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Automatic Switching System of Rotary DIP Switch in Inspection of Digital Relay Board

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Abstract

A new system for switching rotary DIP switches (RDSs) on the board of a digital relay used as a safety device is described. This system is expected to be used for inspecting the performance of digital relays in the manufacturing process. The three-dimensional position of the narrow cross groove of an RDS is measured with a CCD camera attached to a robot hand. A screwdriver attached to the tip of the robot hand is accurately corrected to the right position, using positional data, and inserted into a groove of the RDS. This system can also detect the number of switching steps and read an illuminating pattern of LEDs on the board. The performance of this system was checked in actual use and it was confirmed that the RDS can be switched without precise positioning of the relay.

1. Introduction

The digital relay, which is a kind of breaker, is used to ensure the safety of electrical facilities. Dozens of operation modes can be set by switching rotary DIP switches (RDSs) on the relay board. In the manufacturing process of the digital relay, it is essential that each assembled product be inspected, instead of sampling inspection, because digital relays are used as safety devices.

In inspection, RDSs are adjusted to specify the operation modes of the relay, and the indication on seven-segment LEDs is read to check whether the relay is good or not. Up to now, digital relays have been inspected by hand and it has taken ten minutes per relay. As the modes to check are so many, manual inspection has frequently brought about fatal errors. For this reason, it has been strongly required to inspect the digital relay automatically. It has been difficult, however, to automatically switch RDSs using a robot, because the RDS is made of plastic and is easily damaged when turned with a screwdriver and the size of each cross groove for switching the RDS is small (0.7 mm wide and 2.9 mm long).

In this paper, we propose a system which detects the precise position of each RDS on a relay board with a CCD camera, automatically inserts a screwdriver into the groove, switches the RDS, and reads the illuminating pattern of LEDs. This system is unique in that it uses a multiple-joint robot with a CCD camera on the robot hand to detect the precise position of each RDS. This system has an advantage that it is robust against the three-dimensional positions and orientations of RDSs.

2. System Design and Performance

A schematic diagram of the switching system is shown in Fig.1. This system consists of (1) a fixed CCD camera 1 attached to a solid pole, (2) a multiple-joint robot whose tip is observed with another CCD camera 2 attached to the robot hand, (3) a computer for image processing and robot control, and (4) the digital relay which is operated by power from a current source. CCD camera 1 is used for observing the entire relay board whose size is 120mm x 80mm. A flat-tip screwdriver is also attached to the tip of the robot hand as shown in Fig.2. This screwdriver is made of acrylic resin so that its tip can be illuminated by guiding a light from above. The screwdriver is used to switch RDSs and the tip is also

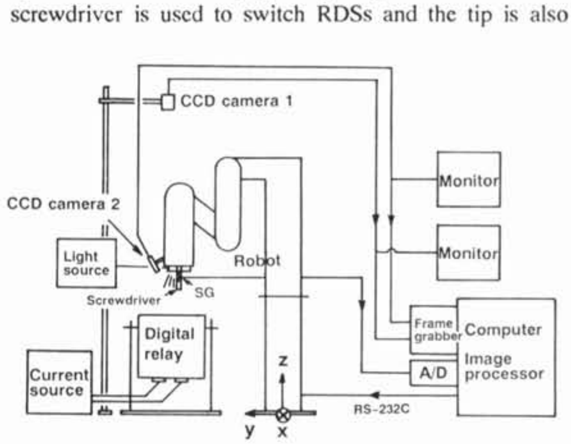

Fig.1 Schematic diagram of RDS switching system.
SG:strain gauge

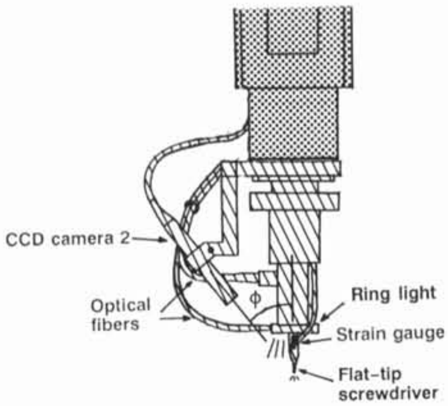

Fig.2 Expanded view of robot hand head.

illuminated by a ring light for a clear image around an RDS. The half of the ring light opposite to CCD camera 2 is shielded so that the light retroreflected by the board hardly comes into the CCD camera. The number of switching steps can be detected with a strain gauge, because the output from the strain gauge changes periodically as the screwdriver is twisted for switching. In order to deal with various types of digital relays which have various designs and sizes, the multiple-joint robot was adopted. The specifications of each component in the switching system are shown in Table 1.

