Research on Calibration Reading Technology of High-Precision Meter

Zhigang Ning nzg0928@163.com
College of Electrical Engineering
University of South China
Hengyang,421001,China

Xueyu Gong gongxy@nhu.edu.cn
College of Electrical Engineering
University of South China
Hengyang,421001,China

Lihong Zhao zhaolh@gmail.com
College of Electrical Engineering
University of South China
Hengyang,421001,China

Changhong Shan shanch801@126.com
College of Electrical Engineering
University of South China
Hengyang,421001,China

Abstract

The paper proposes a way to achieve camera positioning tasks by 2D visual servoing. By observing both the camera and the features of meter reading, the camera is able to be positioned with an accuracy in hand-eye calibration. The calibration reading method is used to recognize high-precision meter reading.The paper mainly includes three parts. Firstly, the geometrical model of parallax formation is constructed and the importing error is analyzed. Secondly, according to the analysis of importing error, the calibration reading technology of high-precision meter and the experimental platform of calibration reading technology are designed. Finally, the experiment on the calibration reading technology is researched. The experimental results show the method is applicable to automatic recognition of high-precision meter.

Keywords: Calibration Reading Technology,High-Precision Meter,Camera Lenses Locating, Importing Error.

1. INTRODUCTION

Although many digital meters have output ports which can directly connect with computer digital output ports, it is difficult for some practical application to operate automatically and recognize meter reading with person's eye. In addition, sampling meter reading in some running systems or at some dangerous scenes is needed. Automatization and communication of these systems need improving.Intelligent examination method based on machine vision is a fundamental way to improve conventional examination method, which carries machine vision and artificial intelligence in meter detecting process. The method has eliminated personal error of labour examination and improved examination precision and speed. The method is a new attempt of automatic technology applying to industrial production and examination process.

Industrial development and multi-subject cross-research need all sorts of examination meters. Because of output ports of different sorts of digital meters produced by different corporation and their communication agreements, it is a great workload that output ports are connected by all sorts of communication agreements. It isn't immediately realized that all kinds of meters with or without digital output ports are constituted an integrated and automatic examination system. Owing to above mentioned reasons, it is practically valuable that meter digital reading is photographed and recognized.

Dial meters with simple structure, easy use and low price are widely used to measure electrical current, distance, water, gas, etc. The precision level of recognition system of meter reading of dial meter is under 1.0 at the present time, while high-precision dial meter is not widely researched[1]. The paper adopts calibration reading technology to recognize meter reading of high-precision dial meter.The first stage of our research is focused on camera locating. Calibration reading technology is used to calibrate camera position, which makes optical center of camera lens locating in the permissible error area[2-4].

The paper is organized as follows. Section two discusses some of the relevant visual servoing positioning literature. The geometrical model of parallax formation is constructed and the importing error is analyzed in Section three.Section four describes the calibration reading technology of high-precision meter. The experiment on the calibration reading technology is shown in Section five.The paper ends with conclusion.

2. RELATED WORK

Traditional method of sensor-guided fine-positioning is based on hand-eye calibration. Hand-eye calibration is a process used in the field of robotics to determine the orientation of a camera in relation to the recognition of meter reading of high-precision dial meter. Only focusing on vision-based positioning relative to a static(unmoving) target, it can be argued that the basic principles for implementing visual feedback are well understood by now[5-6].With dynamic visual features, a positioning task consisting of moving the camera to the parallel position of a planar object is achieved[7]. A robot arm is used to locate a camera in known poses relative to an observed object [8].

