Chapter 14
Design of Fully Automatic Calibration Scheme for Load Box Based on Visual Recognition

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Abstract At present, the calibration of the transformer load box adopts a "semi-automatic" device, which automatically measures the load value and manually switches gears. This article designs an automatic shift device for load box gear based on visual recognition. The device can recognize the load box gear information through the visual subsystem, upload it to the upper computer to form a calibration plan, and then automatically switch the mechanical gear of the load box to the corresponding load point on the plan through a motion control adapter for calibration, achieving full automation of load box calibration.

14.1 Introduction

The transformer load box is an auxiliary equipment in transformer calibration and requires regular calibration. At present, the automatic calibration device of the load box is usually used to calibrate the load box. The process is that the automatic calibration device outputs the working voltage U_0/working current I_0, and calculates the load value of the load box by sampling the current I/voltage U at both ends of the load box. The entire measurement process can be switched to different gears based on the different values of the tested object, and the current voltage ampere number, power factor, and error of the load box can be automatically calculated based on the measurement results. Due to the fact that a load box has multiple load value ranges, switching between different load values requires manual operation by humans, with each measurement being adjusted one by one, resulting in a cumbersome and redundant process and low efficiency [1].

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At present, there is relatively little research on fully automatic measurement of load boxes in China. Reference [2] introduces an intelligent calibration system for load boxes, which can achieve automation of load value measurement. Manual operation is required for gear switching of load boxes; Reference [3] introduces a simple mechanical rotation scheme for switching the gear knob of the load box. This article designs a visual recognition based automatic adjustment output system for the load value of the load box, which can recognize the load gear information of the load box through the visual subsystem, upload it to the upper computer to form a calibration plan, and then automatically switch the mechanical gear of the load box to the corresponding load point on the plan through the motion control adapter for calibration, achieving full automation of the load box calibration process without manual intervention throughout the entire process.

14.2 Technical Proposal

14.2.1 Overall Design Plan

The automatic detection system device for the payment process of fee controlled electricity meters is a highly representative detection device formed by combining three major systems: mechanical and electrical automation, software-integrated control, and calibration system. This device completes the transmission, transportation, positioning, monitoring, etc., of various links through electrical control. Realize data exchange between the energy meter data collection and calibration device through software, as well as overall equipment operation scheduling and screen monitoring, as shown in Fig. 14.1.

Manually place the meter into the standard meter fixture, which provides a power supply slot for the meter and can automatically control the 220 V power supply of

Fig. 14.1 Overall frame diagram
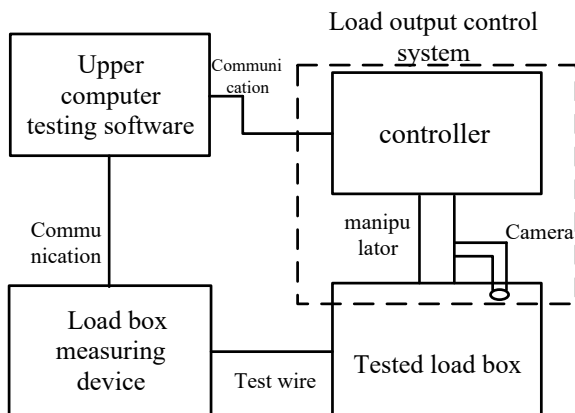
the meter. The robotic arm can automatically insert and remove the payment card of the meter and press the display button on the meter. Two sets of visual inspection systems, with cameras placed directly above the electricity meter, take photographs to determine the presence or absence of two models of electricity meters (one photograph position), precise positioning of the sockets of two electricity meters (two photograph positions), and display detection of two electricity meters (two photograph positions). There are a total of five photograph positions, and the mechanical arm presses the electricity meter. The designated 10 page display content of the camera's photograph display is identified [4].

14.2.2   Load Output Control System

The load output control system consists of a combination of visual subsystem, motion control subsystem, and motion mechanical subsystem to achieve the above functions. The detailed system diagram is shown in Fig. 14.2.

