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An Automotive Needle Meter Dynamic Test Method Based on Computer Vision and HIL Technology

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Abstract

In the production of automotive gauge, one of the most important step is to test the meters on the dashboard some of which are needle meters. Based on computer vision technology, a dynamic automatic reading value test method is presented in the paper. With a hardware in the loop (HIL) platform simulating the actual vehicle running state and providing sensor signals or data via CAN(controller area network) bus for the tested automotive dashboard, the needle meters of the dashboard are tested by comparing the input and indication which is obtained through image process method. As the core technology of the method, how to read the indication of the needle meters automatically is expounded in detail. The proposed method is tested on an experimental system which is composed of a HIL platform based on VECTOR dSpace and a computer vision equipment including several MV-VS078FC cameras. The HIL and vision parts can coordinately work to fulfil the automatic test procedure. The meters can be dynamically driven and precisely automatically read out.

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Keywords: Computer Vision, automatic reading value, automotive meter, hardware in the loop

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1. Introduction

In the production or in the product testing process of automotive gauge, one of the most important step is to test the meters on the dashboard some of which are needle meters. Automatic test methods play an increasingly important role in the field. Automatic reading of the needle meters is one of most challenging task in designing the automatic test systems. As the needle meters is functionally oriented to the human vision, the image recognition is the most direct and effective technical method to read their value and automatic test system based on computer vision technology is an effective way to solve this problem[1]. Some automatic reading techniques of meters based on computer vision are presented[2,3,4]. Now the needle meters of automobiles usually receive the data detected by the intelligent sensors or control units from such in vehicle communication networks as CAN(controller area network)[5]. In order to give out the dynamic data parameters in variety of vehicle operating conditions, HIL (hardware in the loop) platform is widely used in research and development of automotive electronic devices as well as their test process[6,7,8]. According to the configured automobile and its driving environment parameters, HIL platform simulates the actual automobile running situation and outputs state parameters to the detected meters on which the parameters are to be displayed[9]. Through comparing of the value displayed on the needle meters and that sent by HIL through CAN, the performance of the mater can figured out. Based on the idea, an automatic needle meter reading method based on HIL and computer vision method is presented in the paper.

2. Basics Structure and Work Flow

2.1 Basic structure

Fig.1 shows the basic structure of the system to support the test method. HIL platform comprises a computer and such hardware equipment as electronic control units and interface devices. The computer runs the automobile simulation program with the received signals from the hardware and outputs the running state parameters to the hardware. The system generates dynamic simulation data of an automobile with HIL and sends them through CAN to the tested dashboard which composed of several meters. A vision box based on MV-VS078FC cameras is employed to get the images of the concerned needle meters on the dashboard. The cameras are controlled by a computer which is named “camera control computer” in Fig.1. It receives commands from the master computer, controls the camera’s status according to the command, finishes the acquisition, and process of the meter images. The “master computer” is the control center of the system. Connected to the camera control computer and HIL with Ethernet, master computer mainly achieves human-computer interaction, configures HIL automobile simulation parameters, sends operating commands to camera control computer, receives recognition results from the camera control computer, and generates test reports.

2.2 Basic testing process

As in Fig.1, the tested instrument assembly is placed in a dark box. After installing the instrument assembly in the dark box and connecting it to HIL through CAN network, we can start the test process. The basic workflow of the testing includes six steps:

- 1) Calibration of the image operation. The master computer sends control commands to the camera control computer to complete the background image acquisition operation;
- 2) Selection of the test cases. According to the test targets the operator selects the required test cases from the HIL test case library;
- 3) Starting the testing process. The master computer sends commands to the camera control computer to start collecting the images at the set sampling rate, and sends commands to HIL to make it sends the dynamic displayed data to the dashboard through CAN according to the test case at the same time;
- 4) Collection the meter images. The camera control computer controls the cameras to continuously capture the dynamic images of the meters on the dashboard, and caches the images;

5) Analyzing the images and get the recognition results. After the dynamic test is finished, the cached images are uploaded to master computer from the camera control computer. The read values from the meters are obtained through the procession of the images, and to be compared to those sent by HIL;

6) Generation test report. The master computer generates a test report based on the test case and the meter's behavior on the reading values.

