THE DEVELOPMENT OF A UNMANNED WATCHING SYSTEM USING VIDEO CAMERAS

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ABSTRACT

This paper describes a technique for detecting trespassers in real time, applicable both indoors and outdoors, based on image processing.

The main part of the proposed system consists of a video camera, an image processor and a micro-processor. Images are input from the video camera to the image processor every 1/60 second, and intruding objects in the image are detected by measuring changes of intensity level in selected sensor areas.

The system exhibits the following features: (1) intruders can be detected in real time, (2) shapes and locations of active sensor areas can be selected based on detection application, (3) spurious detections are prevented by using noise removal filters, (4) high detection sensitivity is guaranteed under any environmental condition.

In this paper, the system configuration and the detection method are discussed. Experimental results under a range of environmental conditions are given.

INTRODUCTION

Techniques used to detect intruders in a hazardous site, such as a power plant or substation, or in an unmanned building at night, are quite significant in the field of unmanned watching systems.

Traditionally, the following types of methods have been used to detect intruders[1]:

(1) setting various kinds of sensors such as infrared or tension sensors,
(2) setting video cameras and a human who monitors TVs continuously,
(3) combining (1) with (2), that is, the video cameras are automatically controlled to display the detection area on a monitor when intruders are detected by a sensor.

In (1), major defects are that the active detection area is only a line, and is fixed, and that the detection area cannot be changed easily. Method (2) has the advantage of providing for more information, namely, an image of the intruder. However, a human beings are very ill-suited to this type of monitoring work, and the responsibility is too heavy. Also, this method tends to be expensive. Method (3) offers same merits as Method (2). However, the cost of the system is very high because it uses a special control unit to direct a video camera toward the point where an intruder might enter.

To solve these problems, unmanned watching systems based on video cameras have been developed, and research has been reported[2]-[5] of detecting and tracing moving objects using multiple image processing.[6] However, these systems cannot detect moving objects in real time because all pixels in an image are processed. Methods of real-time measurement of pedestrian flow and traffic flow have been reported.[7],[8] However, these methods are not suitable for watching systems because of restrictions on detectable objects and detectable passing directions of the objects.

This paper describes a technique used to detect intruders in real time without spurious detections, in both indoor and outdoor environments, using a micro-processor.

In the proposed method, the detection area is limited to a finite area surrounded by fences and/or walls. Therefore, the detection area can be reduced, because it is adequate to watch only over the boundary surrounding the detection area, which intruders must cross. In our system, several active areas are set on a monitor screen based on possible intruders' paths (see Figure 1), and trespassers are detected in real time by measuring changes of image intensity level in these active areas.

Spurious detections caused by climatic changes, optical and electric noise, or blooming phenomenon in the video camera are prevented by using noise removal filters in both time and space domains. Dummy observing pixels are also utilized.

The system configuration and the intruder detection method are discussed below. For demonstration, experimental results under various conditions are also provided.

SYSTEM CONFIGURATION

The hardware configuration of our unmanned watching system is shown in Figure 2. The main part of the system consists of a set of video cameras (four sets are the current maximum), the channel switching unit and the control unit. Other equipment includes the targets lighted at night, spot lights to illuminate intruders at night, switching relay to turn on and off the lighting equipment, power supply, VTR to record the image of a trespasser, and TV monitor.

(1) Video camera

CCD video cameras are used in the system for their durability compared to other types of video cameras. A lens with an automatic diaphragm, which controls the exposure under a wide range of brightness conditions, is used to process slow changes in brightness such as the daily change of brightness due to rising and setting of the sun.

(2) Channel switching unit

The function of the channel switching unit is to distribute video signals to the control unit and the VTR. The video signal from each video camera is transmitted to the corresponding image processor, and the unit selects one video signal channel from output of video cameras and image processor depending on the mode: (i) recording a camera image with the VTR or (ii) setting sensor points using a digitized image. The unit is controlled by the detection signal from the host processor I/O, and the selected video signal is automatically recorded by the VTR.

(3) Control unit

The control unit consists of a host CPU and pairs of image processors and slave CPUs.

The host CPU deals with the detection signals from slave CPUs, and controls other units.

Each image processor converts the video signal from its video camera into a digital image every 1/60 second, and stores the image in image memory. The slave CPU can access the image memory directly because it is located in the slave CPU's memory space. In addition to functioning as an image digitizer, the image processor generates a digital video signal which displays the location of the active areas on a monitor TV.

Each slave CPU detects intruders in real time by using the multiple image processing technique described in the following section. The intruder detection software resides in a ROM, and runs on a 16-bit micro-processor.