2D visual servoing is based on using features directly calculated from the images which are used as input in the control scheme. Former work started using image points which is still one of the most popular primitivenesses today[5,9-10]. Other 2D primitivenesses have been modelled on straight line[5,11], segments, circles, ellipses, cylinders and spheres[5,12]. Some other work tends to combine different visual features in a unique control scheme. Point coordinates, area enclosed by points and angle between segments are used to improve the performance of the system[13]. Imaged-based visual servoing is traditionally robust against modelling errors of system. Since controlling is made in the image space, it is easier to design strategies to avoid the image features going out the image bounds[13-14]. Hybrid visual servoing approach combines 2D with 3D features. In case of knowing the model of the object, classic pose recovering algorithms can be used to estimate some 3D features as in position-based visual servoing. A lot of visual servoing approaches have been probed when the desired image is known. Some of them are based on recovering the partial pose between the camera and the object from the desired image and the current image[15-16].

3. ANALYSIS OF IMPORTING ERROR

The camera position greatly influences meter reading. Figure 1 is the stereogram of optical center of camera lens, meter pointer and scale. The plane Γ_1 is scale plane, and arc cd denotes the segment of scale line of dial meter on the plane Γ_1. The plane Γ_2 is pointer plane, and the line op denotes meter pointer on the plane Γ_2. The point o denotes rotary axis of meter pointer, and the point p denotes the tip of meter pointer. The plane Γ_1 and the plane Γ_2 are parallel to each other. The plane Γ_3 including meter pointer op is the vertical plane of pointer plane Γ_2. The point o' is an optional point over the point o. The point o'' is the projection of the point o on the plane Γ_1. The point p'' is the projection of the point p on the plane Γ_1. The line $o''p''$ is the projection of meter pointer op on the plane Γ_1. The point p'' is on scale arc cd. The meter reading which the point p'' denotes is the accurate reading of meter without any parallax. The point f is an optional point over the line op, which is on the plane Γ_3. The point b' is an optional point above the line op, which is not located on the plane Γ_3. So the point b' is not located on the line $o'o''$. The line $o'b'$ and the plane Γ_2 are parallel to each other. According to the principle of parallax formation, reading parallax of meter is researched when optical center of camera lens is located at the point b', the point f and the point o' respectively. When optical center of camera lens is located at the point b', the line $b'p$ and the scale plane Γ_1 intersect at the point n, and the line $o''n$ and the scale arc cd intersect at the point j. The arc jp'' denotes reading parallax of meter. The line fp and the scale plane Γ_1 intersect at the point a. Because the intersecting point a must locate on the extended line $o''p''$, reading parallax of meter is zero when optical center of camera lens is located at the point f. The line $o'p$ and the scale plane Γ_1 intersect at the point m. Because the intersecting point m must locate on the extended line $o''p''$, reading parallax of meter is zero when optical center of camera lens is located at the point o' on the plane Γ_3. According to above mentioned analysis,when optical center of camera lens is located at any optional point over rotary axis of meter pointer or the line op on the plane Γ_3, which is the vertical plane of the plane Γ_1 and includes meter pointer op, reading parallaxes of meter don't exist.

