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A Shadow Removal Method for a Mobile Robot Localization using External Surveillance Cameras

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Abstract

Shadow detection and removal is important to deal with vision based mobile robot localization. The shadow cast by objects within environment which a mobile robot moves can lead to inaccurate object feature extraction and an erroneous scene analysis. To remove the shadow of an object, the difference image between the original and background image is usually used. However, as the shadow area caused by the light source comes out, it should be removed to obtain the accurate object image. In this paper, we used the surveillance cameras installed at the room ceiling for vision based robot localization. Time-consuming algorithm is difficult applied for the mobile robot localization. Therefore, we proposed a fast shadow removal algorithm based the HSV color space. Generally, the shadow removal method by the HSV color space is speedy but not enough to find shadow property compared with other methods. Shadow mask and HSV color space are used together to detect the shadow region. Experimental results show that the proposed method is simple to understand, can detect and remove shadow effectively for a mobile robot localization.

Keywords: Shadow; Removal; Shadow Mask; HSV; Localization; Mobile Robot; Surveillance; Camera

1. Introduction

Shadow detection and removal is important to deal with vision based mobile robot localization. The shadow cast by objects within environment which a mobile robot moves can lead to inaccurate object feature extraction and an erroneous scene analysis. Currently, the most commonly used approach of removing shadow of object is background
subtraction because of its high accuracy, but it has considerable burden of computation. Since shadow area caused by indoor light source is remained in the subtracted image, such area has to be removed to obtain accurate object image. Many researches for shadow removal have been studied and focused to find fast computed algorithm. Though the shadow detecting method of HSV color space has a little bit speedy compared with others, the property of shadow isn’t often detected. Han suggested a shadow removal way in HSV(Hue, Saturation, Value) color space by shadow mask made from background subtraction. But it has low speed, so isn’t adequate for mobile robot. In this paper we proposed a fast and efficient shadow removal method based on the HSV color space. Shadow mask and HSV color space are used together to detect the shadow region. The effectiveness of the suggested method is shown through the experiments of a mobile robot localization.

2. Shadow Removal Algorithm in HSV Color Space

In this paper, localization of a mobile robot was carried out by using several neighboring surveillance cameras mounted at indoor ceiling. Fig. 1(a) shows object images with shadow viewed by the camera. The proposed shadow removal method is composed of three steps. First step is detection of binary background subtraction image with both of object and shadow area. We got the binary image $D(x, y)$ having both of the object and shadow after background subtraction of Fig. 1(b) by applying Eq. (1). This image plays a role of mask to detect only shadow area.

$$\begin{align*}
D(x, y) &= \begin{cases} 
1, & \text{if } |I_B(x, y) - I_C(x, y)| > th \\
0, & \text{otherwise}
\end{cases} 
\end{align*}$$

where $I_B$ and $I_C$ are the gray scaled images of the background and the original by indoor surveillance camera at each. Here, the threshold value of $th$ is about 50 in gray scale and determined from previous experience.

Second step is detection of object area by using HSV color space. In the HSV color space, each H, S, V space are divided and get corresponding image information at each. In this paper, since the image from H space was unstable, we used only the property of S and V for detection of shadow. Fig. 2(a) and (b) represent detected object area by using the property of S and V in HSV color space.
where $F_S^I$ represents S channel of input image, $F_B^I$ means S channel of background image, $F_V^I$ represents V channel of input image and $F_B^V$ means V channel of background image.

$SS(x,y) = \begin{cases} 1, & \text{if } |F_S^I(x,y) - F_B^S(x,y)| \geq th_S \\ 0, & \text{otherwise} \end{cases}$ \tag{2}

$DV(x,y) = \begin{cases} 1, & \text{if } |\frac{F_V^I(x,y)}{F_B^V(x,y)}| \leq th_V \\ 0, & \text{otherwise} \end{cases}$ \tag{3}

Fig. 2. (a) SS-Binary image of background subtraction of S space; (b) DV-binary image of background subtraction of V space.

Eq. (4) and Eq. (5) were introduced to compensate the object area and we got the result of Fig. 3(a) by applying Eq. (4) and Eq. (5).

