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A Change Detection Method for Image Sequences Based on Physical Models

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SUMMARY Change detection methods are used to detect changes between two frames in an image sequence. Fundamental techniques for detecting changes use a difference image between the two frames. The change of each pixel is detected if difference values exceed a pre-set threshold, which is determined on the basis of the estimated value of the variance of noises on the frames. Not only the noises on the frames but also illumination changes between the frames are critical problems for change detection. A recently proposed approach gives a threshold derived from the average of the difference image over areas which are estimated as non-change parts. However, such a threshold may not be appropriate since the approach uses no physical parameters such as light sources, the reflection of objects. This paper proposes a new change detection method based on a physical model, which describes physical parameters such as light sources and the reflection of objects, known as an illumination model. First, we show the derivation of a new threshold based on the illumination model. The threshold is derived from the angle of the light of sources, the gray level of background objects, and the normal-vector of the background objects. A new change detection algorithm using such a threshold is shown. Next, we show experimental results and comparison, in which the proposed method improves the accuracy of detection results, compared to change detection by using the conventional threshold. We also give discussion on the features of the proposed method.
key words: *change detection, image processing*

1. Introduction

Change detection methods are used to detect changes between two frames in an image sequence. They are fundamental techniques for many applications such as object tracking, traffic flow analysis, and security systems. So far, many change detection methods have been proposed [1]–[8]. Fundamental techniques for detecting the changes are to calculate difference values in the gray level of pixels between two frames in the image sequence. The change of each pixel is detected if the difference values exceed a pre-set threshold. The threshold is determined on the basis of the estimation of the variances of added noises on the frames. The existence of illumination changes between the two frames as well as the addition of noises is one of critical problems in the change detection. Robust methods against the existence of the illumination changes have been proposed. It has been experimentally shown that the methods can reduce detection errors [6]–[8]. The techniques they use are either to adopt evaluation functions that can make the change detection tolerant of the illumination changes, or to set a threshold for a difference image between the two frames, so that the detection errors can be reduced. Especially discussion on the threshold of the illumination changes for the difference image is important, since differential (subtraction) processing is a fundamental and less-cost approach for the change detection. For example, Ref. [8] determines the threshold by calculating the averages of pixel values over estimated non-change areas in the difference image. However, such a threshold may not be appropriate since it is independent of physical parameters such as the intensity of light sources and the reflection coefficients of objects, which affect the gray level of the frames.

This paper proposes a new change detection method based on a simplified physical model which describes the physical parameters, known as an illumination model. We discuss the derivation of a new threshold for the difference image, and a new change detection algorithm by using the threshold. First, we propose a method to set the threshold on the basis of the illumination model. The threshold is derived from the angles of light sources, the gray level of objects in the first frame and the normal vectors of the objects in the first frame. For the derivation of the normal vectors, the distance image of the first frame is required. We obtain the image by triangulating stereophonic image of the first frame. A change detection algorithm is obtained based on the discussion. Next, we show simulation results. It is confirmed that the proposed approach improves detection results, compared to change detection by using the conventional threshold. We also give discussion on the features of the proposed method.

2. Proposed Change Detection Method

We assume that noises on the frames are additive white gaussian noises through this discussion, which is similar to the conventional discussion. In this section, first, we mention a threshold for illumination changes used in the conventional method. Next, the derivation of a threshold based on an illumination model is given, and a new change detection algorithm using the threshold is proposed.

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2.1 Threshold of Conventional Method

Fundamental techniques for detecting changes use difference values in the gray level of pixels between two frames in an image sequence. The change of each pixel is detected if difference values exceed a pre-set threshold. The threshold value is determined based on the estimated value of the variances of noises on the frames.

Not only noises on the frames but also illumination changes between the two frames may increase detection errors. It is very important to set an appropriate threshold in order to reduce the detection error caused by the illumination changes, similar to the noises. A conventional method gives a threshold derived from the calculation of the averages of pixels in a difference image over areas which are estimated as non-change parts [8]. The threshold value is derived as follows.