3. Image Preprocess and Parameter Calibration

The needle meters can be considered as a disc. When the scale is evenly marked up, the reading value of the current pointer can be converted by the relative angle between the needle's current position and the “zero” scale position. In order to get this relative angle from the meter images some pre-procession and calibration must be accomplished first.

3.1 Image gray processing

Scale numbers, symbols and the needle of a meter on automotive dashboard are usually in color. In order to get the information of the instrument interface and take into account the need of color detection, the image acquired by the camera is color. In the proposed method, we only are concerned with the number symbols and needle position. Therefore, the image should be first processed to get the gray image. That is to merge three gray level of RGB to a unique level for pixels in the image.

The color camera obtains a 24bit RGB image G. Its pixel (i, j) is represented with three 8-bit binary $r(i, j)$, $g(i, j)$ and $b(i, j)$ components. There are many methods to convert a color image to gray image based on the three components[10]. On the meter, each icon, number or scale, etc., usually is in one color. Therefore, the maximum value method is more conducive to get a gray image which has bigger contrast between background and foreground. The gray image F converted from G with the method can be calculated out with Equation (1).

$$f(i, j) = \text{Max}\{r(i, j) + g(i, j) + b(i, j)\} \quad (1)$$

Where $f(i, j)$ is gray level of pixel (i, j) in image F .

3.2 Binary image

In meter detection, that we only are interested in is the position of the needle and the scale marks. To cut them from the background, corresponding binary image D of F is calculated with Equation (2).

$$d(i, j) = \begin{cases} 1 & , f(i, j) \geq T \\ 0 & , f(i, j) < T \end{cases} \quad (2)$$

Where $d(i, j)$ is binary gray level of pixel (i, j) in D, T is the segmentation threshold obtained by the gray histogram of F according to OTSU method[10]. In the followings, all work is based on the binaryzation images.

3.3 Meter background image

To obtain the meter's background image, two data are sent to the meter to drive its needle at two about orthogonal positions and the images at the two case are collected respectively. The corresponding gray images are named as F_1 and F_2 . Their difference image F_s can be obtained from Equation (3).

$$f_s(i, j) = f_1(i, j) - f_2(i, j) \quad (3)$$

where $f_1(i, j)$, $f_2(i, j)$ and $f_s(i, j)$ are gray level at pixel (i, j) in F_1 , F_2 and F_s respectively.

In F_s , the pixel gray level of the meter background part is neutralized for it is same in F_1 and F_2 . The foreground is the part of the needles which is different in F_1 and F_2 . From Equation (3), it is obvious that the part of needle in F_2 is of negative gray level and the needle in F_1 being of positive gray level in image F_s . Therefore, the needle image P_1 in F_1 could be cut out through Equation (4), and the background image G_0 could be estimated with Equation (5).

$$p_1(i, j) = \begin{cases} f_s(i, j) & , f_s(i, j) \geq 0 \\ 0 & , f_s(i, j) < 0 \end{cases} \quad (4)$$

$$g_0(i, j) = f_1(i, j) - p_1(i, j) \quad (5)$$

Where $p_1(i, j)$ is the gray level of pixel (i, j) in P_1 , $g_0(i, j)$ is the gray level of pixel (i, j) in the background image G_0 .

After G_0 has been obtained, when needle moves, the needle's image P_t can be figured out through subtracting G_0 from the dynamically taken meter images.

3.4 Determination of the axis of a meter

In the process of reading the needle indication, only does the needle's position change real-timely in the obtained images, and it is the key to judge the indication. The binary image of current needle P_t could be acquired with subtracting G_0 from current image. Through Hough transform of P_t , we can get an optimal estimation of the centerline of the needle[11,12].

According to the work principle of needle meter, the intersection point of the needle's centerline at two different angle position is its axis. In order to improve the accuracy and anti-jamming capability, more than two needle centerlines are employed to estimate the axis point. Supposing that the initial point is "0" and the maximum value is "m", as well as a_m is the included angle between the centerline when the needle points to "0" and that when the needle points to "m", the following algorithm is used to calculate the needle axis coordinate:

1) From the initial position, the HIL sends excitation value data to the meter at intervals of m/n , and the camera control computer records the image $G_c(i)$, $i = 0, 1, \dots, n$, for each needle position;

2) The needle centerlines $L_p(i)$ of $G_c(i)$ is extracted by the method described above;

3) The intersection $(x(i), y(i))$ of $L_p(i)$ and $L_p(i + \Delta)$ is calculated. Where $\Delta = INT(n\pi/(2a_m))$, $i = 0, 1, \dots, n_c$, $n_c = INT(n(1 - \pi/2a_m))$;

4) The needle axis coordinate (x_c, y_c) is estimated with $x_c = \sum_{i=0}^{n_c} \frac{x(i)}{n_c}$, $y_c = \sum_{i=0}^{n_c} \frac{y(i)}{n_c}$.

