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Illumination-invariant Active Vision

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Abstract

We have developed a visual system which adapts for varying illumination. The system has three features. First, the intensity of the image is kept constant by automatically adjusting the iris value which is a camera parameter. Second, the gray levels of an image portion of the user's interest are averaged on the assumption that localized illumination changes uniformly, and the difference between the obtained gray level average and a predetermined reference value is calculated as an illumination variable. Third, the iris value, which zeroes the illumination variable, is estimated linearly because the relationship between the iris value and the gray level average can be locally approximated by a linear function. The system was evaluated with an edge detection, while changing the illumination in a variety of ways. The system proved capable of detecting edges more stably and reliably than when the system was not used.

1 Introduction

Recently, extensive efforts have been made to develop visual systems for outdoor use, such as systems for autonomous vehicles and intrusion alarms. Unfortunately, most of the image processing algorithms used in these systems have been developed in environments with the illumination held constant. Thus, their performance is expected to deteriorate under conditions where the illumination varies with weather and time. The reason is explained below using binarization as an example. Since binarization is sensitive to variations in illumination, thresholds for binarization should be selected considering illumination. In indoor environments, where the illumination is constant, fixed thresholds can give good results. Outdoors, however, the thresholds must be changed according to the illumination. Many techniques have been proposed for automatically determining thresholds. Otsu's[1] and Kittlers'[2] methods are typical examples. Most optimal threshold techniques use calculations based on statistical methods. Before statistical techniques can be effective, they require clear images. Since it is often difficult to obtain clear-contrast image outdoors, these techniques may not always produce good effects. There are many other image processes besides binarization which depend on illumination. Thresholds for such processes must also be determined considering illumination. A system could be used outdoors if it has only one threshold process which must be determined in this way. However, outdoor use would be impossible if the system has more than one process requiring such threshold determination.

Since algorithm design alone is not a complete solution, we considered automatically-adjusting the iris value to compensate for variable illumination. Recently, devices have been developed which adjust the iris value in optical equipment. These devices estimate the illumination by scanning the entire image. Unfortunately, estimation of the entire image tends to incorrectly assume that the illumination is uniform. To solve the problem, we developed an intelligent sensor which estimates the illumination of only a localized area and adjusts the iris value according to the estimate. Even if, for example, thresholds for binarization are fixed, devices using this sensor will have brightness levels best suited for binarization.

In this paper, we first describe the structure of the sensor system and then discuss our illumination detection and sensor adjustment methods. We also report on our edge count processing experiments, performed varying the illumination. We finish with a description of the active vision we want to develop.

2 Illumination-Invariant Active Vision

Figure 1 shows our sensor system. It consists of a camera system and a controller. Bases on values from the controller, the camera system adjusts the iris value and produces images The controller receives images from the camera and estimates the current illumination by image processing. It also determines an iris value which make the difference between the estimated illumination and the predetermined reference value as close to zero as possible, sending this value to the camera system. In this way, the camera system and the controller form a loop through which the two exchange images and iris values. This feedback is repeated until the difference between the illumination estimated by the controller and the reference value is zeroed. To ensure that the level is maintained, the camera system continues to send images, allowing the controller to monitor for changes in illumination.

Two problem had to be solved when constructing this system. One was in estimating illumination through image processing and the other was in determining an iris value which make the difference between the estimated and reference illuminations as close to zero as possible.

2.1 Illumination estimation method

The gray levels in an image are closely related to the illumination. As far as one pixel is concerned, higher illumination gives a higher gray level. The illumination change in each pixel can be estimated from the difference between the gray levels before and after the change. Consider illumination changes over an entire image. Since the illumination changes uniformly over the entire image, illumination changes cannot be estimated correctly from the difference between the average of the gray levels and a reference value. For example, when the image of an object near the light source is taken, illumination changes on the object are ignored because of the strong influence of the light source.

To avoid this problem, we estimate the illumination for a localized area, designated by the user, rather than estimating illumination for the entire image. For example, the illumination of a 64 x 64 pixel sub-image, from 640 x 480 image, undergoes approximately uniform changes. The method we adopted is to calculate the gray level average over this sub-image and define the difference between the gray level averages before and after an illumination change as the value of the illumination change.

Before illumination changes can be estimated, it is necessary to determine when the illumination to be used as the reference is in effect. Before estimating illumination changes, we asked the user to designate a sub-image where the illumination is to be kept constant. At the time of designation, the method measures the gray level average over the designated sub-image and records this value in this controller.