First, difference values of the illumination between two frames are estimated. The values in each pixel, $d_l(p)$, are calculated as

$$d_l(p) = \frac{1}{M}\sum_u d(u) \tag{1}$$

which are the averages of the difference image $d(p)$ over an adjacent area M. Next, a difference image after eliminating the illumination changes, $d_c(p)$, is derived as

$$d_c(p) = d(p) - d_l(p) \tag{2}$$

Finally, the average of $d_l(p)$ is calculated over areas which are estimated as non-change parts

$$N = \{p : (|d_c(p)| < 2\sigma_d) * (|d_l(p)| < T_m)\} \tag{3}$$

The average, which is used as an threshold for the illumination changes, is represented as

$$T_l = \frac{1}{N}\sum_u d_l(u) \tag{4}$$

where σ_d is the standard deviation of the noises on the difference image, T_m denotes the median value of $|d_l(p)|$, and $*$ represents product set. After this calculation, a threshold for the noises is added to the threshold (4).

Such a threshold, which is essentially set by the average processing, may not be appropriate in each pixel. Moreover, the threshold may be said to be "gray-level based," since physical parameters such as light sources, the reflection of objects, are not used. In next subsection, we propose a threshold for illumination changes, based on an illumination model.

2.2 Proposed Threshold

Throughout this paper, we call the first frame "background image," since we assume that the first frame forms only a background, and the second one has new getting-in objects in addition to the background objects. The getting-in objects are corresponding to changes between the two frames. This paper treat the alteration in the size and position of an object as changes between the two frames. However, this paper does not consider which object changes. The goal of change detection in this paper is the detection of the new objects, regardless of noises, illumination changes, and shadows, etc., which exist on the two frames.

The gray level in each pixel of the background image is represented by using an illumination model, approximately as

$$G_1 = G_p k_d \mathbf{n}_{i1}\mathbf{n}_v + G_p k_s(\mathbf{n}_{h1}\mathbf{n}_v)^n \tag{5}$$

in the proposed method. G_p is the gray level of the background objects under the assumption that the objects are plane, and the light of sources comes straight into the objects. k_d denotes the coefficient of the diffuse reflection of the objects. Similarly, k_s and n represent the coefficients of specular reflection. In this paper, x-axis is a left-direction on a camera-surface, y-axis is an upper-direction, and z-axis is a coming-direction to the camera-surface. β represents the angle of lights on x-direction, and $-\gamma$ denotes the angle of lights on y-direction. $\mathbf{n}_{i1}$ and $\mathbf{n}_v$ are the normalized vector of the light of sources, and the normal-vector on the surface of the objects, respectively. Figure 1 shows a graphical representation for relations between the vectors and the axes. Similarly, $\mathbf{n}_{h1}$ is a normalized vector derived from a relation between the vector of the light of sources and the vector on the direction of camera-view angle. Please note that the estimation of the coefficients of the specular reflection of objects from the gray levels of the images is difficult, since they depend on the surface characteristics of the objects. Therefore, we simplify Eq. (5) as

$$G_1 \approx G_d \mathbf{n}_{i1}\mathbf{n}_v \tag{6}$$

where G_d is a corresponding parameter to G_p in Eq. (5). We use such a simplified Eq. (6), that is a diffuse reflection model, as an approximation of the first images in the proposed method.

A parameter G_d is calculated as

$$G_d = \frac{G_1}{\mathbf{n}_{i1}\mathbf{n}_v} \tag{7}$$

from Eq. (6). Now, please consider that new illumination is

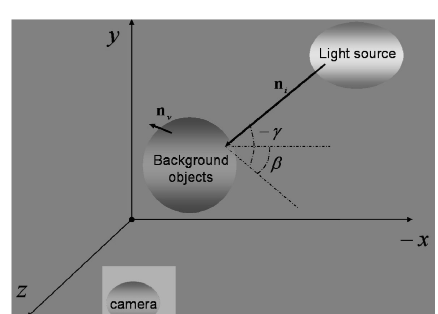

Fig. 1 A graphical representation for relations between the vectors and the axes.

added on the second image in which both the background objects, and the new objects getting in, they should be detected as changes, exists. A gray level of background parts of the second image G_2 is represented as

$$G_2 \approx G_d \mathbf{n}_{i1} \mathbf{n}_v + \alpha_G G_d \mathbf{n}_{i2} \mathbf{n}_v \tag{8}$$

$\mathbf{n}_{i2}$ is the new normalized vector of the light of sources, added on the second image. α_G is the ratio of illumination between the first light and the new light of sources, under the assumption that the objects are plane, and the light of sources comes straight into the objects.

