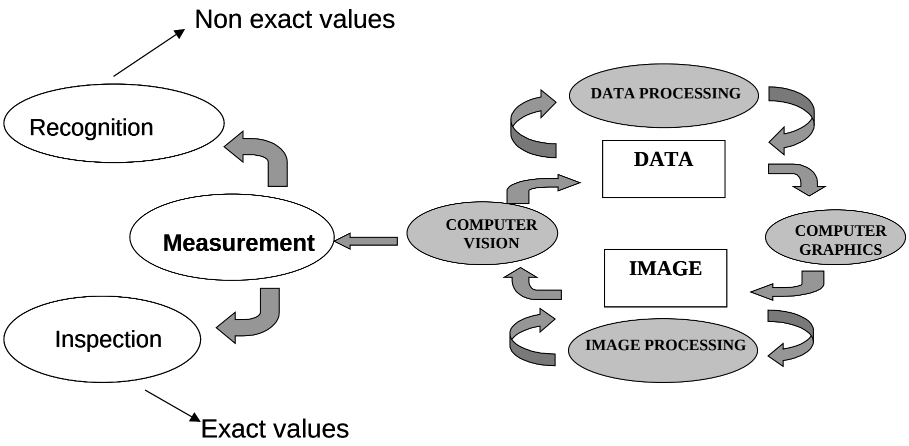


Figure 1. Image science relationships.

In this context, we can point out some industrial application examples like: a system to identify parts' fails in quality control; a system to guide a robot; a traceability system to identify codes and text; and a system to measure parts.

There are several application fields where image measurements can assume a great relevance. Luo et al. (2004) combined machine vision, laser interferometer and coordinate measuring machine (CMM) to develop a vision inspection system. They note the use of vision systems to increase and improve measurement accuracy of the CMM. The work reported in Khotanzad et al. (1994) describes a vision system for: automatic inspection of that part of the wire bond in integrated circuits where the wire connects to the bond pad on the chip; and the 2-D profile of the bonding wire inspection. Shankar e Zhong (2005) presents a template-based vision system for the inspection of wafer die surfaces. But many of these works haven't considered the measurement accuracy. This is, in fact, because of their principal objective, which reflects a quality control inspection and not an exact measurement. Therefore, they just discriminate products into acceptable and non-acceptable items. Liguori et al (2001) present an application in biomedical images. They propose an automatic measurement system for the measurement of carotid *intima-media* thickness based on digital processing of ultrasound images.

Despite the high level of technological development, it is still impossible to get perfectly accurate manufactured parts. Therefore, always a limit of tolerance in the measurements is remained. It is common to appear parts with surfaces rejections, since they are out of the tolerance limit. Many times rejection is because of an inadequate measurement instrument or procedure. The Computer Vision application chosen in this paper deals with conformity analysis of parts, considering the specified tolerances. The idea is to extract some measurements and verify if they are inside of the limits of acceptable tolerances. An automated manufactured parts measurement and conformity analysis system is proposed using Computer Vision techniques. We discuss the problem of using image-based measurements for engineering purposes.

2. Computer Vision Measurement System

2.1. General aspects

A Computer Vision measurement system using digital images can be divided in five steps: (1) image acquisition; (2) image pre-processing; (3) object segmentation; (4) recognition of the interested objects; and, (5) measurement (Fig. 2). In the first step it is necessary a good camera and lighting. Steps 2-4 consist in the application of image processing techniques to prepare the manufactured parts to measurement.