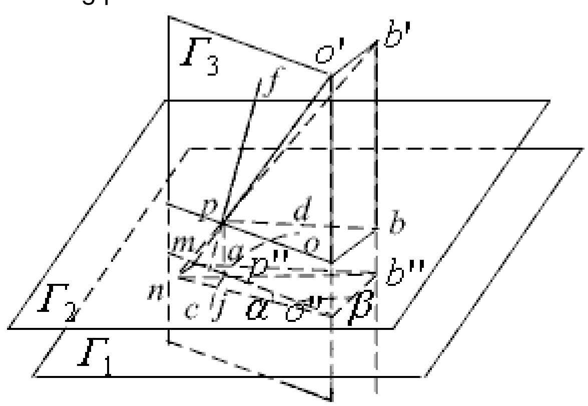


FIGURE 1: Stereogram of Optical Center of Camera Lens, Meter Pointer and Scale

The point b is the projection of the point b' on the pointer plane Γ_2. The point b'' is the projection of the point b' on the scale plane Γ_1. $o'b'$ □ob□ $o''b''$ □mn, op□ mo'',□mnp□□ $o'b'p$,□ $o'po$ □ □ $o'mo''$, $\frac{|mn|}{|o'b'|}=\frac{|mp|}{|o'p|}=\frac{|oo''|}{|oo'|}$, $\frac{|mo''|}{|op|}=\frac{|o'o''|}{|oo'|}$ .So, $|mn|=\frac{|oo''|}{|oo'|}\times|o'b'|$, $|mo''|=\frac{|o'o''|}{|oo'|}\times|op|$. □$pob$ is the angle between the line ob and the pointer line op. If the pointer line op is rotated around the point o, the size of angle □pob will change.□ $mo''b''$=□pob, $\angle no''m=\alpha$, $\angle mo''b''=\beta$,so $\angle nmo''=\beta$. In the triangle $o''mn$,the following formulation is concluded on the foundation of law of sines:

$$\frac{|mn|}{\sin\alpha}=\frac{|mo''|}{\sin(180°-\alpha-\beta)}$$

By calculating, $\alpha = arcctg\left[\frac{(|oo''|+|oo'|)\times|op|}{|oo''|\times|o'b'|}\times\csc\beta - ctg\beta\right]$. The length of arc jp'' corresponding to reading parallax of meter is as follows :

$$err = |o''p''| \times \alpha = |op| \times \alpha = |op| \times arcctg\left[\frac{(|oo''| + |oo'|) \times |op|}{|oo''| \times |o'b'|} \times \csc\beta - ctg\beta\right] \qquad (1)$$

where, the degree of angle β ranges from - 180° to 180°. When camera lens lies on the right side of the vertical plane of pointer plane and scale plane, the projection of meter pointer lies on the left side of accurate reading of meter pointer, and meter reading is less than the accurate reading. The angle β is defined as a negative angle, and the reading parallax is defined as a negative reading parallax. When camera lens lies on the left side of the vertical plane of pointer plane and scale plane, the projection of meter pointer lies on the right side of accurate reading of meter pointer, and meter reading is bigger than the accurate reading. The angle β is defined as a positive angle, and the reading parallax is defined as a positive reading parallax. $|oo''|$ is the distance between the pointer plane Γ_2 and the scale plane Γ_1.$|oo'|$ is the upright distance between the point o' and the pointer plane Γ_2. $|o'b'|$ is the upright distance between the point b' and the line $o'o''$. $|op|$ is defined as the length of meter pointer. The tolerant error of 0.5 precision level milliammeter is 5‰, so the maximum of absolute permission error of scale is 0.07cm(5‰ ×100×0.14).If $|oo''|$=0.2cm,$|op|$=8cm,β,$|oo'|$ and $|o'b'|$ are three groups of different data respectively, all of importing errors are listed in Table 1.According to all data of Table 1, the maximal importing error is 0.019698 cm, and the percentage of maximal importing error to maximal scale permission absolute error is 28.14%. The big importing error increases reading parallax of meter undoubtedly. The higher the precision level is, the bigger the permission error is. So automatic recognition methods of high-precision meter need to be researched. The calibration technology of high-precision meter is researched in the paper. If optical center of camera lens is located at a point over rotary axis, the importing error doesn't exist.

err(cm) \ β / oo'	$\beta = 60°$			$\beta = 90°$			$\beta = 135°$		
	$\|o'b'\| = 0.5$ cm	1cm	1.5cm	0.5cm	1cm	1.5cm	0.5cm	1cm	1.5cm
$\|oo'\| = 15$ cm	0.005698	0.011403	0.017101	0.006601	0.013202	0.019698	0.005499	0.009303	0.013902
$\|oo'\| = 20$ cm	0.004298	0.008603	0.012901	0.004998	0.009898	0.014903	0.0035	0.007	0.0105
$\|oo'\| = 25$ cm	0.003206	0.006902	0.010297	0.003997	0.007903	0.0119	0.0028	0.0056	0.0084