The vision subsystem is used for camera recognition and feedback control of the gear output of the load box. It is composed of an image acquisition card, an industrial camera, and a light source generator. The industrial camera captures the gear information and pointer position of the tested load box and transmits them to the image acquisition card. The image acquisition card is preprocessed and uploaded to
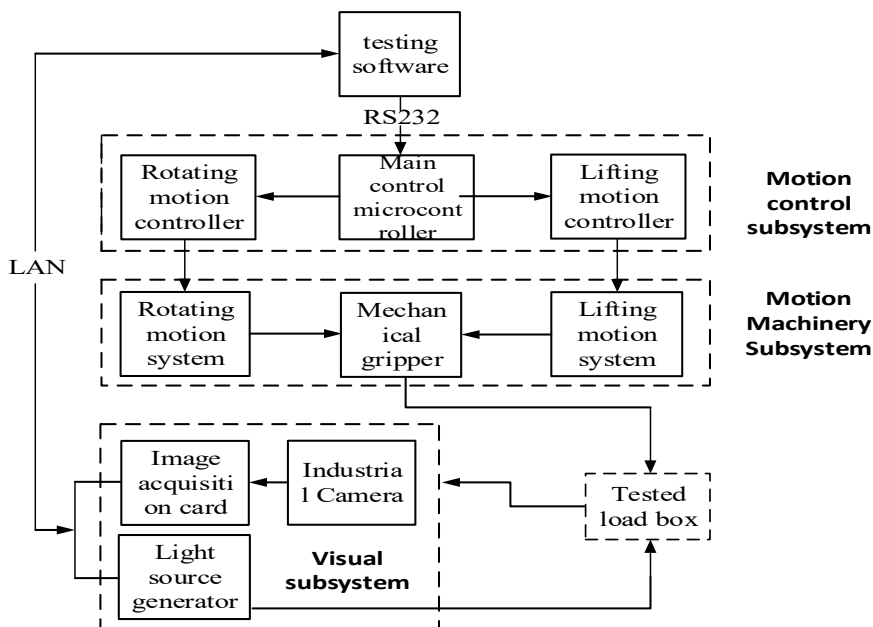

Fig. 14.2   Load box output regulation control system diagram

the image processing module of the upper computer testing software, which recognizes the image, Match the current pointer position with the required adjusted gear to provide control information for the motion control subsystem [5].

The motion control subsystem consists of a main microcontroller, a knob sleeve lifting controller, and a knob sleeve rotation controller. The master MCU communicates with the upper computer test software, and the test software sends the knob sleeve control information to the master MCU according to the image information uploaded by the vision subsystem, and the master MCU distributes the information to the lifting motion controller and the rotating motion controller [6].

The operating machinery subsystem is composed of a rotating motion system, a lifting motion system, and a knob clamp. The rotating motion system is composed of a rotating motor and a rotating screw [7]. The rotating motor receives instructions from the rotating motion control system for movement, while the lifting operation system is composed of a lifting motor and a lifting screw. The lifting motor receives instructions from the lifting motion control system for lifting movement. The lifting and rotating motion system controls the lifting and rotation of the sleeve clamp, and positions and rotates the load box gear knob [8].

14.3   Hardware Composition

14.3.1   Pin Automatic Insertion Power Supply Device

The device adopts a cylinder to push and crimp the pins, and the device has one set of single-phase and three-phase electricity meters each. This plug-in device is a professional plug-in device for the power grid, as shown in Fig. 14.3.

The upper computer uses LAN and RS232 ports to communicate with the vision subsystem and operation control subsystem, responsible for controlling the entire system work, reading industrial camera images, and analyzing the content contained

Fig. 14.3 Schematic diagram of single-phase plug-in device
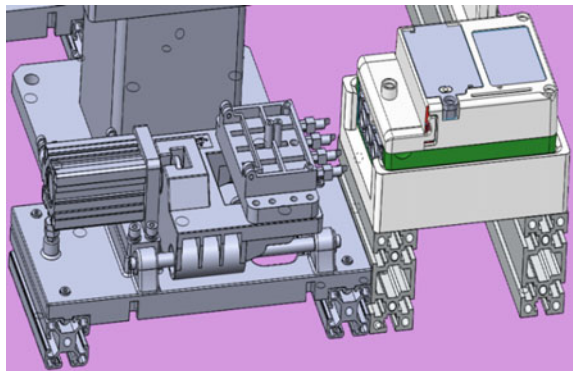
in the images; send instructions to the microcontroller controller to control the rotating motor and lifting motor for related actions.