From above discussion, we determine the threshold for the illumination changes T_p as

$$T_p = \alpha_G G_d \mathbf{n}_{i2} \mathbf{n}_v \tag{9}$$

Also adding the threshold for the noises on the images, we finally set a threshold as

$$T_f = \alpha_G G_d \mathbf{n}_{i2} \mathbf{n}_v + \alpha_N \sqrt{2\sigma^2} \tag{10}$$

α_N denotes a parameter for adjustment, and σ represents the standard deviation of the noises.

Now, we should determine $\mathbf{n}_{i1}$, $\mathbf{n}_{i2}$, α_G, α_N, and $\mathbf{n}_v$, in order to get the threshold (10). The parameters α_G is important, since this value determines the threshold value. This parameter α_G has relation with the conventional average-threshold. We discuss this relation as follows. The threshold T_p, which is represented as Eq. (9), may have different values on the each pixel of the difference image. On the other hand, the conventional threshold described as Eq. (4) is an average-threshold. Therefore, following relation

$$m[T_p] \approx T_l \tag{11}$$

holds approximately, where $m[\cdot]$ represents average operation. For simplicity, we assume that α_G is constant on all the pixels, then, α_G is derived as

$$\alpha_G = \frac{T_l}{m[G_d \mathbf{n}_{i2} \mathbf{n}_v]} \tag{12}$$

The parameter α_N is set experimentally. We assume that the vectors of the light sources are known. At this point, a parameter unknown is the normal-vector of the background objects, which is determined as follows. We propose the calculation of the gradient of the background objects by using distance measurement from camera surface to the objects, in order to derive the normal-vector. Distance values are derived by using triangulation, that is a well-known conventional approach for distance measurement, with a stereophonic background image. In this way, the normal-vector is derived as

$$[n_{vx}\ n_{vy}\ n_{vz}] = \left[\alpha_D \frac{\partial D}{\partial x}\ \alpha_D \frac{\partial D}{\partial y}\ 1\right] \tag{13}$$

where D represents the distance value, and α_D is a parameter for adjustment, that is also set experimentally. Please note that the proposed procedure requires not only the two image frames but also the stereophonic background image.

A new change detection algorithm based on the proposed threshold is shown as follows. Note that the distance image is already derived.

The Proposed Change Detection Algorithm:

(1) The calculation of the difference values between the frames

(2) The calculation of the threshold based on the illumination model
  1) The derivation of the normal-vector
  2) The computation of the parameter G_d
  3) The setting of the threshold

(3) Change detection by comparison between the diffrence values and the threshold

Above discussion does not include a threshold for specular reflection at all. Setting the threshold for the specular reflection is important, especially in the case that the reflection is strong. We utilizes the property of the specular reflection, that is, the reflection may occur in a particular direction, in order to set the threshold. We also mention the threshold in next sub-section.

2.3 Threshold for Specular Reflection

We give an improvised discussion on setting the threshold. Strong specular reflection may occur in a particular direction. Hence, it is important to detect the strength of the reflection for recognizing the reflection. This may be possible, for instance, by using edge detectors such as sobel operators for the first and the second frame.

First, we mention the case that the strong specular reflection exists on the first frame. In the case that the surface of background objects is not plane, the normal vectors of the objects change in small areas of the background image. Hence, the strength of the reflection also changes on the small areas. The change parts of the strength may be recognized as areas having the gray level of strong edges or impulse-type signals. For example, the changes of the strength may occur on the edges and the vertexes of sphere or polyhedron-type objects, etc. The real edges of other parts should not be recognized as the specular reflection. It may be possible by setting a large threshold for the edge detection. In the restricted case, an edge detection approach for recognizing the specular reflection may work. However, in the other case that, for example, the background objects are plane, the approach can not recognize the specular reflection since the reflection exists strongly in overall small areas.

Next, we mention the case that the strong specular reflection exists on the second frame where the new objects exist. Discussion on the background parts of the second frame is similar, so we mention the new objects that cover other background parts. If the coefficients of the new objects for the specular reflection is not large, then strong edge-type or impulse-type signals may not be recognized by the edge detectors. However, if the coefficients is large, then the signals may exist. The signals may be recognized as the specular reflection, not for the new objects, but for the covered background parts, since all the pixels of the second frame are interpreted as the background parts at this point. The edge detection approach can be applied to the restricted case that the new objects do not have the strong specular reflection coefficients.