In the algorithm, n is a proper selected number according to a_m and the intersection number n_c . The higher the value of n_c , the more accurate the estimated axis coordinate. In another side, bigger n_c would make the calculation more complicated. In step 3) of the algorithm, Δ is so selected that the two centerlines used to calculate an intersection would be as close as orthogonal to make the estimation more accurate.

In a test process of a meter its axis is calculated once only at the beginning.

4. Method to Obtain Dynamic Indication

4.1 Needle direction during dynamic test

In the test, the direction of the needle needs to be obtained first if the relative angle method is used to determine the current reading value. The direction can be determined with two points in the needle's centerline. The needle's centerline is to pass the centroid point of the binary image of the needle[13]. Obviously, the centerline is also to pass the axis position (x_c, y_c) . If needle image centroid point (x_m, y_m) could be picked up, the needle centerline can be obtained with (x_c, y_c) and (x_m, y_m) . The centerline's direction on the meter image plan and the angle between the centerline and the line passing "0" value position also may be figured out. Therefore, the reading value may be reckoned with them.

After the image of current needle P_t is acquired as in Section 3.3, the centroid point coordinate (x_m, y_m) could be calculated with Equation (6) according to the definition of centroid.

$$A = \sum_{i=0}^N \sum_{j=0}^M P_t(i, j)$$

$$x_m = \sum_{i=0}^N i \sum_{j=0}^M P_t(i, j) / A$$

$$y_m = \sum_{j=0}^M j \sum_{i=0}^N P_t(i, j) / A \quad (6)$$

As shown in Fig.2, if the included angle between the current needle position and abscissa is a_p and the included angle between the “0” value position and abscissa is a_0 in the coordinate system (x, y), the included angle a_t between current needle position and “0” value position can be calculated according to Table 1. In the table, a_p is defined as Equation (7).

$$a_p = \tan^{-1} \left| \frac{y_m - y_c}{x_m - x_c} \right| \quad (7)$$

4.2 Calculation of reading value

From the above analysis, the needle dynamic indication can be obtained with the following algorithm:

- 1) The camera acquires the current meter image G_t ;
- 2) The current needle image P_t is calculated out from G_t as in Section 3;
- 3) Centroid position coordinate (x_m, y_m) is calculated out with Equation (6);
- 4) a_p is calculated out with Equation (7);
- 5) a_t is calculated out according to Tab.1;
- 6) The current reading value with the needle pointing is $V_t = a_t \cdot m/a_m$.

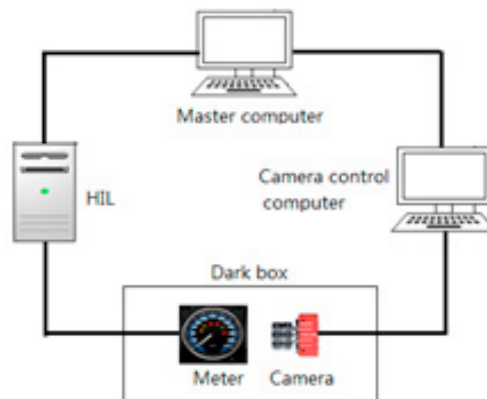


Figure1. System structure



Figure 2. (x,y) coordinate system

Table 1 Needle Angle Position Calculation Relationship

Relative position between needle centroid point and axis	a_t
$y_m - y_c > 0, \quad x_m - x_c > 0$	$\pi - a_p + a_0$
$y_m - y_c < 0, \quad x_m - x_c > 0$	$\pi + a_p + a_0$
$y_m - y_c > 0, \quad x_m - x_c < 0$	$a_0 - a_p$
$y_m - y_c < 0, \quad x_m - x_c < 0$	$a_p + a_0$

5. Experiment

The proposed method is experimented with the needle meters on an automotive dashboard.