2.2 Determining the iris value

As mentioned, the illumination change is defined as the difference between the gray level average at a given time and the reference gray level average. The controller determines the iris value so that this difference is zeroed. However, since the relationship between gray level average and iris value varies with illumination, iris values cannot be determined uniquely. Although illumination changes can be estimated from gray level average as discussed earlier, absolute illumination values cannot be estimated from gray levels. Since the relationship between gray level average and iris value is not definite, there is no other method than gradually changing the

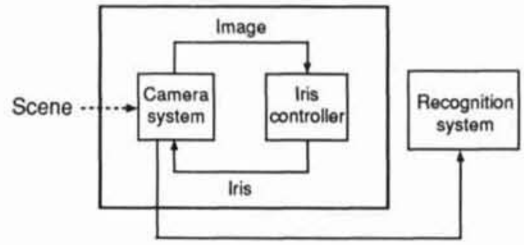


Figure 1 Sensor system configuration

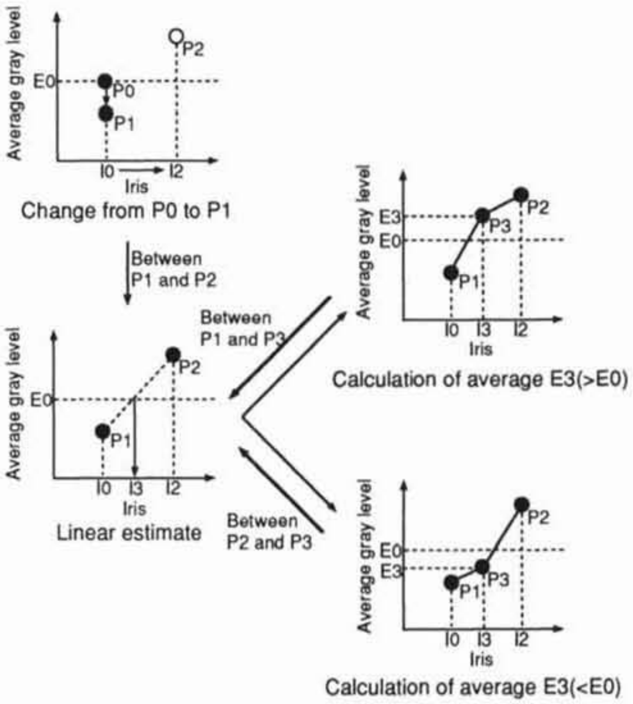


Figure 2 Determinig the iris value

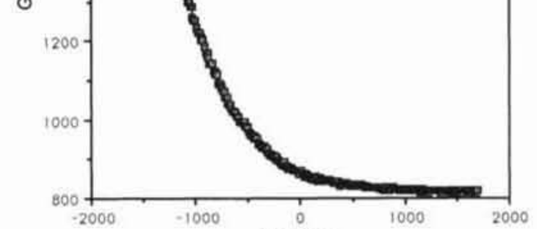


Figure 3 Relationship between iris value and gray level

iris value to make the difference close to zero.

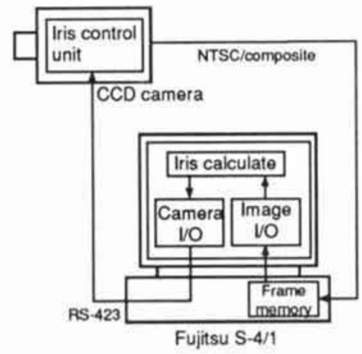
Figure 2 illustrates how the controller determines optimal iris values. Let P0 be the controller state in which the difference is 0, E0 be the gray level average in state P0, and I0 be the iris value. Suppose that the illumination changes to cause state transition from P0 to P1 in which the gray level average is E1. The controller increases the iris value so that the gray level average exceeds E0. If the gray level average fails to exceed E0, the controller further increases the iris value. When E0 is exceeded, the controller enters state P2, in which the iris value is I2. Assuming that changes in illumination are negligible during iris changes, the relationship between the iris value and the gray level average is represented by a cubic function as shown in Fig. 3. If the changes in gray level average is not extremely large, the cubic function can be approximated by a linear function. Therefore, the controller determines an iris value I3 which gives an estimation of E0, using the linear function which assumes a transition between P1 and P2. The controller sends the new iris value, I3, to the camera system and receives an image obtained with this value. The actual gray level average, E3, is calculated from this image. The controller is now is state P3. The controller compares E3 with the reference value E0. If E3 is greater than E0, the controller uses the linear function again, assuming a transition from P1 to P2. Processing is performed as in the first estimate. If E3 is less than E0, the controller uses the linear function assuming a transition from P3 to P2 for the same purpose. The controller stops adjusting the iris value when E3 and E0 become equal.

3 Experiment

In an experiment where the designated area in a stationary scene was illuminated with a lamp or masked with a plate to gradually change the illumination, the sensor system proved capable of keeping the gray level constant.

As shown in Fig. 4, the experimental system consisted of a CCD camera, which serves as the camera system with a freely adjustable iris value, and Fujitsu S family (an OEM production of SUN Microsystems Inc., SPARC station series), which serves as the controller with frame memory capable of storing images. The camera system and the controller are interconnected by a coaxial cable so that images can be transmitted from the camera system to the controller by an NTSC-compatible method. The controller stores images in its frame memory and sends iris values to the camera system through an RS-423 interface.