We show a simple approach for recognizing the strong specular reflection in the restricted case by setting a large threshold for the edge detection, as follows. If the output of the edge detectors exceeds a pre-set threshold T_e, then, we reset the threshold for change detection as follows. In such a case, we represent the gray level of the background image as

$$G_1 \approx G_s k_s (\mathbf{n}_{h1} \mathbf{n}_v)^n \tag{14}$$

The gray level of background parts of the second frame, where the new objects getting in exist, and the new illumination is also added, is described as

$$G_1 \approx G_s k_s (\mathbf{n}_{h1} \mathbf{n}_v)^n + \alpha_S G_s k_s (\mathbf{n}_{h2} \mathbf{n}_v)^n \tag{15}$$

Therefore, the reset threshold is derived as

$$T_s = \alpha_S G_s k_s (\mathbf{n}_{h2} \mathbf{n}_v)^n \tag{16}$$

The parameter α_S is derived similarly, as discussed in the previous sub-section. The parameters k_s and n should be set as large constant values since the specular reflection is strong, although they are unknown, and also depend on the surface characteristics of the objects. The threshold of the edge detectors T_e should be also a large value.

In this way, we are able to set an improvised threshold. However, such a threshold may be less accurate. The derivation of more accurate threshold should be future work.

3. Simulation Results and Discussion

3.1 Results and Comparison

We show experimental simulation results in this section. Test images used in the simulation are the first frame that is the background image, and the second frame that has new objects getting in, where illumination changes also occur. The size of the frames is 320×240. The illumination of the first frame is almost from room lights. The second frame has another illumination, that comes out of a window.

We show detection results by using differential processing with the conventional [8] and the proposed threshold in the simulation. Both the conventional and the proposed threshold are the sum of a threshold for the illumination changes and the noises.

(Example 1)

Figure 2 and Fig. 3 show the first frame and the second frame, respectively. The variance of noises is $\sigma^2 = 3.3^2$ in both the conventional and the proposed approach. We also set the parameter for the noises as $\alpha_N = 2.5$. Figure 4 shows change detection results by using our proposed method. The parameters α_G, α_D, and α_N are 0.09, 1.0, and 3.0, respectively. The first frame has illumination with $\beta_1 = 120°$, $\gamma_1 = 30°$. The second frame has another illumination with $\beta_2 = 54°, \gamma_2 = 30°$. These values are set experimentally. For comparison, we also show detection results with the conven-

Fig. 2 The first frame (Example 1).

Fig. 3 The second frame (Example 1).

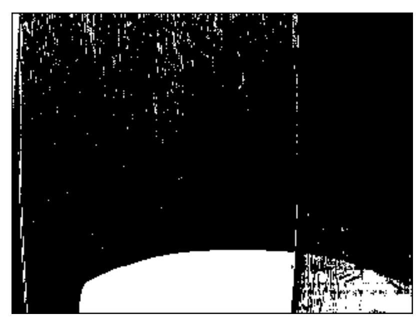

Fig. 4 The detection result by the proposed method.

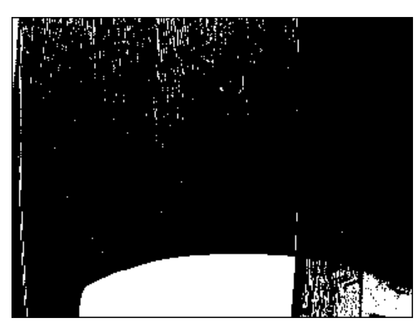

Fig. 5 The detection result with the conventional threshold.

tional threshold, shown in Fig. 5. The parameter M in the Eq. (1) for the conventional threshold is set as $M = 5 \times 5$, which is a better value than $M = 3 \times 3$, $M = 7 \times 7$, and $M = 9 \times 9$ in this example. The value of the threshold is $T_l = 23.3$. Note that change parts are marked as white, and non-change parts are black. We show these two results with almost same error in background-parts, that is the error of non-change parts, for clearness of comparison. In this example, only an elliptic object (a new object) shown in Fig. 3 should be detected, where a background object is a wall which has wooden texture shown in Fig. 2. It is difficult to detect the right side of the new object as change parts, when the conventional threshold, that is constant in all the pixels, is used. Since the gray level of the right side of the new object is similar to that of background object, the constant threshold is large for this part, so that detection is not sufficient. On the other hand, the proposed approach has better detection results, since more appropriate threshold can be set by estimating the illumination changes in each pixel by using the illumination model. The upper side of the images has large illumination changes, which may be increased by ambient lights. Such a part is detected as a change part in both the conventional and the proposed approach.