Eventually, it is necessary some pre-processing to increase image quality, just in case of a bad image acquisition using an inappropriate lighting and camera. After that, it is necessary to isolate regions of interest, which is in this application the manufactured part. The process of segmentation groups pixels to form higher-level regional image structures. The simplest segmentation process is a *noncontextual* segmentation, where relations among features (pixels or regions) are ignored (Schalkoff, 1989). In this case, the gray level of an object is useful in separating it form other objects and from the background for the purposes of analysis. The simplest segmentation process consists in object/background discrimination by transforming the gray-level object in a black object and the gray-level background in a white background in the image. The use of binary image is very common in many Computer Vision applications because of its dimensionality reduction. To have a good segmentation result it is necessary that object and background have sufficient contrast level. Therefore, considering pixel intensity values the classification is successful when the intensities of the different classes cluster into separate regions, which can be observed in the image histogram.

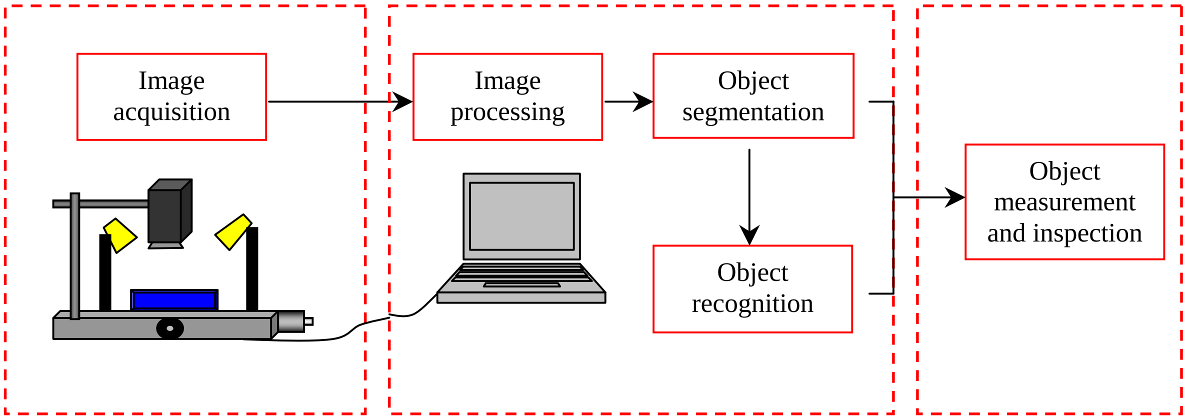


Figure 2. System overview.

Sometimes, as the studied case, it is necessary also to discriminate some object regions to carry on the measurement process. In this case a connectivity algorithm should be used and following that an object recognition process is required. A morphological operation (4-connectivity or 8-connectivity) may be used to distinguish the object holes. It consists in assessing the four direct neighbors of each pixel (smaller picture element) of the image. Two pixels are connected in a region if they are adjacent to each other and have the same color (gray level) value. In the 8-connectivity concept, all the eight neighbors are evaluated in order to find out which of them has the same value (Fig. 3).

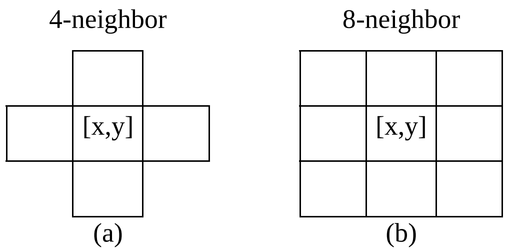


Figure 3. Connectedness of pixels. (a) 4-connected neighbors and (b) 8-connected neighbors.

After all, finally we recognize each significant region of the manufactured part in order to go on with the measurement. The first step is to identify the object/regions position in the image. The simplest parameter is the "center of area or gravity" of each region, described by its x and y coordinates. This position can be obtained from the binary mask of the object weighted by the pixel intensity in the original image. It considers the area of each object region, obtained digitally by simply counting the number of pixels in the object. In digital image each pixel is considered as a little object with a known area, so the center is obtained considering the central position of each pixel. To illustrate this, observe a pixel center in Fig. 4.