$M(x,y) = SS(x,y) + DV(x,y)$ \tag{4}

$Object\ Area(x,y) = \begin{cases} 1, & \text{if } M(x,y)=1 \\ 0, & \text{otherwise} \end{cases}$ \tag{5}

Shadow mask image $SM(x,y)$ is obtained by subtracting object area image of Eq. (5) from the difference image $D(x,y)$ of Eq. (1) as shown in Eq. (6).

$SM(x,y) = D(x,y) - Object\ Area\ (x,y)$ \tag{6}

Fig. 3. (a) Object area image; (b) shadow mask image.
Shadow mask image is in state of deleted object area but is noisy yet. In order to remove the noise component and get stable shadow area, a 7x7 median filter was applied to the shadow mask image and resulted in Fig. 4.

![Shadow mask image applied by median filter.](image)

Third step is shadow removal and restoring for the input image from the surveillance camera, and then finally detection of reliable object area. Removal of shadow is carried out by Eq. (7).

$$SR(x, y) = \begin{cases} I_B(x, y), & \text{if } SM(x, y) = 1 \\ I_C(x, y), & \text{otherwise} \end{cases}$$

(7)

where $I_B$ and $I_C$ are the gray scaled images of the background and the original by indoor surveillance camera at each.

Eq. (8) is derived to minimize noise of the object area in Fig. 3(a). In Eq. (8), only object area is remained by subtracting background image $I_B$ from shadow removed image $SR(x, y)$ of Eq. (7). And after applying thresholding work, more improved object area image can be obtained as shown in Fig. 5.

$$OD(x, y) = |SR(x, y) - I_B(x, y)| \geq \text{th}_{OD}$$

(8)

![Fig. 5. (a) Background subtracted SR image; (b) binarized image by thresholding work.](image)

3. Experiment and Discussion

Three steps for shadow removal of images from indoor surveillance cameras were proposed in this paper. The result of the proposed method is shown in Fig. 6. Comparing Fig. 6 with Fig. 1(a), we find that shadow region of objects in Fig. 1(a) is clearly removed.
Computing speed of the proposed algorithm is about 55ms for one cycle and it means 18 fps (frame per second). Comparing 0.5 s of processing speed of Han with the performance of our method, the proposed algorithm is considerably improved.

A series of experiments were carried out to show the effectiveness of the proposed shadow removal method for a mobile robot localization by using two indoor surveillance cameras. Dimension of the floor viewed by two neighboring cameras is 2.2m width and 6m length. A self-developed mobile robot with omnidirectional wheel was applied for the experiment as shown in Fig. 7. The surveillance camera has resolution of 320 x 240 pixels and 3 channels of RGB. Two neighboring cameras were used to build a map for mobile robot localization.

Fig. 8 shows two images viewed by two surveillance cameras. As shown in Fig. 8, there are several objects on the floor. A mobile robot was controlled to move one position to the opposite position. The objects, obstacles, on the floor were detected as the object area and the robot’s moving path was planned considering the object removed shadow by using the proposed algorithm. If the shadow area of the object is not removed enough, the planned moving path planning of the robot using the image information of the surveillance cameras has to consider needless area of shadow. In other words, we can obtain shorter moving path of the mobile robot by removal of shadow effects. The experimental result of the robot’s path control is shown in Fig 9. The error bound between the planned and actual moved path of the robot was about ±5 cm. This means that the proposed shadow removal method might be effective for the mobile robot localization at indoor.
4. Conclusions

A new shadow removal algorithm for a mobile robot localization in HSV color space is proposed to speed up the processing time of algorithm and maximize efficiency of shadow removal. The proposed algorithm is composed of three steps. First step is detection of binary background subtraction image with both of object and shadow area. Second step is detection of object area by using HSV color space. And third step is shadow removal and restoring for the input image, and then finally detection of reliable object area. The suggested method uses Saturation and Value regions of HSV color space to detect shadows and then apply the shadow mask to delete shadows. And to minimize the effects of noise, we used a median filter to the shadow mask. The results are quite effective and it seen that shadows are removed enough through the experiments of a mobile robot localization. Future work is to reduce the false detection rate of shadow while raising the speed of shadow removal.

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