(Example 2)

Figure 6 and Fig. 7 show the first and second frame, respectively. The variance of noises is $\sigma^2 = 3.9^2$ in both the conventional and the proposed approach. We also set the parameter for the noises as $\alpha_N = 2.9$. Figure 8 shows change detection results by using our proposed method. Parameters α_G, α_D, and α_N are 0.05, 1.2, and 3.2, respectively. The first frame has illumination with $\beta_1 = 120°$, $\gamma_1 = 10°$. The second frame has another illumination with $\beta_2 = 60°$, $\gamma_2 = 10°$. We also show detection results with the conventional threshold, shown in Fig. 9. The parameter M in the Eq. (1) for the conventional threshold is set as $M = 5 \times 5$, similar to Example 1. The value of the threshold is $T_l = 20.1$. We show these two results with almost same error in object-parts, that is the error of change-parts, as opposed to Example 1. In this example, only an envelope (a new object) shown in Fig. 7 should be detected, where a background object is a book shelf shown in Fig. 6. Detection errors are also reduced in the detection results of the proposed method in this example. Localized specular reflection exists on overall small areas in the left-upper side of the frames. The proposed approach detect the part as a change part, although detection errors in this part are smaller than them of the conventional method. Since a large threshold for the edge detection is set for recognizing the specular reflection, and the reflection exists in overall small areas, the reflection is not recognized well, although the real edges of other background parts are not recognized as the specular reflection. This is a result for $T_e = 100$, $k_s = 0.9$, and $n = 10$.

(Example 3)

Figure 10 and Fig. 11 show the first and second frame, respectively. The variance of noises is $\sigma^2 = 3.7^2$ in both the conventional and the proposed approach. We also set the parameter for the noises as $\alpha_N = 2.9$. Figure 12 shows change detection results by using our proposed method. Parameters α_G, α_D, and α_N are 0.05, 1.4, and 3.2, respectively. The first frame has illumination with $\beta_1 = 105°$, $\gamma_1 = 5°$. The second frame has another illumination with $\beta_2 = 45°$, $\gamma_2 = 5°$. We also show detection results with the conventional threshold,

Fig. 6 The first frame (Example 2).

Fig. 8 The detection result by the proposed method.

Fig. 7 The second frame (Example 2).

Fig. 9 The detection result with the conventional threshold.

Fig. 10 The first frame (Example 3).

Fig. 11 The second frame (Example 3).

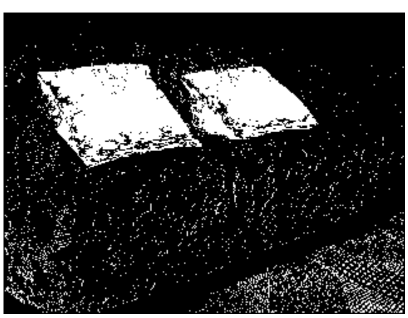

Fig. 12 The detection result by the proposed method.

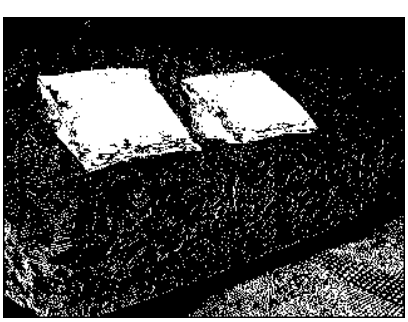

Fig. 13 The detection result with the conventional threshold.

shown in Fig. 13. The parameter M in the Eq. (1) for the conventional threshold is set as $M = 5 \times 5$. The value of the threshold is $T_l = 24.5$. We show these two results with almost same error in object-parts, similar to Example 2. In this example, only two objects (new objects) made of cloth shown in Fig. 11 should be detected, where background ob-

Fig. 14 The ideal detection image (Example 1).

Fig. 15 The ideal detection image (Example 2).

Fig. 16 The ideal detection image (Example 3).

jects are a couch, a floor, and a wall shown in Fig. 10. The illumination changes exist on the overall floor and the couch. Change detection by using the proposed threshold has better detection results, compared to the results of the change detection by using the conventional threshold. However, shadows caused by lights from right side to the objects are detected as changes in both the conventional and the proposed method.