The microcontroller chip (SMT32F4 series) of the mainstream Italian semiconductor used for industrial control is used as the main control chip of the lower computer [9]. The chip adopts an ARM-32 bit core, including 32KRAM, RS232, ADC, and 32 IO control ports.

14.3.2   Visual Inspection System

There are two sets of visual inspection, one set for each camera and one set for each light source. The visual camera adopts an industrial grade 10 million pixel camera, which meets the equipment usage requirements. The light source adopts a strip visual light source. The form is shown in the following figure, as shown in Fig. 14.4.

The industrial camera captures the text, color, area, and other features corresponding to the knob of the tested object (load box), and uploads the captured content to the upper computer software through the LAN port. Industrial cameras need to be equipped with a gigabit LAN network interface. Select a 25 mm lens and set the working distance from the lens to the knob to approximately 170 mm. Design field of view is 100 mm × 80 mm with a resolution of 1292 × 964, with a design accuracy of 0.0772 mm/pix. The lens adopts a parallel light path design, placing the aperture diaphragm of the visual system on the focal plane of the imaging side to eliminate perspective distortion and adapt to the visual image acquisition of the system.

The light source adopts a circular diffuser design, with a distance of about 100 mm from the measured object knob. It is equipped with an NG-1000 light source controller to control the brightness and lighting status (on/off).

A PCI image acquisition card with a 32bit/66 MHz LAN interface is used for the collection, recording, and processing of characteristic image data such as text, color, and area of the load box, completing functions such as testing, measurement, and signal processing analysis.

Fig. 14.4 Visual inspection system
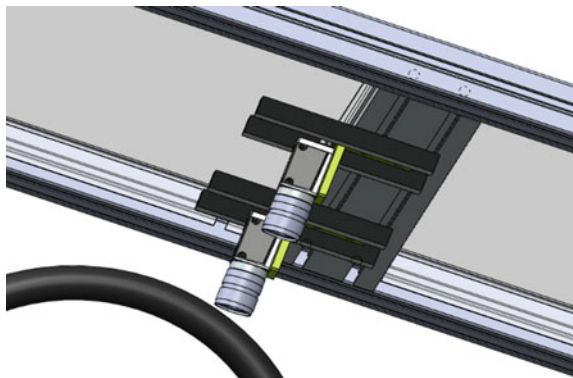
Fig. 14.5 Schematic
diagram of motor controller
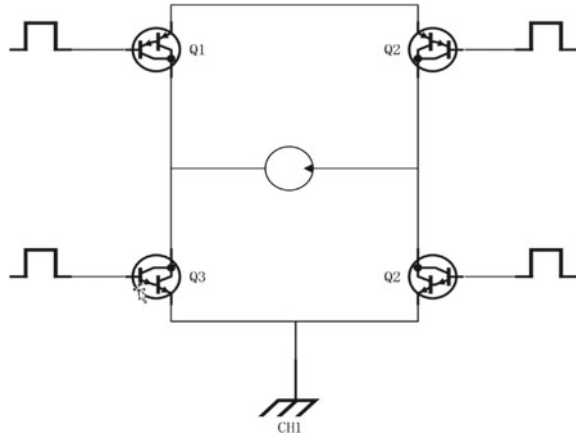
14.3.3 Motor Control System

The motor drive circuit consists of a bridge circuit composed of four high-power transistors, which can control the motor to perform forward, reverse, and brake actions, and read the corresponding protection signals to provide power outage protection for the motor [10]. The schematic diagram is shown in Fig. 14.5.