TABLE 1: Importing Error Calculating

4. CALIBRATION READING TECHNOLOGY

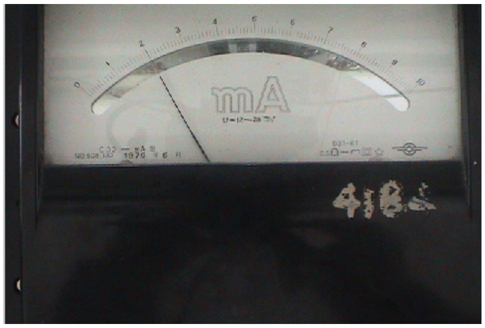
The calibration technology of camera is the key technology of precision measure in the computer vision field. Measure error of high-precision meter must be small, and the parallax of meter reading has a great influence on measure precision. In order to obtain the corresponding relative position between a special point and relevant image point, imaging system must be calibrated. According to the analysis of importing error, when optical center of camera lens is located at a point over rotary axis or meter pointer, reading parallax of meter doesn't exist. The process of calibration technology is based on the principle of parallax formation. When meter pointer points at zero scale and the maximal scale respectively, images of zero scale and maximal scale are photographed respectively. Then meter images of zero scale and maximal scale are recognized respectively. If optical center of camera lens is located at a point over rotary axis, camera or meter doesn't need to be moved.Otherwise, the relative position of camera and meter needs to be adjusted until optical center of camera lens is located at a point over rotary axis.

Computer test equipment system 1000(CTES-1000) is the experimental platform, which includes X-Y reference frame table, camera,computer, 0.5 precision level milliammeter, direct current power, resistance box and lamp-house. The X-Y reference frame table is controlled by X direction stepping motor and Y direction stepping motor. The high-precision meter is placed on the X-Y reference frame table. The orientation precision of X-Y axis is 0.005mm. Exprimental equipment is depicted in Figure 2.

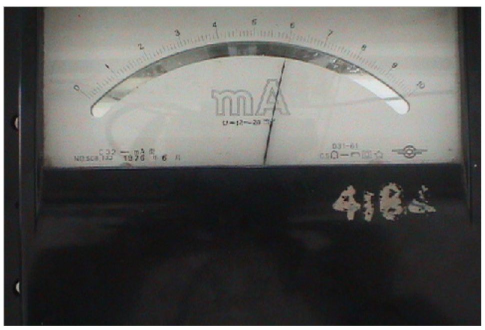
FIGURE 2: Experimental Equipment

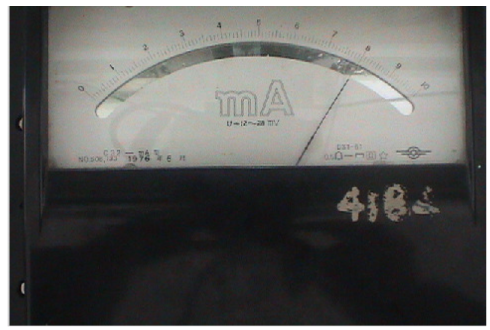
The algorithmic process of calibration reading technology is as follows:
□ The high-precision meter is placed on X-Y reference frame table.
□ When the meter is not electrified, meter pointer should point at zero scale. If meter pointer does not point at zero scale, adjusting zero device works by hand until meter pointer points at zero scale as depicted in Figure 3(a),which is confirmed by manual recognition method of simple eye.
□ The meter image is photographed and recognized. If recognition result of meter image is zero,optical center of camera lens is deemed to be located at a point over rotary axis.Then the process □ is executed.
□ If the recognition result of meter image isn't zero, X-Y reference frame table is moved and the meter image is photographed and recognized repeatedly, till the recognition result of meter image is zero.
□ Standard power is electrified and controlled till meter pointer points at the maximal scale as depicted in Figure 3(b), which is confirmed by manual recognition method of simple eye.
□ The meter image is photographed and recognized. If the recognition result of meter image is the maximum value of meter scale, optical center of camera lens must be located at a point over rotary axis and the calibration process is finished.
□ If the recognition result of meter image isn't the maximum value of meter scale, X-Y reference frame table is moved in order to make optical center of camera lens moving along meter pointer direction and the meter image is photographed and recognized repeatedly, till the recognition result of meter image is the maximum value of meter scale. The calibration process is finished.
Meter images of pointing at different scales are depicted in Figure 3 as follows:

(a) Pointing at the Zero Scale (b) Pointing at the Maximal Scale



(c) Pointing at the Scale 2 (d) Pointing at the Scale 4





(e) Pointing at the Scale 6 (f) Pointing at the Scale 8

FIGURE 3: Meter Images of Pointing at Different Scales

5. EXPERIMENTAL RESULTS

The measurement range of milliammeter is between the current 0 mA and 50mA, and calibration reading technology is used to recognize the reading of milliammeter. Firstly meter pointer is conformed to point at the scale 0, the scale 2, the scale 4, the scale 6, the scale 8 and the scale 10 by manual recognition method of simple eye respectively. The scale 0, the scale 2, the scale 4, the scale 6, the scale 8 and the scale 10 correspond with 0mA,10mA,20mA,30mA,40 mA and 50mA respectively. Secondly meter image is photographed,when meter pointer points at the scale 0, the scale 2, the scale 4, the scale 6, the scale 8 and the scale 10 respectively, as depicted in Figure 3(a),(c),(d),(e),(f) and (b). Finally different meter images are recognized respectively. All recognition results are listed in Table 2.

Practical scale(mA)	0	10	20	30	40	50
Recognition result(mA)	0.002312	9.996288	20.006673	29.997416	40.001856	49.998483
Absolute error(mA)	0.002312	0.003712	0. 006673	0.002584	0.001856	0.001517

TABLE 2: Recognition Results

According to all data of Table 2, the maximum of meter reading parallax is 0.006673 cm, which is less than 0.007 cm(1 / 10×5‰×100×0.14). Because the maximum of parallax of meter reading is less than one tenth of the maximum of absolute permission error of scale, system error can be neglected.

The distance between camera lens and pointer plane ranges from 18 cm to 20cm, where meter image which includes all meter scales can be photographed. When the rotary center of meter is used as the center of circle, and the length of radius $|o'b'|$ is 0.1 cm, 0.2 cm, 0.3 cm, 0.4cm, 0.5 cm and 0.6 cm respectively, and the length of $|oo'|$ is 18 cm, 18.5 cm, 19 cm, 19.5 cm and 20 cm respectively, and β equals to 90° and - 90° respectively, maximal parallaxes of these zones can be calculated according to the formulation (1). All maximal parallaxes are listed in Table 3. The maximum of meter reading parallax is 0.006593 cm from all data of Table 3, which is less than 0.007 cm. Because the maximum of parallax of meter reading is less than one tenth of the maximum of absolute permission error of scale, system error can be neglected. When optical center of camera lens is located over the circle zone where the rotary center of meter is used as the center of circle and the length of radius is 0.6 cm, reading parallax of 0.5 level precision meter is less than 0.007 cm, which can be neglected. The absolute error of each recognition result is less than 0.007 cm, which is within the range of permission error. So calibration reading technology is a feasible recognition method of high-precision meter in the paper.

err_{max}(cm) oo' / $o'b'$	18 cm	18.5 cm	19 cm	19.5 cm	20 cm
0.1cm	0.001099	0.001070	0.001042	0.001015	0.000990
0.2 cm	0.002198	0.002139	0.002083	0.002030	0.001980
0.3 cm	0.003297	0.003209	0.003125	0.003046	0.002970
0.4 cm	0.004396	0.004278	0.004167	0.004061	0.003960
0.5 cm	0.005495	0.005348	0.005208	0.005076	0.004950
0.6 cm	0.006593	0.006417	0.006250	0.006091	0.005941

TABLE 3: $|o'b'|$ to Satisfy Parallax Permission Value

6. CONCLUSION

The automatic recognition method of high-precision meter can eliminate subjective error of manual recognition method, and improve the automation of measure. Calibration reading technology is a method of easy operation and realization, which is a good recognition method of high-precision meter.