Using a mouse, the user first selects a 64 x 64 pixel sub-image as a localized area to be processed from the image on the controller display. The controller uses the gray level average over the sub-image for each time frame as the reference for determining an iris value. In addition to the workstation control, the experiment ex-



Fugure 4 Experimental system configuration

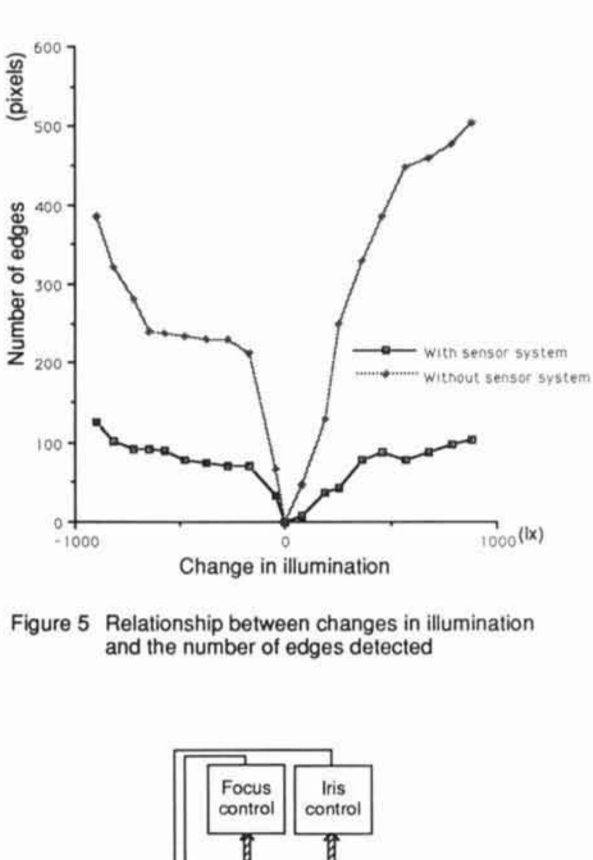


Figure 5 Relationship between changes in illumination and the number of edges detected

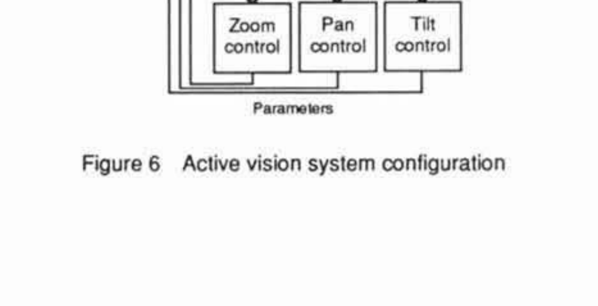


Figure 6 Active vision system configuration

amined two other types of image processing: edge detection and binarization using fixed thresholds. The controller received images with constant gray levels and performed these processing operations. The next step in the experiment was to determine how many binarized edges were detected.

Figure 5 compares the results with and without using our sensor system. Edge detection performance was evaluated by the number of edges detected before and after each change in illumination. Edges were counted for 20 changes in illumination, in 90-lx increments, under a 428-lx fluorescent lamp. As shown, the difference in the number of edges detected is much lower when the sensor system is used. This indicates that differences in the number of edges are kept stable and nearly constant in response to changes in illumination. These findings suggest that the sensor system can keep the gray levels in images constant even with variation in the illumination.

4 Discussion

We developed sensor system for automatic iris adjustment. We hope to expand on this system by building a sensor which can self-adjust the five camera parameters shown in Fig. 6: iris, focus, zoom, tilt, and pan. This system is intended to autonomously sense and compensate for environmental changes. A system which capable of automatic tilt and pan adjustment for sensing the shape, motion, and distance of objects is known as an active vision system [3][4][5]. We believe that environmental information can be obtained in greater detail. This can be achieved with active vision for the object shape and other additional pieces of environmental information, and by adjusting the iris, focus, and zoom to change the internal camera conditions. For example, resolution of density can be changed easily by changing the focus. This means that picture fineness can be easily changed in a range from somewhat blurred image, for rough sketches, to very shape images, for close pictures. The zoom can be used to adjust spatial resolution. Thus, since the image of a particular portion of an object can be taken in detail, both the outline and details of an object can be easily observed. These functions seem to allow the easy implementation of human visual capabilities, including scanning, seeing, and staring. Considering this, it seems likely that vision technology will shift its focus in the future from the study of camera movement to the study of internal camera conditions. This would allow more detailed and precise information about changes in environmental conditions.

5 Conclusion

We developed an intelligent sensor system capable of adjusting image reception so that localized areas always have a constant gray level. The gray level of these user-designated areas remain constant, even when the illumination changes. We then experimented on the system to verify its validity. As the field of image processing systems expands to outdoor applications, it becomes more difficult to adapt systems to environmental changes by only considering the image processing algorithm. Sensor systems seem to be better for adaptation to variable environments. Naturally, sensor systems are very responsive to large changes, but insensitive to subtle changes. Therefore, a primary subject for future research lies in building system adaptable to outdoor environments by combining sensor systems with image processing algorithms suitable for subtle changes.

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