The rotating motor adopts a combination motor with a built-in reduction gear, which has simple control, high torque, and relatively low speed, making it easy to control.

The power supply adopts a 100 W AC–DC power conversion module, which can convert 220 V AC power into 24 V, 12 V, and 5 V DC.

14.4 Module Functions

14.4.1 CCD Detection

Liquid crystal image recognition is based on the image processing software of Convision in the United States, which is developed and deepened by our company. It uses industrial cameras to automatically recognize image acquisition, calibration devices load voltage, automatically analyze manufacturer information, cooperate with (image template), query and identify the image template of the manufacturer in the comparison system database, and automatically store the recognition results in the system database. The collected images are automatically stored in the corresponding barcode database, and process and upload.

Camera: The advantage of a smart camera is that it separates from the capture card and directly uses a network interface to capture images. The smart camera has

a DSP image processing system inside, which can integrate some image algorithms and more efficiently complete the tasks specified by the system. This system adopts imported high-end intelligent cameras, which have high stability and have been widely used in many industrial sites, with good practicality.

14.4.2 Identification Scheme

LCD image recognition is divided into two parts

Step 1: Template production, select a standard image as the template image, and create an image comparison template. The operation process is as follows:

(1) Template production

Click on the green small box on the interface, adjust its size and position to cover the desired positioning area. Click on the Add Locator button on the interface to confirm the positioning template.

Adjust the green small box, select the character you want to create, enter the name of the character in the character name field of the interface, set the score for the character template, and then click the Add Character button. The system will automatically create a character template for the selected area and save it to the database with the set name. Create all the characters to be recognized in sequence and complete the template production.

(2) Image recognition

After creating the template, exit the template creation interface and return to the main interface. Select the type of recognition you want to perform on the interface, and then load the image for the recognition operation into the interface by capturing or importing images with a camera.

Click the start recognition button on the interface, and the system will automatically load the corresponding template and start the template recognition operation. During the recognition process, there will be prompts on the interface for qualified, unqualified, and recognition progress.

By comparing with LCD, the unqualified images will be saved in the database for easy viewing by operators; at the same time, in order to compensate for misjudgment in image recognition (such as differences in the LCD screen itself and misjudgment in image recognition itself), the system provides a function of manually reviewing unqualified images.

The system provides an operation interface to view unqualified images based on information such as image recognition time. At the same time, meters that have not uploaded packing conclusions can be manually reviewed and modified with image conclusions. The system will update the final verification conclusion according to the situation to avoid meter verification failure due to misjudgment.

14.4.3   Real-Time Alarm

Real-time collection of PLC alarms, control system abnormal alarms, and calibration system abnormal alarms display the alarm information in the alarm information column. Once an alarm occurs, the operator can immediately detect it and take corresponding measures based on the alarm information. At the same time, the system will save the alarm information in the database for future reference. The alarm is divided into different levels, and the system will pop up an alarm information box for alarms that require human intervention based on the situation, and provide suggestions for handling and solving them. The operator can handle it according to the suggested solutions.

Output important links in the system operation process to the information list, such as starting the robot to grasp the meter, and starting the calibration line to enter the board. Record the event and its occurrence time. This way, operators can better grasp the verification process and understand the operation of the system.

This will display the current calibration process of each device in real time. If the calibration line is currently in the loading state, unloading state, or calibration state; if it is in the verification state, the specific verification phase and the estimated time required for the current phase will be displayed. The processing batch represents the total number of batches verified by the device. The last column of the table displays the connection status between the control system and the calibration system. If the calibration system program connection is closed or the connection port is caused by network reasons, this column will be displayed.

14.5   Algorithm Design

14.5.1   Image Preprocessing

Before image recognition or analysis, it is generally necessary to preprocess the image first, eliminate irrelevant information in the image, recover useful real information, and enhance the detection of information, so as to improve the reliability of feature extraction, image segmentation, matching and recognition, and make the recognition effect of image recognition algorithm more accurate. The main steps of preprocessing include grayscale, geometric transformation, and image enhancement.