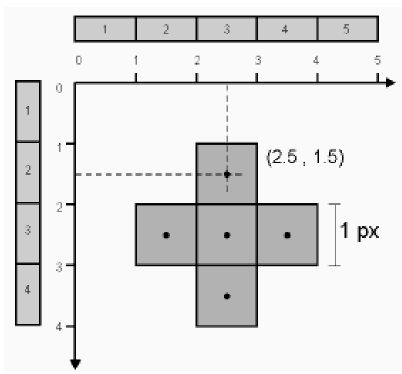


Figure 4. Pixel center (position).

Once each object region is distinguished from the others we can extract some measurement attributes, like area, perimeter, center, height and width. All of these attributes are obtained in the part contour. Thus lines are very import features that my have to be detected.

In order to help the detection of edges it is necessary to determine changes in intensity in the neighborhood of a pixel (Jain et al., 1995). We can use digital filter to enhance the part border. But frequently it is sufficient a threshold, which provides the criterion used for detection. To find the object contour we present two different approaches, the first identify all pixels that are in the boundary of the object reading each image scan line; the second finds one pixel in the boundary and after starts to look around its similar pixel, that is the pixel which has black and white neighbors. We have also to consider that a pixel has a specific dimension, so if we are obtaining the length of a line, depending on its angular position in the image we may have an imprecise measurement. It can be noted in Fig. 5, when computing the length between pixels 1, 2 and 4.

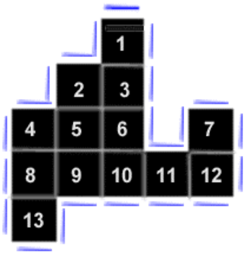


Figure 5. Perimeter.

2.2. Object measurement and inspection

In industrial process, it is very difficult to execute parts with the rigorously accurate measures, because all manufacture process have inaccuracies. It is required that similar parts can be replaced, without repairs or adjustments (interchangeability). The practice has demonstrated that the measurements of the parts can vary, within certain limits (tolerances), without harms the quality.

The following methods to obtain the vertexes consider that it is known how many vertexes the part has and also that the object contains only straight-line edges. The first one is based on identifying the points of the contour with biggest distance to the object center. The second approach identifies abrupt direction changes in the object border. To evaluate both methods, it is essential that the system distinguish previously which pixels belong to the boundary.

The first method is based on calculating the distance of each point of the contour to the center of the object and is realized that the points of biggest distance are its vertexes. The number of looked vertexes (“n”) is indispensable to found the "n" biggest distance to the center, this is a “search stop” criteria. It is important to observe that all identified points should have a minimum distance between each other. This prevents the error illustrated in Fig. 6, where two pixels were identified as vertex (the second and the third) because of the corner irregularity. There is a limitation of this method; it fits only for convex figures, because the object center would be in a position that allows error. However, it functions very well for regular figures as triangles, squares, pentagons and etc.

The second approach identifies the straight lines that compose the edges of the object and, with the interception of the straight lines equations; we have a common point, which is the vertex. Differently from the first it is not necessary to give the number of vertexes and it can be used for non-convex figures. Knowing all the points of the contour, this amount of points in equal intervals is divided and is calculated the equation of the straight line. A point of each small interval is stored, generating a vector with the points and the angular coefficients of each interval. Having defined a tolerance angle, it is evaluated the difference between each angular coefficient and its previous one, until it finds the difference biggest that the tolerance. Thus, the average of the angular coefficients and distances x and y of the points is taken off, thus generating information that define a straight line. The search continues until it finds a new difference bigger that the tolerance. Each distinct straight line corresponds to an edge and its vertexes are defined in the interception of these edges (Fig. 7).

