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Technique for calibration of chassis components based on encoding marks and machine vision metrology*

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A novel technique for calibrating crucial parameters of chassis components is proposed, which utilizes the machine vision metrology to measure 3D coordinates of the center of a component's hole for assembling in the 3D world coordinate system. In the measurement, encoding marks with special patterns will be assembled on the chassis component associated with cross drone and staff gauge located near the chassis. The geometry and coordinates of the cross drone consist of two planes orthogonal to each other and the staff gauge is in 3D space with high precision. A few images are taken by a high-resolution camera in different orientations and perspectives. The 3D coordinates of 5 key points on the encoding marks will be calculated by the machine vision technique and those of the center of the holes to be calibrated will be calculated by the deduced algorithm in this paper. Experimental results show that the algorithm and the technique can satisfy the precision requirement when the components are assembled, and the average measurement precision provided by the algorithm is 0.0174 mm.

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The precise calibration of the chassis is crucial to the performance of motorcycles, electric bicycles and bicycles , especially for the stability and safety of these vehicles, which fully depend on the precision of the junction between the chassis and other components. In order to accurately assemble the components, the precise calibration of the key points of the chassis components is indispensable and significant[1]. The 3D calibration machine is widely used to measure the parameters of the chassis, which needs to touch the components[2]. The component to be calibrated must be fixed on the machine and measured point by point[3]. It will cost half an hour per time. Due to the waste of time and the inconvenience, lots of manufactories can not have enough energy and resource to ensure every chassis to be calibrated, resulting in just only a part of chassis can be measured.

The novel technique proposed in this paper is focused on the machine vision calibration. In the technique, an encoding mark with a special pattern serves as the medium to obtain the 3D coordinates of the center of the component's hole for assembling[4-6]. The 3D coordinates of 5 key points on the encoding marks can be obtained by the high-precision machine vision technique[7-10]. Each calibration takes about 3 min and the 0.0174 mm measurement accuracy means that it can meet the necessary calibration and assembly requirement.

With the technique and algorithm, the chassis can be fully or 80% calibrated, which contributes to promote the product quality of chassis components. When the unqualified product is detected in the manufacture process of chassis, the immediate repairment can be offered or the subsequent processing can be ceased in order to avoid dispensable waste.

Since the hollow nature of the hole, the coordinates of the center of the assembled hole can't be directly calibrated. The traditional method can only provide fitting coordinates for the hole's center through measuring the points on the edge of a hole. The more the points are calibrated, the smaller the measurement error of the fitting center will be. The 3D calibration machine also can not satisfy the massive amount of measurements for the manufactory, since the measurement time is too long.

A kind of encoding marks are designed: each mark with a special pattern has a unique code number. Fig.1 illustrates the layout of the encoding marks. The encoding marks can

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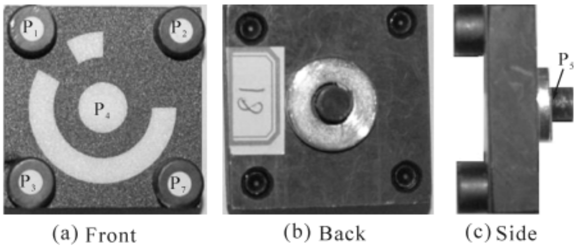
be precisely assembled together with the chassis and other components. There are 4 key points: P_1, P_2, P_3 and P_7, which are located in the same plane *A* and P_4 is the center of the encoding marks as shown in Fig.1. P_5 is the 3D center of the hole located below P_4. The thickness *D* of the mark object is the distance between P_5 and P_4. The line through P_4 and P_5 is perpendicular to the plane *A* through P_1, P_2, P_3 and P_7.



(a) Front (b) Back (c) Side

Fig.1 Layout of the encoding marks

(x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3), (x_4, y_4, z_4) and (x_5, y_5, z_5) are the coordinates of P_1, P_2, P_3, P_4 and P_5, respectively. There are two vectors in the plane *A*:

$$\boldsymbol{p}_1\boldsymbol{p}_2 = (x_2\text{-}x_1, y_2\text{-}y_1, z_2\text{-}z_1), \boldsymbol{p}_1\boldsymbol{p}_3 = (x_3\text{-}x_1, y_3\text{-}y_1, z_3\text{-}z_1) \ . \tag{1}$$

The normal vector of plane *A* is:

$$\boldsymbol{n} = \begin{vmatrix} i & j & k \\ x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \end{vmatrix} \ , \tag{2}$$

which can be converted to:

$$\begin{aligned} \boldsymbol{n} = [&(z_3 - z_1)(y_2 - y_1) - (y_3 - y_1)(z_2 - z_1), \\ &(x_3 - x_1)(z_2 - z_1) - (x_2 - x_1)(z_3 - z_1), \\ &(x_3 - x_1)(y_2 - y_1) - (x_2 - x_1)(y_3 - y_1)] \ . \end{aligned} \tag{3}$$

