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Locating Mechanical Switches Using RGB-D Sensor Mounted on a Disaster Response Robot

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Abstract

To achieve one of the tasks required for disaster response robots, this paper proposes a method for locating 3D structured switches' points to be pressed by the robot in disaster sites using RGBD images acquired by Kinect sensor attached to our disaster response robot. Our method consists of the following five steps: 1)Obtain RGB and depth images using an RGB-D sensor. 2) Detect the bounding box of switch area from the RGB image using YOLOv3. 3)Generate 3D point cloud data of the target switch by combining the bounding box and the depth image.4)Detect the center position of the switch button from the RGB image in the bounding box using Convolutional Neural Network (CNN). 5)Estimate the center of the button's face in real space from the detection result in step 4) and the 3D point cloud data generated in step3) In the experiment, the proposed method is applied to two types of 3D structured switch boxes to evaluate the effectiveness. The results show that our proposed method can locate the switch button accurately enough for the robot operation.

1. Introduction

In recent years, large-scale disasters such as accidents at the Fukushima Daiichi Nuclear Power Plant have occurred. In such disaster sites, it is necessary to investigate the damage status and to perform emergent restoration works. However, such extreme sites are very dangerous for humans to work. Therefore, demand for disaster response robots that can work on behalf of humans in the extreme sites is increasing. To meet to this demand, we are developing a disaster response robot called "WAseda REsCuer-No.1" (WAREC-1) [1], which is a quadruped robot that can work in such extreme environments.

Among many restoration work capacities required for disaster response robots, switch operation is one of the most important functions. The switch operation is also adopted as one of the tasks in the Darpa Robotics Challenge (DRC) [2], which is a competition for disaster response robots held in the United States. The switch operation is also listed as one of the work capabilities required for disaster response robots at Council on Competitiveness-Nippon [3,4] in Japan.

At present, WAREC-1 can be remotely operated so as to turn on/off a switch like many other robots participated in DRC. Such a remote operation needs tele-communications between the operator and the robot. However, in extreme environments, tele-communication is not always fully available, because tele-communication disruptions could happen frequently. In such a case, it is difficult to remote-control the restoration work. In DRC, there is also a task that simulates environments in which tele-communication is not available in a good state by intermittently interrupting tele-communication between the operator and the robot. In such a situation, it is necessary for a robot to have a certain level of autonomy for carrying out restoration works. Therefore, this research focuses on estimating the switch position necessary for operating switches autonomously using the RGB-D sensor mounted on WAREC-1.

Related studies of autonomous switch operations can be found in the field of service robots. In these studies, the robot presses general elevator buttons autonomously to navigate people across floors. These studies' methods for detecting switches are to detect the button area as a bounding box using Convolutional Neural Network (CNN) [5], or to combine Faster RCNN and OCR [6]. Elevator switches, which are addressed by these studies, are usually flat. To press the flat switch, the robot just needs to move its hand to the center of the detected bounding box. Therefore, in the bounding box these studies do not need to locate the position that should be pressed with the robot hand. In contrast, switches to be pressed by a disaster response robot are not only flat switches such as elevator switches, but also mechanical switches having 3D (3-dimentional) structures. In case of such a mechanical switch, depending on the view point, the point to be pressed by the robot is not necessarily the center of the bounding box. Thus, in addition to detecting the bounding box of a switch area, a method for locating the mechanical switch's point to be pressed needs to be achieved

This paper proposes a method that detects a 3D-structured switch and calculate the position to be pressed using the information obtained by the RGB-D sensor attached to WAREC-1. This paper focuses on pushbutton switches and tactile switches among switches.

2. Proposed Method

RGB and depth images acquired by an RGB-D sensor are used to calculate the switch position, which is necessary for an autonomous switch operation. An overview of our proposed method is shown in Fig. 1.