Fig.3 is an example of data in the calibration process. Fig.3 (a) is an original image of an engine tachometer, Fig.3(b) is the gray image, Fig.3(c) is the binary image, and Fig.3(d) is the result of Hough transform of the needle image. They are calculated out successively according to the process described in Section 3 to get the centerline of the needle.

Fig.4 and Fig.5 show two dynamic test examples. In both the experiments, HIL emulates a signal source to provide displayed real data through CAN bus. In Fig.4, Fig.4(a) is the original engine speed data which is sent from HIL with an interval of one second. The engine speed data decrease linearly by the step of 100rpm from 7000rpm to 0rpm. Fig.4(b) is the displayed value which detected from the engine tachometer by the vision equipment with the rate of 10 frames per second. Fig.5(a) is the original vehicle speed data which is sent from HIL with an interval of one second. The speed data increase linearly by the step of 1km/h from 0km/h to 240km/h. Fig.5(b) is the displayed vehicle speed value which detected by the vision equipment with the rate of 10 frames per second.

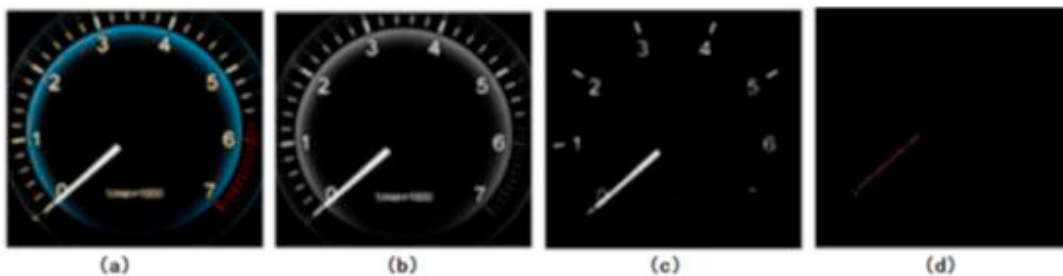


Fig.3. (a)Engine tachometer image; (b) Gray image; (c)Binary image; (d) Hough transform the result

6. Conclusion

The presented system employs a method to automatically obtain the needle meter indication based on computer vision. It can dynamically test the meters as they are working in a real application environment. The indication is derived from the needle's direction angle which is calculated with its axis and its image centroid point. The method uses the Hough transform, which is of high computational complexity, only in the calibration phase of the test process to determine the axis of the needle. In the dynamic test process, only the needle's image centroid need to be calculated with a simple algorithm. Therefore, the method is of better computational efficiency compared with the methods based on such mathematical transformation as Hough transform in all the dynamic test process. It also is of good robustness to random interference for the centroid of the needle image is insensitive to the noise. These characteristics are in favor of application in the production environment.

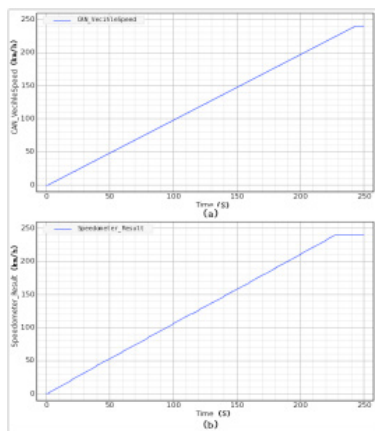


Figure.4. Dynamic test of engine tachometer

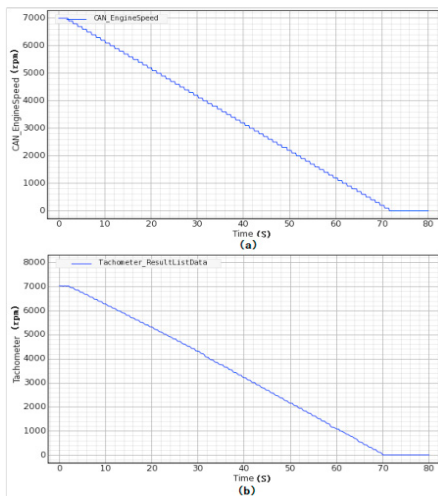


Figure.5. Dynamic test of vehicle speed meter

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