An assumption for $\boldsymbol{n}$ is $\boldsymbol{n}=(m, l, n)$, with

$$\begin{aligned} m &= (z_3 - z_1)(y_2 - y_1) - (y_3 - y_1)(z_2 - z_1), \\ l &= (x_3 - x_1)(z_2 - z_1) - (x_2 - x_1)(z_3 - z_1), \\ n &= (x_3 - x_1)(y_2 - y_1) - (x_2 - x_1)(y_3 - y_1) \ . \end{aligned} \tag{4}$$

The unit vector is

$$\left(\frac{m}{\sqrt{m^2 + l^2 + n^2}}, \frac{l}{\sqrt{m^2 + l^2 + n^2}}, \frac{n}{\sqrt{m^2 + l^2 + n^2}} \right).$$

The line through P_4 and P_5 is perpendicular to the plane *A*, and $\boldsymbol{p}_4\boldsymbol{p}_5$ is parallel to $\boldsymbol{n}$. Due to the distance *D* between P_5 and P_4, we can get

$$(x_5 - x_4, y_5 - y_4, z_5 - z_4) = \left(\frac{Dm}{\sqrt{m^2 + l^2 + n^2}}, \frac{Dl}{\sqrt{m^2 + l^2 + n^2}}, \frac{Dn}{\sqrt{m^2 + l^2 + n^2}} \right) \ , \tag{5}$$

from which the coordinates of P_5 are

$$\left(\frac{Dm}{\sqrt{m^2 + l^2 + n^2}} + x_4, \frac{Dl}{\sqrt{m^2 + l^2 + n^2}} + y_4, \frac{Dn}{\sqrt{m^2 + l^2 + n^2}} + z_4 \right) \ .$$

The calibration procedure is as follows.

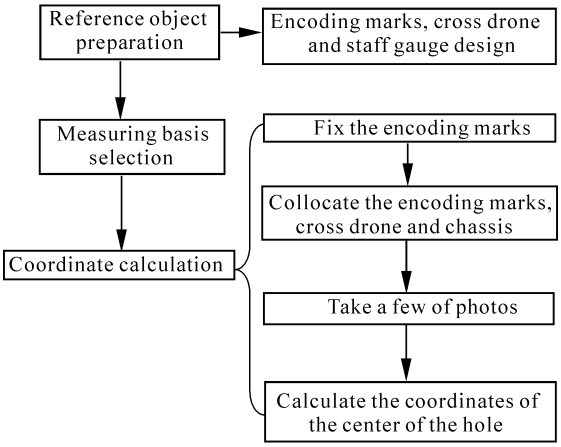


Fig.2 Procedure of calibrating the key points of a chassis

Step1. Reference object preparation: Design and produce the object for encoding marks, the cross drone with 5 marks fixed in the 4 vertexes and the center of the cross drone, and the staff gauge with 2 marks fixed on the 2 sides of the gauge. The coordinates of all the encoding marks are known.

Step2. Measuring basis selection: Choose several appropriate perspectives to take some photos. It is significant to ensure that the cross drone, the staff gauge and the chassis to be calibrated are always taken in one image.

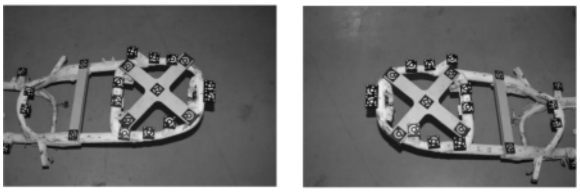
Step3. Coordinate calculation: The overall procedure to compute the coordinates of the key positions can be subdivided into eight steps:

(1) Fix each key position to be calibrated with an encoding mark.

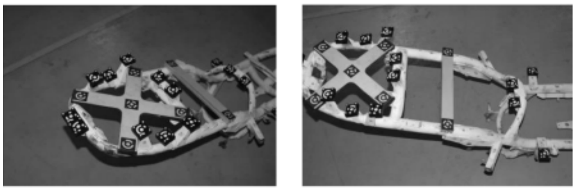
(2) Collocate the cross drone and staff gauge together with the chassis in the particular relation: there are at least three marks in one image, except for the marks of cross drone and gauge.

(3) Take a few photos for all the objects in different orientations and perspectives by moving the high-resolution camera. There must be both the cross drone and staff gauge within at least 3 images.

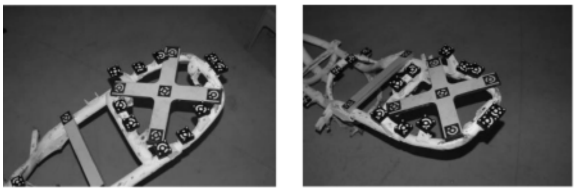
(4) Continue to take photos until all the encoding marks are shot in the particular rule: there are at least 3 marks shared by the adjacent images, as seen in Fig.3.



(a) First image (b) Second image



(c) Third image (d) Fourth image



(e) Fifth image (f) Sixth image

Fig.3 Images of the chassis taken in different perspectives

(5) Based on the 3 images taken in the step3, which contain the known information of cross drone and staff gauge and the 3D coordinates of their encoding marks, the coordinates of the camera in 3 different positions can be obtained by utilizing the machine vision metrology.