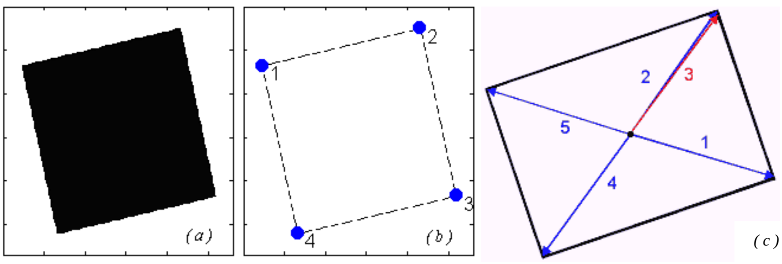


Figure 6. (a) Original image. (b) Identified vertexes. (c) Possible identification error.

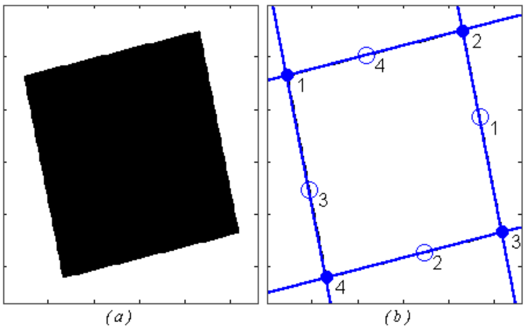


Figure 7. (a) Original image. (b) Identified straight lines and vertexes.

Having the object vertexes, we compute each edge dimension, which have to be fitted in a dimensional tolerance limit. The manufacturing of parts respecting the indicated dimensional tolerances does not guarantee an adequate functioning of the same ones. It is necessary also that these parts are in accordance to the specified forms (geometric tolerances), hence they will be able to be put together adequately. Geometric tolerances are classified into: form (straightness, flatness, circularity, cylindricity), profile (of a line, of a surface), orientation (angularity, perpendicularity, parallelism), location (position, concentricity) and runout (circular, total) (ABNT, 1997).

Form tolerance is an error that corresponds to the difference between the object real surface and the theoretical geometric form. The form of an element will be correct, when each one of its points will be equal or inferior to the given tolerance limit. The straightness tolerance consists in how much the edge deviates from a straight line. It can be computed comparing the coordinates of all edge points to the two straight tolerance limit lines. Another geometric tolerance contemplates the parallelism and perpendiculars error between object edges. The position tolerance examines the relationship between two or more elements. This tolerance establishes the allowed variation value of an element relative to its theoretical position.

Roundness is one of the basic geometric forms expected from circular features and most traditional roundness measuring instruments are contact-type (Chen, 2002). The hole center is obtained by its center coordinates, after that it is possible to compute the distance from the hole boundary to the center and get the average diameter. Using this procedure we can evaluate the roundness, computing by the measured points the minimum and the maximum circumscribed circle. Knowing the roundness geometric tolerance we can say if the conformity of the part.

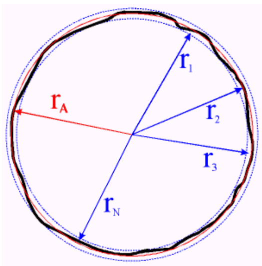


Figure 8. Roundness measurement.

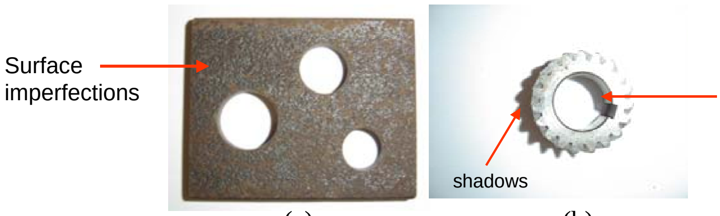
A Computer Vision system to evaluate tolerances must be capable to detect geometric tolerances with accuracy. This is possible since there is a great number of computed comparisons between the real object border and the specified tolerances.

3. Results

We have chosen a manufactured part having the two main measurement features in industrial context, line and circle. We can measure them and check dimensional tolerance and at least four geometrical tolerances (linearity, parallelism, position and roundness). Hence the tested object is a rectangle part with three different holes and we are interested in extract its measurement and shape. The parts were manufactured without a great rigor, and for that reason the measures obtained by the Computer Vision inspection system (CV) are in majority out of specification.