(1) Graying

In this paper, the component method is used to grayscale the image. Component method refers to the brightness of the three components in the color image as the gray value of the three gray images, that is

$$f_1(i, j) = R(i, j) \; f_2(i, j) = G(i, j) \; f_3(i, j) = B(i, j)$$

where $f_k(i, j)$ $(k = 1, 2, 3)$ is the gray value of the converted gray image at (i, j).

(2) Geometric Transformation

In order to correct the systematic error of the image acquisition system and the random error of the instrument position, the geometric transformation of the image acquisition is carried out by the translation method. In addition, a grayscale interpolation algorithm is required, as the pixels of the output image may be mapped to non-integer coordinates of the input image according to the calculation of this transformation relationship.

(3) Image Intensification

In order to enhance the useful information in the image, the image can be distorted to improve its visual effect. For a given image application, it purposefully emphasizes the overall or local features of the image, makes an otherwise unclear image clearer or emphasizes some interesting features, enlarges the difference between the features of different objects in the image, and suppresses the features of interest. It can improve image quality, enrich information, enhance image interpretation and recognition ability, and meet some special analysis needs.

14.5.2 Image Preprocessing

(1) Feature extraction

Image feature extraction refers to the processing and analysis of the information in the image that is not easily disturbed by random factors, and the extraction of iconic information as image feature information. Feature extraction algorithms include: SIFT, SURF, BRISK, FREAK, and MSER.

SURF algorithm is adopted in this paper. When generating feature vectors, integral graphs and fast Hessian detectors are used to determine whether the key points extracted in scale space are extremal points. The main direction of each extreme point is determined, the window area is constructed along the main direction, and the feature vector is extracted in the window to describe the key points. Compared with SIFT algorithm, SURF algorithm maintains scale-invariant and rotation-invariant characteristics, with high speed and good robustness.

(2) Image segmentation

Image segmentation is the process of dividing an image into regions with similar features. The most basic feature of image segmentation is the brightness amplitude of monochrome image and the color component of color photograph.

This paper adopts the method of region merging. The first step is the initial region segmentation of the image. In extreme cases, each pixel can be seen as a small region. The second step is to determine the similarity standard, according to the adjacent areas of gray, color, texture, and other parameters to compare. If the gray levels of

adjacent regions are evenly distributed, the average gray levels between regions can be compared. If the average gray difference is less than a certain threshold, it is considered that the similarity of the two regions can be combined. Step 3: Determine whether the adjacent areas in the image meet the similarity criteria, and merge if they are similar. Repeat this step until there are no more regions to merge.

14.6   Software Design

The intelligent measurement system consists of four parts: automatic detection, data recording, system management, and assistance. The software composition is shown in Fig. 14.6.

Automatic detection: including visual detection and motion control, where visual detection achieves functions such as control, acquisition, and analysis of industrial cameras, while outputting control information (including control signals and position information) to the motion control subsystem; Motion control achieves motor control and mechanical action control [11].

System management: including visual calibration and system parameter setting, where visual calibration realizes the calibration functions of the visual system, initial position, and accuracy; the system parameter settings include system settings such as industrial camera IP address and local IP [12].
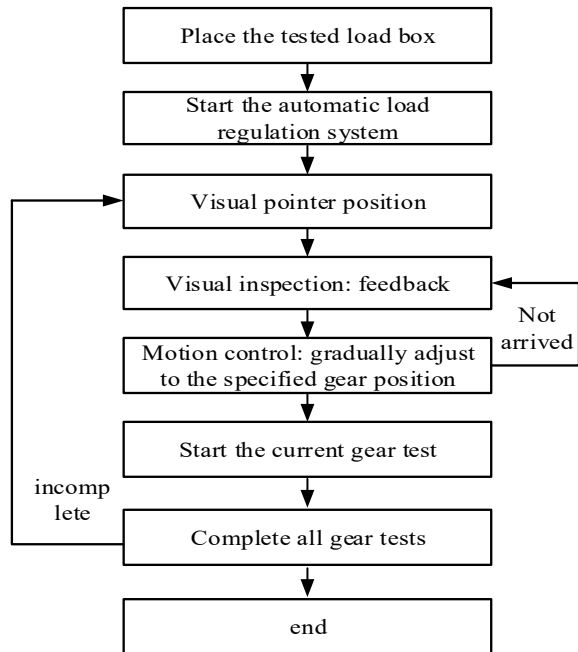
Data management: achieved the function of recording process data for visual image detection (DATALOG).