(6) From the 3D coordinates of the camera in 3 different positions, we can have the 3D coordinates of P_4, P_1, P_2, P_3 and P_7 (see Fig.4) for all the encoding marks shot in these images, except for the known-information encoding marks of cross drone and staff gauge.

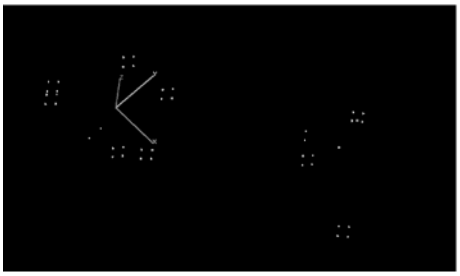


Fig.4 3D coordinates of the 5 points

(7) From Eq.(5), the 3D coordinates of a key point, like a hole, can be obtained, according to the coordinates of P_4, P_1, P_2, P_3 and P_7 for encoding marks got from stpe6.

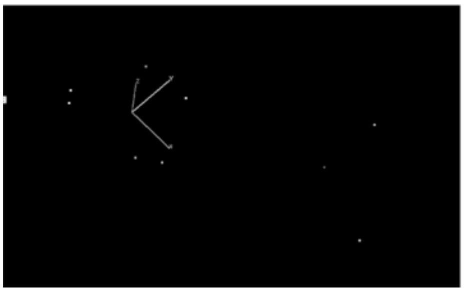


Fig.5 Coordinates of the hole

(8) The step7 is carried again until the 3D coordinates of all key points are obtained.

In order to verify the applicability, robustness and precision of the technique proposed in the paper, we accomplish the control experiment and give the table as follows containing the results calibrated by the novel technique and the traditional 3D calibration machine. The measuring accuracy of the 3D calibration machine is 0.01 mm.

Tab.1 Results of the control experiment

Code	Coordinates calibrated by the proposed technique			Coordinates calibrated by the 3D calibration machine			Measurement error		
	X	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*
74	78.183	128.412	17.834	78.173	128.403	17.820	0.009	0.008	0.014
76	637.359	301.867	-198.970	637.323	301.847	-198.997	0.036	0.019	0.027
77	451.055	333.782	-93.523	451.036	333.767	-93.538	0.018	0.015	0.015
81	31.116	-115.422	26.806	31.106	-115.436	26.795	0.010	0.013	0.010
82	173.287	-49.465	17.844	173.276	-49.475	17.832	0.011	0.010	0.012
83	-159.126	-94.272	11.596	-159.145	-94.286	11.581	0.018	0.013	0.014
84	-133.987	-125.209	11.054	-134.005	-125.224	11.039	0.017	0.015	0.015
87	-80.646	133.836	-13.965	-80.660	133.826	-13.976	0.013	0.010	0.010
89	406.992	587.417	-203.721	406.960	587.379	-203.761	0.031	0.037	0.039

The table above clearly demonstrates that the average accuracy of measurement of the proposed technique is 0.0174 mm, which can achieve the precision required by manufactories. The technique based on encoding marks and machine vision metrology just needs a high-resolution camera. It can work without the projective light source, which means that the technique has solved the headache issue about the calibration of black objects or reflective objects. It is also suitable to calibrate the objects with various sizes or configurations. With the advantageous features like small volume, light weight, portable and high accuracy, it can be widely utilized in the real world, like calibrating 3D coordinates of the bulky object with a large size, or other objects with an any-material surface (cast, model, sculpture, human body, etc.).

References

[1] XU Qiao-yu, WANG Heng-di and CHE Ren-sheng, Journal of Optoelectronics • Laser **20**, 1332 (2009). (in Chinese)

[2] Lenz RK and Tsai RY, IEEE Transactions on Pattern Analysis and Machine Intelligence **10**, 713 (1988).

[3] Zhang Zhengyou, IEEE Transactions on Pattern Analysis and Machine Intelligence **22**, 1330 (2000).

[4] WANG Ying and SU Xian-yu, Journal of Optoelectronics • Laser **19**, 1561 (2008). (in Chinese)

[5] SUN Jun-hua, YANG Zhen and LIU Qian-zhe, Journal of Optoelectronics • Laser **20**, 789 (2009). (in Chinese)

[6] LiMei Song and DaNv Wang, NDT & E International **39**, 282 (2006).

[7] LiMei Song, MingPing Wang, Lu Lu and Huang JingHuan, Optics and Laser Technology **39**, 1413 (2007).

[8] LiMei Song, Lu Lu and JingHuan Huang, Journal of Computational Information Systems **5**, 1023 (2008).

[9] LiMei Song, XingHua Qu and ShengHua Ye, Image and Vision Computing **25**, 614 (2007).

[10] Limei Song, Xinghua Qu, Yangang Yang, Yong Cheng and Shenghua Ye, Optics and Lasers in Engineering **43**, 1118 (2005).