The proposed method consists of the following five steps:

1. An RGB image and a depth image that could contain the target switch are acquired using KINECT v2, which is an RGB-D sensor mounted on the body of WAREC-1.
2. The bounding box of the switch in the RGB image is detected using YOLOv3 [7], which is one of the object detection methods based on deep learning.
3. The center of the button's face, which is considered as the point to be pressed, is estimated within the bounding box using a CNN.
4. From the information on the bounding box and the depth image obtained from KINECT v2, depth information in the bounding box is extracted.
5. The shape of the switch is reconstructed as a 3D point cloud from the depth information, and after the noise of the 3D point cloud is removed, the center of the button's face is located using CNN.

2.1. Obtaining RGB-D information using KINECT v2

To calculate the switch position, RGB image and depth image are acquired by KINECT v2. KINECT v2 can acquire both RGB and depth images simultaneously with a resolution of 512 × 424 pixels. The effective measuring range of depth information of KINECT v2 is 0.5 [m]-8.0 [m]. KINECT v2's view angle is 70.6 x 60 degrees.

The RGB image is used to detect the switch. The depth image is used to calculate the switch position in 3D.

2.2. Detecting switch using YOLOv3

Since information such as the shape of the target switch in the disaster site is in general unknown in advance, versatility of the process for detecting different switches is required. Therefore, YOLOv3 is used to detect the switch area from the RGB image, as described in Section 2.1. The area, which could contain a switch is outputted as a bounding box. The RGB images of different switches to train YOLOv3 were collected beforehand from the Internet. Among the switches, we collected the pushbutton-type and tactile-type switch images that are the targets of the method proposed by this paper and used them as training data. The encoder used for feature extraction is Darknet53.

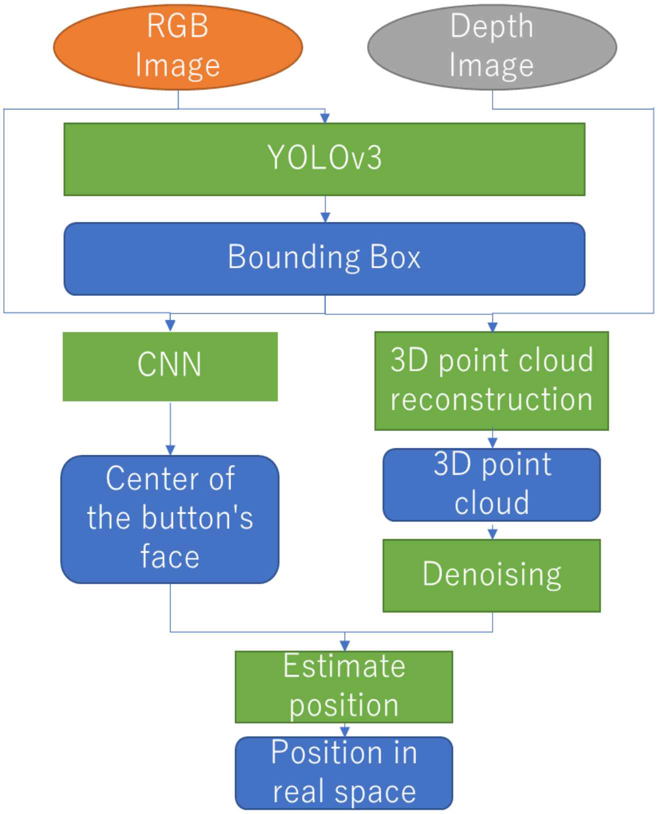
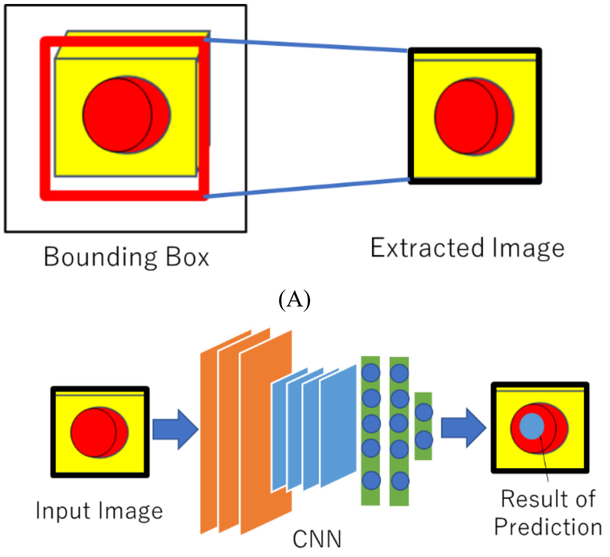