The detection process is shown in Fig. 14.7.
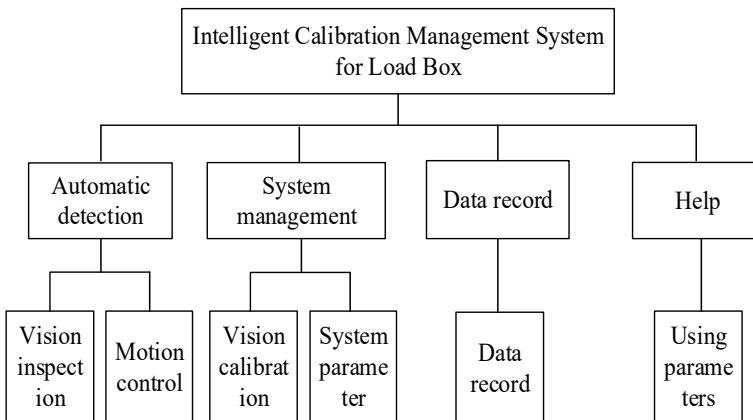
Fig. 14.6   Software composition

Fig. 14.7 Calibration
software flowchart

14.7 Conclusion

The traditional load box calibration method of manually switching gears is cumbersome and inefficient. The difficulty of fully automatic calibration of load boxes lies in the accurate adaptive adjustment output of non-programmable load box values. This article designs a circular mechanical snap ring that can grasp knobs of different sizes. Visual recognition is achieved through industrial cameras and graphics acquisition cards, tracking and feedback the pointer position of the knobs, ensuring that the load value of the load box is consistent with the current value of the test plan, and achieving the entire process automation of load box calibration.

References

1. Verification regulation of JJF1264-2010 "Measurement Transformer Load Box"
2. Lu, J., Wang, H., Li, W., Liu, Y., Wang, T., Liu, Y., Jia, J.: Transformer load box intelligent verification system design. Electrical Meas. Instrumentation **51**(11), 6–8 (2014)
3. Fu, L., Liao, Y.: A design scheme of full automatic measuring device for load boxes. Electrical Meas. Instrumentation **47**(539), 55–57 (2014)
4. Wu, Y.: Image target recognition. Nanjing University of Science and Technology School of Electronic Engineering and Optoelectronics Technology (2016)
5. Chen, H.: A computer vision recognition and matching method and its application. Comput. Telecommun. **08**, 86–88 (2007)

6. Chen, W., Wang, J., Li, X., Liang, Y., Li, L.: Discussion on calibration method of transformer load box tester. Autom. Instrumentation **02**, 137–138 (2013)
7. Chen, G.: Transformer load box method of calibration errors. Metrol. Meas. Technique 6 (2009)
8. Zhang, J., Huang, H., Fang, J.: Current transformer load box detection and error analysis. Metering Technol. 12 (2010)
9. Ren, M.: Overview of image visual recognition algorithm. Intell. Comput. Appl. **9**(3), 294–297 (2019)
10. Ren, Y.: Research on visual recognition technology of power equipment with improved maximum category variance method. China New Technol. New Products **4**, 20–22 (2021)
11. Xu, Z., Wu, W., Luo, X.-H., Zhu, D., Chen, X.-W.: Research on power equipment recognition technology based on machine vision application. Experimental Res. 23–25 (2022)
12. Wu, X., Huang, G., Sun, L.: Fast visual identification and location algorithm for industrial sorting robots based on deep learning. ROBOT **38**(6), 713–719 (2016)