7. ACKNOWLEDGMENT

The research work described in the paper was fully supported by a grant from the Natural Science Foundation of Education Department of Hunan province (Project No.08C751) and a grant from Doctor Startup Foundation of University of South China (Project No.2007XQD23).

8. REFERENCES

1. Zhigang Ning. *“Research on key technologies of meter image recognition”*.PhD Thesis, Guangdong University of Technology ,Guangzhou,China,June,2007.(In Chinese)

2. Jian Zhou,Hong Zhao,Feng Tian. *“Non-contact type photoelectric system for measuring displacement of rigid body”*.Opto-Electronic Engineering, 24(6):60-66,1997. (In Chinese)

3. Ying Zha,Tiegen Liu,Dong Du. *“Application of image recognition in automatic recognition system for part assembling”*.Computer Engineering,32(10):178-179,185,2006, (In Chinese)

4. Jianfei Mao,Jing Zhu. *“Study on high accurate calibration of industrial robot vision positioning system”*.Robot, 26(2):139-144,2004. (In Chinese)

5. B.Espian,F.Chaumette,P.Rievs. *“A new approach to visual servoing in robotics”*.IEEE Transactions on Robot and Automation,8:313-326,1992.

6. J.Feddema,C.Lee,O.Mitchell. *“Weighted selection of image features for resolved rate visual feedback control”*.IEEE Transactions on Robot and Automation,7(2):31-47,1991.

7. A.Cretual,F.Chaumette. *“Positioning a camera parallel to a plane using dynamic visual servoing”*.Proceedings of IEEE/RSJ International Conference Intelligent Robots and Systems,IROS’97,Grenoble,France,pp.43-48,September,1997.

8. P.Wunsch,G.Hirzinger. *“Registration of CAD-models to images by iterative perspective matching”*.Proceedings of the 13th International Conference on Pattern Recognition,Vienna, Austria,pp.77-83,August,1996.

9. C.Collewet,F.Chaumette. *“Positioning a camera with respect to planar objects of unknown shape by coupling 2-D visual servoing and 3-D estimations”*.IEEE Transactions on Robot and Automation, 3(18):322-333,2002.

10. G.D.Hager. *“A modular system for robust positioning using feedback from stereo vision”*,IEEE Transactions on Robot and Automation,13(4):582-595,1997.

11. E.Malis,J.J.Borrely,P.Rives. *“Instrinsics-free visual servoing with respect to straight lines”*. Proceedings of IEEE/RSJ International Conference Intelligent Robots and Systems,Vol.1, Laussane,Switzerland,pp.384-389,September,2002.

12. E.Marchand,F.Chaumette. *“Active vision for complete scene reconstruction and exporation”*.IEEE Transactions on Pattern Analysis and Machine Intelligence,21(1):65-72,1999.

13. P.I.Corke,S.A.Allotta. *“A new partitioned approach to imaged-based visual servo control”.* IEEE Transactions on Robot and Automation,17(4):507-515,2001.

14. Y.Mezouar,F.Chaumette. *“Path planning for robust image-based control”.* IEEE Transactions on Robot and Automation,18(4):534-549,2002.

15. E.Malis,F.Chaumette. *“Theoretical improvements in the stability and analysis of a new class of model-free visual methods”.* IEEE Transactions on Robot and Automation,18(2):176-186,2002.

16. G.Morel,T.Leibezeit,J.Szewczyk,S.Boudet,J.Pot. *“Explicit incorporation of 2D constraints in vision-based control of robot manipulators”*.International Symposiums on Experimental Robotics,Vol.150,LNCIS,pp.99-108,Sidney,Australia,2000.Springer Verlag.