In this paper we present some results of the system, which was adjusted to extract the measurements of width and length of the rectangle, position and diameter of the holes and still to compute circularity error of each hole, and straightness of each side. Comparing the obtained measures of the part with the project, it is possible to know if they are in accordance to the specified tolerance, thus we can evaluate its conformity.

In the proposal automatic system, the first step is to acquire the image with the best illumination and image resolution. It is necessary to obtain and capture a noiseless and clear image of the interested part. But we can observe, that several surface defect and shadow continue (Fig. 9(a)). Another detected problem consists in the object depth, in this situation it is necessary a good image pre-processing in order to minimize any system wrong decision about the correct boundary. This is more critical in parts with large thickness (Fig. 9(b)). Besides, a more meticulous observation will show that the part boundary is irregular. Those irregularities make, especially for human beings, the measurement more difficult. Some Computer Vision techniques may be used to minimize the lack of clearness of the borders (Leta et al, 2001).

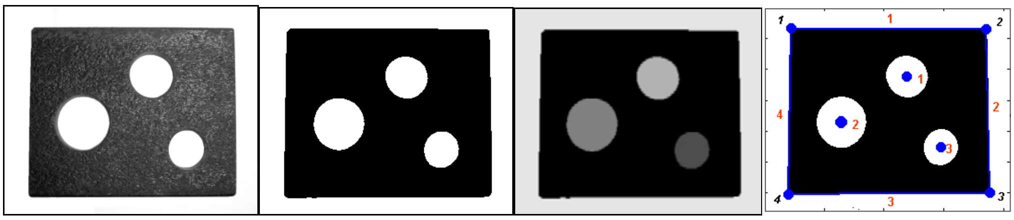


(a) (b)

Figure 9. Image problems. (a) Surface defects and (b) thickness and shadows.

In Fig. 10 we present the following implemented steps:

(a) The original image is converted to a gray level image.
(b) A threshold procedure segments the object from the background.
(c) A morphological operation (4-connectivity) is used to distinguish the object holes and the rectangle part (each one is considered an interested feature).
(d) According to each part characteristics it is possible to label each one.



(a) (b) (c) (d)

Figure 10. (a) Gray level image. (b) Threshold image. (c) Segmented features. (d) Recognized features.

After these procedures, it is possible to compute all measurements, based on the methodologies presented previously. The measurements are in pixel unity and must be converted to millimeters. To get the conversion factor, a standard object was photographed using the camera in different heights (Tab. 1). Observing these results we note that the conversion factor (λ) increases as the height diminishes. Seeing that λ express the amount of pixels that corresponds 1 mm, we realize that to get more accurate measurements, the camera must be next to the analyzed part.

To show the measurement program performance, six parts had been used and were pictured using the lowest possible camera height. We have chosen one of them (part C) to show in this paper. We underline that the high values of the precise tolerances are in accordance to the quality required to inexpert operators. Table 2 presents plan specifications. In Tab. 3 we show the obtained results, considering different object positions (Fig. 11) and their average measures (Feliciano et al., 2004). It is important to compute the measure considering part rotations because in this case it is possible to have loss of accuracy in digitized straight lines, coming from quantization process. It is intrinsic to the digitalization process. This effect is called aliasing.

Table 1. Camera height, standard length in pixels and conversion factor (R- standard block -50 mm).

Picture	Height (mm)	Standard length P (pixel)	Conversion factor λ $\lambda = \frac{P}{R}$ (pixel/mm)
a	100	496	9,92
b	150	363	7,26
c	200	275	5,50
d	250	228	4,56
e	300	197	3,94

Table 2. Project specifications.