In the operation of the system, the image of the relay board is first observed with CCD Camera 1. An example image observed with the camera is shown in Fig.3. The flow of switching process is shown in Fig.4. In this type of digital relay, three RDSs are arranged in line at the center and an RDS in the upper right. Seven-segment LEDs indicate a numerical value. In the image, illuminating LEDs and the left edge of the relay board can be extracted by simple thresholding. The two-dimensional coordinates (x_L, y_L) of the right LED's right lower edge and the counterclockwise inclination angle θ of the relay board against the y-axis are determined. The rectangular coordinates are as shown in Fig.1. The two-dimensional coordinates (x_n, y_n) (n=1,2,3,4) of the centers of RDSs are calculated as follows by using the obtained positional data, which are (x_L, y_L) and θ, and the relative positional relations (xr_n, yr_n) (n=1,2,3,4), or x and y components of the distance between the LED's edge and the centers of RDSs.

$$x_n = x_L + xr_n \cos\theta - yr_n \sin\theta \tag{1}$$

$$y_n = y_L + xr_n \sin\theta + yr_n \cos\theta \tag{2}$$

(n=1,2,3,4)

Relative distance data are stored in advance in the computer. The measurement accuracy is determined by the resolution of CCD camera 1. The pitch of the input image is 0.23 mm. This value is insufficient for inserting the screwdriver into a groove of an RDS. Therefore, the following process was added.

Table 1 Specifications of components in RDS switching system.

	Type	Specifications
Robot	Mitsubishi Electric MOVEMASTER RH-M2	Horizontal multi-joint type Degrees of freedom: 4
Robot hand	(of our own making)	With an acrylic flat-tip screwdriver
CCD cameras	1.Panasonic WV-MF212	1/2 inch CCD device Field: 160mm × 110mm
	2.Teli CS3150	1/2 inch CCD device Field: 16mm × 11mm
Computer	Sun SPARCStation10 Frame grabber: Data cell S2200 Software: Noesis Visilog4	Number of images captured: 3 frames (8 bit mono, 640 × 480)

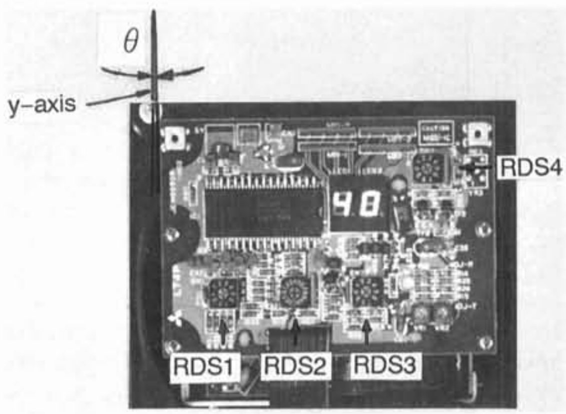

Fig.3 A relay board image observed with CCD camera 1.

After approximate two-dimensional coordinates of the RDSs had been determined, the tip of the screwdriver was transferred to the upper position of an RDS. The optical axis of CCD camera 2 was set in a plane whose y value was constant. A close-up image of the RDS was observed with CCD Camera 2 in order to determine the precise three-dimensional coordinates of the RDS. The processed RDS image is represented in Fig.5(a).

First, the original close-up image was binarized and eroded. As the area of the rotary shaft in the RDS was largest in the binary image, almost only the image of the rotary shaft could remain after erosion. The center of gravity of the eroded image, or an approximate central position of the rotary shaft, was calculated and the objective image area was limited to a small region around the position as shown in Fig.5(a) for simplifying further image processing.