Fig. 1 Overview of the Proposed Method

2.3. Detecting the center of button's face using CNN

CNN is used to estimate the coordinates of the center of the button's face in the RGB image of the bounding box detected as a switch. As the target switch in this paper is not a flat switch, the center of the bounding box is not always a suitable position to press. Therefore, it is necessary to locate the center of the button's face in the bounding box. Since there are many variations in the shape of switches, we utilize CNN to detect the center of the button's face from the bounding box. Figure 2 shows an overview of detecting the center position of the button's face. Fig. 2 (A) shows the process of extracting the data to be inputted to the CNN. The input of the CNN is the image of the bounding box obtained by YOLOv3. Fig. 2 (B) shows the process of estimating the center position of the switch button's face using CNN. Concerning the training data, the part annotated as the switch area was cut out from the switch image data used for training the YOLOv3. Figure 3 shows the structure of the CNN.



(A)

(B)

Fig. .2 Flow of Detecting Center of Switch

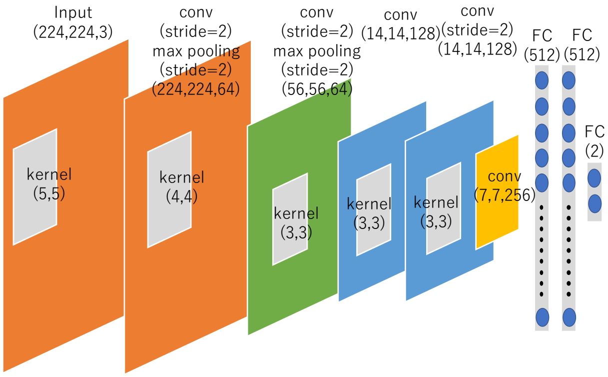
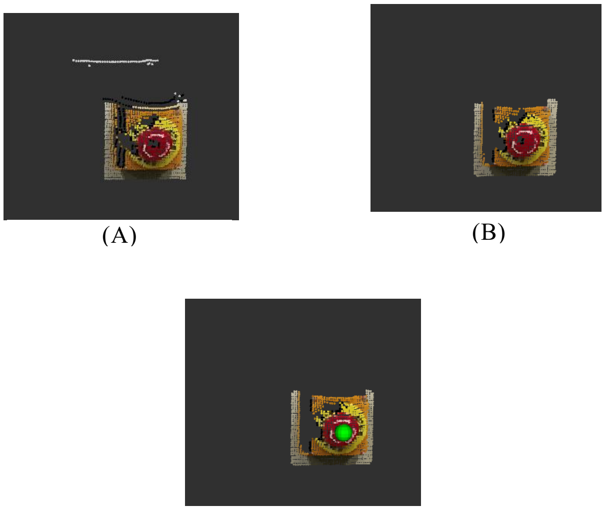


Fig. 3 Structure of CNN

2.4. Reconstructing 3D point cloud information of the switch area by overlaying RGB and depth images

The switch area in the depth image is estimated by overlaying the bounding box in the RGB image on the depth image. 3D point cloud of the switch is reconstructed based on the depth information of the area.

The coordinates of the switch region in the real space can be obtained by converting the depth image information into the 3D point cloud information.