Quantitative comparison is also discussed as follows. The error ratio of the recognition of change-parts is defined as the ratio of the amount of the wrong recognition and the amount of the true change-parts. Similarly, the error ratio of the recognition of non-change parts is derived as the ratio of the amount of the wrong recognition and the amount of the true non-change parts. We show ideal detection images for Examples 1–3 in Figs. 14–16. White parts represent the objects that should be detected as changes. These are handmade images. In Example 1, the error ratio of the recognition of the change-parts is derived as 19.77% when the conventional threshold is used, and 14.55% when the proposed method is used. The error ratio of the recognition of the non-change parts is derive as 1.94% with the conventional threshold, and 2.16% with the proposed method. Similarly, in Examples 2 and 3, the error ratio of the recognition of the change parts is derived as 24.69, 9.20% when the conventional threshold is used, and 26.67, 10.04% when the proposed method is used, respectively. The error ratio of the recognition of the non-change parts is derive as 14.53, 11.09% with the conventional threshold, and 8.80, 6.60% with the proposed method, respectively.

From these experimental results, we see that the threshold derived from the illumination parameters is more appropriate for the change detection under the illumination changes.

3.2 Discussion on The Features of The Proposed Approach

Although the proposed method can reduce detection error in comparison with change detection by using the conventional threshold, the proposed approach has problems. We summarize the properties of the proposed method as follows.

The properties of the algorithm:

1) The proposed method is able to set appropriate threshold since this is calculated in each pixel by using the parameters of an illumination model.

2) There exist many parameters which are adjusted experimentally, such as α_G, α_N, α_D.

3) The proposed approach depends on the accuracy of the distance iamge, which is calculated by using triangulation with the stereophonic background image.

4) The proposed method uses an illumination model for the diffuse reflection, for simplicity of the algorithm. That may cause the increase of detection error, if there exist objects which have strong specular reflection, or there exist strong background lights and shadows.

5) The angle of the light of sources should be known in the proposed method.

The property 3) may be a disadvantage, since triangulation causes the increase of the amount of computation, and the derivation of the stereophonic image requires more hardwares. Moreover, triangulation with the stereophonic image may have poor accuracy if the background image has plane gray level. The property 4) may cause harmful effects on the detection results in complicated situations. The illumination model used in the proposed method is simple one, where background lights or ambient lights, and shadows are neglected, which may cause detection errors. The property 5) may be less suitable for completely computer-automated systems, since we have to use the method under situations where the angle of lights are almost unchanging at least, for example, situations with room lights on ceiling or lights from windows on walls.

The proposed approach may be used for security surveillance, since a security system requires accurate change detection even though the illumination changes exist, and the approach will reduce detection errors under the situation, by using the physical parameters of the illumination model.

We show some situations where the proposed approach seems to be required and work accurately. The directions of the vectors should be known in the proposed method. The proposed method will not work well for the outside where overall natural lights exist, since the natural lights are from almost all the directions, and overall reflection or strong ambient lights exist from surroundings. On the other hand, the proposed method will work well for the inside, if only natural lights from windows or artificial lights from ceiling or walls exist, since the directions of the vectors of these lights may not change and may be known in advance. In such a case, illumination changes are caused by, for example, weather and time, artificial lights from the outside which are strengthened or weakened artificially, and also the power-down of room lights by any causes. These lights have almost fixed directions of vectors, which are set in the proposed algorithm, by studying actual situations.

These situations actually exist in practical scenes. It is important to apply the approach after sufficient experiments with the advance knowledge of actual situations. The simulation results shown in this paper are in the above cases. The two frames given in the experimental simulations are in the situations where room rights or natural lights from windows exist at the inside scene.

4. Conclusion

This paper has proposed a new change detection method based on a physical model, which describes physical parameters such as light sources and the reflection of objects, known as an illumination model. First, we have shown the derivation of a threshold based on the illumination model. The threshold has been derived from the angle of the light of sources, the gray level of background objects, and the normal-vector of the background objects. A change detection algorithm using such a threshold has been shown. Next, we have shown experimental results and comparison, in which the proposed method improves the accuracy of detection results, compared to change detection by using the conventional threshold. We have also given discussion on the features of the proposed method and future work.

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