Then, the limited binary image was eroded until only the image of the rotary shaft remained. An AND operation between the eroded image and the original image brought out the extracted rotary shaft in the RDS as shown in Fig.5(b). The rotary shaft image extracted above was divided into four parts by dilation and sequential erosion as shown in Fig.5(c). The centers of these four fan-shaped images were calculated in the scene for detecting two center lines of the cross groove as

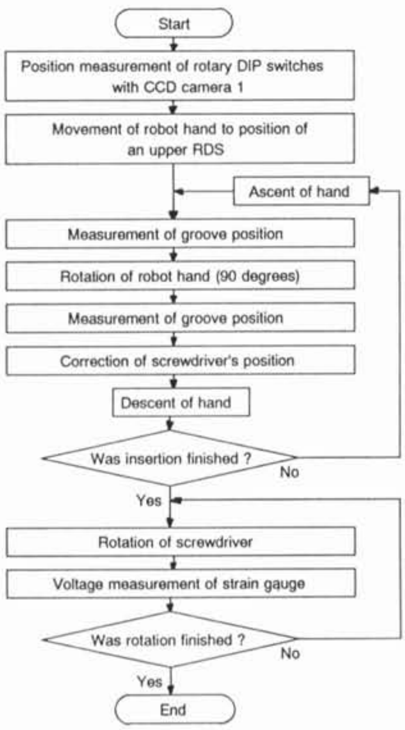

Fig.4 Flowchart for switching RDS.

shown in Fig.5(d). The two-dimensional coordinates of the center of the groove in the scene was calculated from these center lines.

As the next process, the tip of the robot arm with CCD camera 2, or the hatched part in Fig.2, was clockwise rotated by 90 degrees. The position of the cross groove image changed in the scene as shown in Fig.6. Then, the same processing for detecting the center lines of grooves as described above were repeated to determine the two-dimensional coordinates of the groove in a different sight in the scene. Using these two-dimensional coordinate data, the three-dimensional coordinates of the centers of the grooves were correctly determined by triangulation as follows.

$$x=x_a-\Delta x_c \tag{3}$$

$$y=y_a+\Delta y_c \tag{4}$$

$$z= z_s - \frac{1}{\sin\phi}\left(l_y - \Delta x_c \cos\phi \right) \tag{5}$$

where Δx_c and Δy_c are correction values, ϕ is the inclination angle of CCD camera 2 against the z-axis, and z_s is the height of the tip of the screwdriver and is an already known value. The counterclockwise rotational angles ξ_1 and ξ_2 of two grooves against the y-axis were also determined as follows.

$$\xi_1 = \tan^{-1}\frac{l_{1x}}{l_{1y}\cos\phi} \tag{6}$$

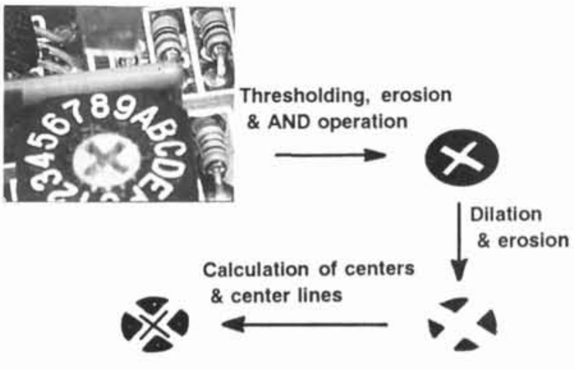

Fig.5 Algorithm for determining RDS groove position in an image.

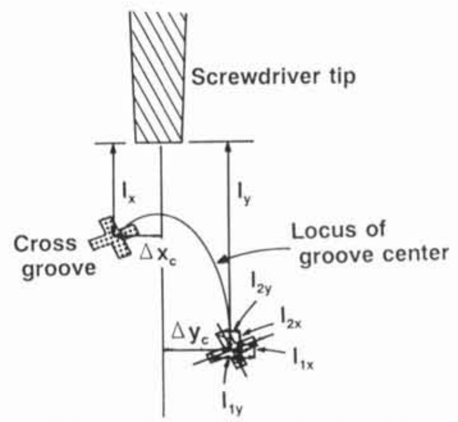

Fig.6 Position change of cross groove image in a scene by rotation of robot-hand head. l_{1x}, l_{1y}, l_{2x}, and l_{2y} are x and y components of the center line in each groove, respectively.
(Cross groove before and after rotation are indicated by hatching and dots, respectively. Position of screwdriver in the scene does not change.)

$$\xi_2 = \tan^{-1}\frac{l_{2x}}{l_{2y}\cos\phi} \tag{7}$$

The two-dimensional position of the screwdriver was then corrected with Eqs. (3) and (4) and its orientation was fitted to one of the two grooves. The screwdriver then moved downward to the groove with the ring light turned off. The tip of the screwdriver was lighted up in a range of 2 mm. When the screwdriver was inserted into a groove, the tip became dark. Although the moving distance of the screwdriver along the z-axis was obtained from the second term of Eq.(5), we could also check whether the insertion was finished or not with CCD camera 2 and stop the hand. After the screwdriver was inserted, it was rotated and stopped at a certain angle using the number of switchings detected with the strain gauge. Each time an RDS was switched, the numerical pattern of RDSs was read with CCD camera 1.