(A)

(B)

(C)

Fig. 4 Preprocessing for Points Cloud

2.5. Detecting the position to be pressed using 3D point cloud processing

The 3D point cloud data obtained in Section 2.4 is processed using Point Cloud Library [8]. Areas that do not correspond to the switch are removed by applying a pass through filter in advance. Then, the influence of measurement errors of the depth sensor is reduced by removing outlier points using a statistical outlier filter. Thereafter, the coordinates of the center of the button's face in real space obtained in Section 2.3 are calculated.

Figure 4 shows an example of the results of each process. Fig. 4 (A) shows the point cloud information after 3D point cloud reconstructed from the depth image, (B) shows the point cloud after removing outlier points, and (C) shows the result of calculating the center coordinates of the switch operation part.

3. Experiment

3.1. Experimental environment

We carried out an experiment to evaluate the proposed method. The switch box and KINECT v2 were geometrically arranged as illustrated in Fig. 5. The distance *d* between the switch and Kinect and the orientation θ are to be estimated. Two types of switch boxes are used in the experiment. One is the switch box with a mushroom-shaped pushbutton switch (*i. e.* an emergency switch) [9], and the other is the switch box [10] with two rectangular ON and OFF buttons. As a whole, three buttons on the two switch boxes were used for the experiments.

Figure 6 shows a photo and the size of each switch box. The distance *d* between the center of the button's face and KINECT v2 was set to 60 [cm] and 80 [cm], and the angle θ was set to 0 [deg], -45 [deg], 45 [deg]. The position was measured 100 times for each switch to evaluate the measurement results.

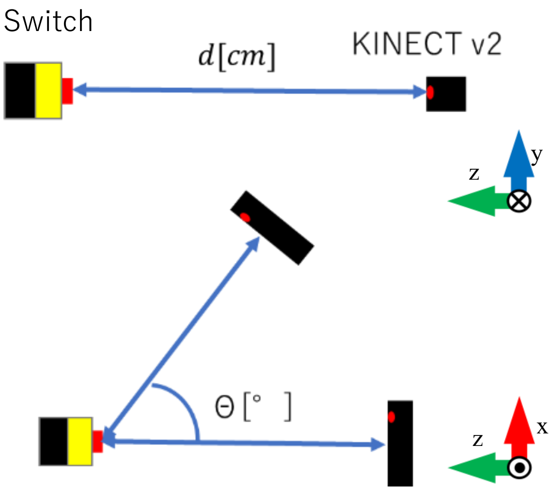


Fig. 5 Experiment Environment

(A)Emergency Switch (B) Power Open / Close Switches

Fig. 6 Target Switches

3.2. *Experimental result*

Tables 1 to 6 show the average and maximum errors of each coordinate of the detection result of the center of the button's face obtained in each experiment.

Table 1 Emergency Switch 60[cm]

	Axis	Mean error [cm]	Maximum error [cm]
-45[deg]	X	2.6	3.1
	Y	1.1	2.1
	Z	0.5	1.2
0[deg]	X	1.0	1.5
	Y	0.6	1.1
	Z	1.0	1.2
45[deg]	X	0.5	1.1
	Y	0.2	0.5
	Z	0.5	1.2

Table 2 Emergency Switch 80[cm]

	Axis	Mean error [cm]	Maximum error [cm]
-45[deg]	X	0.7	1.1
	Y	0.8	1.1
	Z	0.5	1.2
0[deg]	X	0.6	3.1
	Y	0.8	0.9
	Z	0.8	1.2
45[deg]	X	0.3	1.1
	Y	0.4	0.7
	Z	0.5	2.2

Table 3 Power Open Switch 60[cm]

	Axis	Mean error [cm]	Maximum error [cm]
-45[deg]	X	0.3	0.7
	Y	0.7	2.5
	Z	1.0	1.6
0[deg]	X	0.0	5.9
	Y	0.4	8.8
	Z	0.2	0.8
45[deg]	X	0.7	0.9
	Y	0.6	1.8
	Z	1.4	1.8