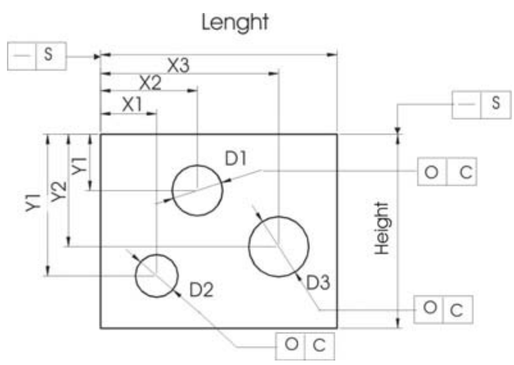
Part		Plan tolerances and dimensional quantity (mm)		
		Straightness	T1	0,80
			T2	0,80
			T3	0,80
			T4	0,80
		Hole Diameter	D1	11,00 ± 0,50
			D2	13,00 ± 0,50
			D3	15,50 ± 0,50
		Circularity (roundness)	C1	0,50
			C2	0,50
			C3	0,50
		Hole Center position	X1	14,50 ± 0,25
			X2	25,00 ± 0,25
			X3	46,00 ± 0,25
			Y1	36,00 ± 0,25
Length	61,00 ± 0,50		Y2	14,50 ± 0,25
Height	50,00 ± 0,50		Y3	29,00 ± 0,25

Table 3. Measurements obtained by the Computer.

Part	Feature		Measurement (mm)	Conformity
C	Length		61,70	no
	Height		49,77	yes
	Straightness	S1	1,30	no
		S2	0,43	yes
		S3	0,41	yes
		S4	1,10	no
	Hole Diameter	D1	11,76	no
		D2	13,61	no
		D3	14,75	no
	Circularity (roundness)	C1	0,47	yes
		C2	0,54	no
		C3	0,62	no
	Hole Center position	X1	14,26	yes
		X2	25,22	yes
		X3	45,42	no
		Y1	35,87	yes
Image Resolution		Y2	14,36	yes
800 x 600		Y3	28,41	no

Figure 11. Part different positions.

4. Conclusions

Computer Vision offers consistency, accuracy and repeatability, in contrast to the subjectivity, fatigue, slowness, and cost associated with human inspection. The advanteges of using a machine vision system for inspection include a decrease in the time required for measurement as well as greater accuracy of measurements and better flexibility than the conventional methods (Chen, 2002). In this context, the methodology presented allow an automatic measurement of parts. Adopting this methodology, the user's skill has no influence in the final measurement and a faster measurement process has been possible. We present the results obtained by different image techniques applied to digital image measurement. Moreover, we discuss the accuracy of an automatic measurement system by image.

The essential problem of using Computer Vision techniques consists in image quality, because image analysis requires that features of interest be well defined, either by edges, brightness or color. The preprocessing step is essential in this context. The choice of the most appropriate method to pre-processing and threshold the image, in its two main components (the object and the background), must be sufficient robust in order to generate images without quality loss. Considering an automatic measurement system by image, it is important to control the lighting and choose the adequated camera posistion.

Besides, it is necessary to calibrate the system considering reference standard. We note that each part has its particular measurement quantities, and for that reason the system must have different usuful measurement algorithms. Every algorithms must be tested previously and compared to the results obtained by using conventional measurement instruments. There are many different possibilities to measure a part using Computer Vision algorithms. Each one of these should be tested considering accuracy and repeatability. It is possible, depending on the resolution and accuracy of these traditional instruments, that the measurement system by image does not present the best result. For that reason we should compare the best relationship between spent time in the measurement process and its acquired accuracy.

In this context, we presented the main stages of a system for automatic measurement by image, which includes from the pre-processing stage to the final stage of analysis of the image. We discussed the problems and accuracy involved in using Computer Vision techniques to measure manufactured parts. At this point it was not our intention to compare the computed results with the gotten ones by conventional instruments. It is also necessary in future works to discuss the uncertainty concerned in image-based measurements.

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