3. Experimental Results and Discussion

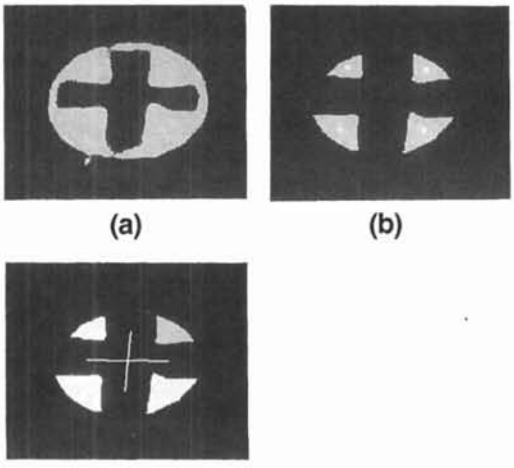

Fig.7 Experimental result of processed RDS image:
(a) extracted image of rotary shaft from RDS image,
(b) four fan-shaped images of rotary shaft separated by two grooves and their centers, and
(c) calculated center line images.

To confirm the performance of this system, switching experiments were carried out. The CCD camera angle ϕ was set at 48 degrees.

The switching operation was repeated ten times for two of four RDSs and all the angles of the rotary shaft except the angles where the RDS did not function, and it was checked whether the insertion succeeded or not. An example of successful processing of an RDS image shown in Fig.7. The frequency of successful insertion is shown in Table.2. The bottom of cross groove of RDS4 had a white stain. For this reason, dividing the rotary shaft image into four fan-shaped parts failed when the cross groove in the image was shaped like the letter "+" and its bottom was observed with the CCD camera. It requires that further experiments are carried out for other relays in order to examine whether the bottom is stained frequently or not.

In the successful operation, the orientation angles of the center lines of grooves were determined with a variation, or error, of 1.5 degrees, and the two-dimensional coordinates of the crossing point, with a variation, or error, less than 0.1 mm. It was also confirmed that the RDSs on the relay board could be switched even if the digital relay was placed in a range of $\pm$3mm from the two-dimensional position and $\pm 3^{\circ}$ from the rotational angle.

The entire switching time for one RDS was approximately 58 s. Out of this time, the positioning time, during approximate positions of RDSs were measured with CCD camera 1 and the robot hand was transferred to the upper position of an RDS, accounted for 18 s. The insertion time, during the position of the screwdriver was corrected, accounted for 31 s. and the RDS switching

Table 2 Frequency of successful insertion in switching experiments

Switch	Success	Failure	Percentage of success (%)
RDS2	160	0	100
RDS4	20	10	67

time, 9 s.

The precise positions of RDS grooves can also be measured by another hand structure, where CCD camera 2 is attached downward. With this hand, after the precise positions of RDS grooves are measured, the tip of the screwdriver is transferred to the position of an upper RDS groove and inserted. Calculation of the two-dimensional positions of RDS grooves is simpler than that by the proposed system. With this hand, however, the heights of RDSs cannot be measured and this system is not robust against the vertical locations of RDSs. Also, it would be more desirable to insert a screwdriver with visual feedback so as to make it possible to insert it even if the allowance between the screwdriver and the groove is small. With the proposed system, the position of the screwdriver will be repeatedly correctable by observing RDSs from a different angle with one more CCD camera.

4. Conclusions

We have proposed a switching system for rotary DIP switches for automatically inspecting digital relay boards. The performance was checked and it was confirmed that the screwdriver could be certainly inserted into the cross groove of the rotary DIP switch.

This method has the following advantages:
(1) relay boards of various sizes and designs can be treated by one inspection system, and
(2) the constraint on the setting of the relay board is relatively little.

An automatic inspection of digital relays may be realized when the entire flow of inspection becomes possible by the switching system.

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