Table 4 Power Open Switch 80[cm]

	Axis	Mean error [cm]	Maximum error [cm]
-45[deg]	X	0.2	0.4
	Y	0.5	1.1
	Z	0.8	1.2
0[deg]	X	0.6	0.98
	Y	0.9	1.6
	Z	0.7	1.4
45[deg]	X	0.0	0.5
	Y	0.8	1.2
	Z	0.2	0.3

Table 5 Power Close Switch 60[cm]

	Axis	Mean error [cm]	Maximum error [cm]
-45[deg]	X	0.2	0.6
	Y	0.3	0.6
	Z	0.2	0.9
0[deg]	X	0.3	0.8
	Y	0.8	1.7
	Z	0.2	0.9
45[deg]	X	0.4	0.7
	Y	0.7	1.0
	Z	0.2	0.3

Table 6 Power Close Switch 80[cm]

	Axis	Mean error [cm]	Maximum error [cm]
-45[deg]	X	0.2	0.4
	Y	0.0	1.3
	Z	1.1	1.4
0[deg]	X	0.6	01.3
	Y	0.6	1.2
	Z	0.7	1.3
45[deg]	X	0.5	0.8
	Y	0.8	1.5
	Z	0.3	1.0

4. Discussion

4.1. Detection of the switch operation center using YOLO v3 and CNN

Figure 6 shows the switch detection results in the experiment. Though there was no significant error from the switch operation part in the detection by YOLO v3, there were some cases where the entire switch operation area is not within the detected bounding box. The reason for this is that there may be cases where CNN cannot obtain enough feature information from the image to detect the center of the button’s face accurately. In addition, since the size of the switch is relatively small in the RGB image, it can be considered that when the center of the button’s face is estimated using the CNN, the pixel resolution becomes rough and sufficient features cannot be obtained.

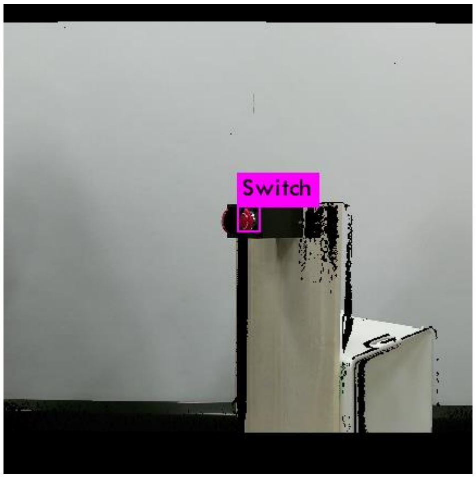


Fig. 6 Switch Detection Result using YOLO v3

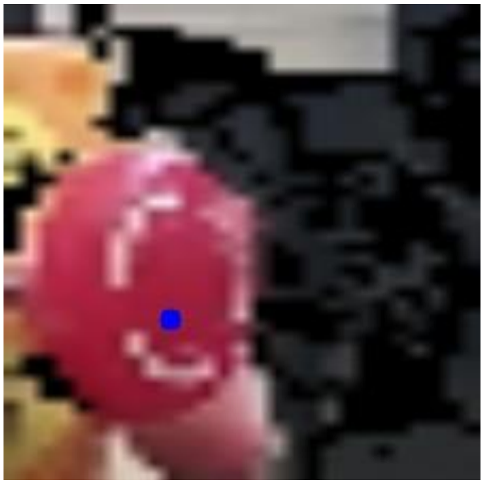


Fig. 7 Center of Switch Operating Part Detection Result using CNN

Furthermore, the center of the button’s face can be accurately detected even when the image of the mechanical switch is taken from an oblique direction, and the center of the operation unit is not at the center of the bounding box (Fig. 7).

4.2. 3D point cloud processing

In this paper, the center of the button’s face is estimated based on only one point information. Therefore, the measurement result is greatly affected by the noise of the depth sensor.

Since the outlier removal filter is not robust enough to remove the noise, it is necessary to improve a method that is more robust to measurement errors of depth information by using the surrounding point cloud information rather than calculating based on only one point cloud information.

5. Conclusion

This paper has proposed a method for locating the switch position information necessary for autonomous switch operation using the RGB-D sensor attached to the disaster response robot and evaluated the proposed method. The proposed method can be applied not only to a planar switch but also to three-dimensionally structured switches such as a mechanical switch. The proposed method contributes to operating the three-dimensional switch, which is required for disaster response robots. In the experiment, we measured the position of two types of mechanical switches by setting the distance between the switch and RGB-D sensor to 60 [cm] and 80 [cm] and the orientation to 0, -45 and 45 [deg]. From the experimental results, it turned out that it is possible to estimate the distance within mean error of 2.6[cm] in the X direction, 1.1[cm] in the Y direction, and 1.4[cm] in the Z direction.

But, to operate a switch, the information about the direction of the button's face is also required. In this research, we proposed a method that assumes that both RGB image information and depth image information can be obtained. However, there is a situation where RGB information cannot be obtained because of insufficient lighting environments at the disaster site, or it is difficult to obtain depth information using infrared rays due to smoke or dust. Therefore, in the future, we would like to develop a method that can autonomously perform restoration work even in an environment where such RGB image information or depth image information cannot be obtained sufficiently.

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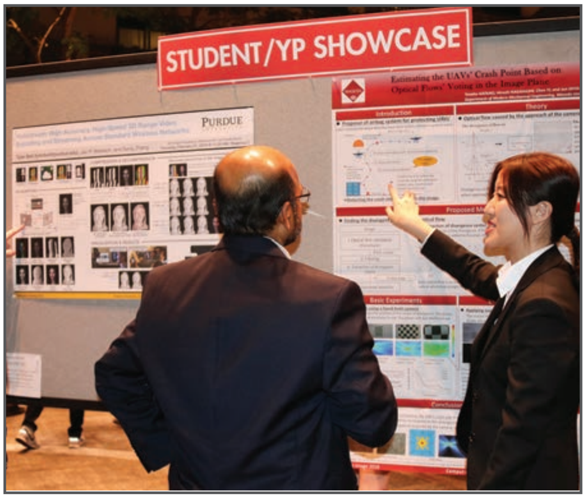

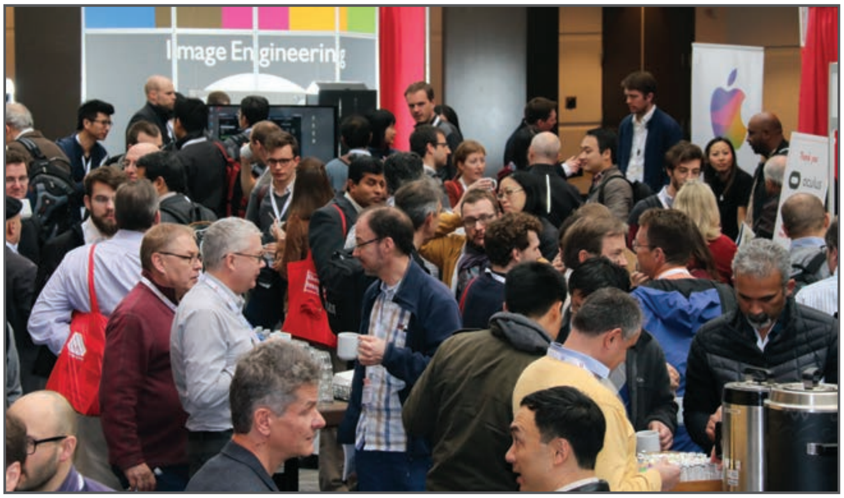

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