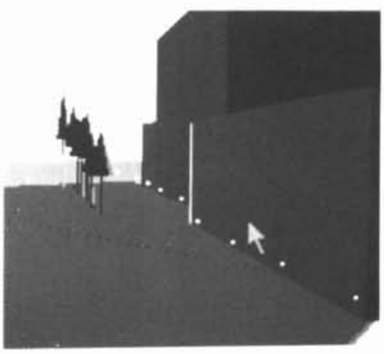

Fig. 1 (a) Active areas (white pixels) set on a screen

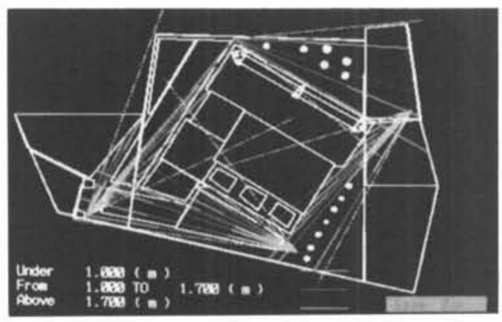

Fig. 1 (b) Top view of the detecting field. The field of view of each camera is shown by dashed lines, and the beams connecting the camera with each active area surround the watching area.

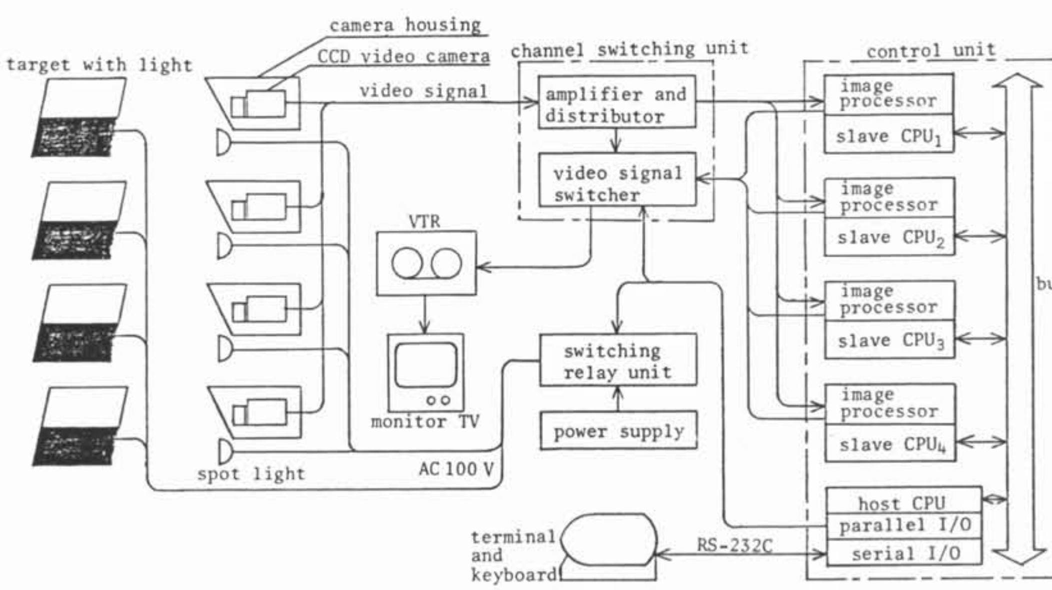

Fig. 2 System configuration

THE METHOD OF DETECTING INTRUDERS

Intruders are detected by measuring changes in intensity level at the selected active areas. The intensity level is converted to binary values by using a threshold, then passed through noise removal filters. The resulting binary values are used to determine whether an intruder has entered the watching zone. (See Figure 3)

(1) Setting active areas

If detection is performed for single pixels, spurious detections occur due to optical and/or electric noise. In order to solve this problem, active areas of pixels (called sampling pixels) are used, and intruders are detected using these sampling pixels. One of three sampling pixel configurations can be selected based on the type of objects to be detected.

(2) Intensity threshold

The method of simply comparing the intensity of two pixels that correspond to the same point on two different images may be used to detect changes in images. However, because of changes due to weather, this simple method produces numerous spurious detections when used outdoors. To solve this problem, a background intensity is calculated for each sampling pixel by averaging intensity levels over several images, using the following equation.

$$I_{AVi} = \frac{1}{K} \sum_{t=T-K+1}^{T} f_{i,t} \qquad (1)$$

I_{AVi} : background intensity of sampling pixel i
T : present time
K : number of images to calculate the background intensity (detecting parameter)
$f_{i,t}$: intensity of sampling pixel i at time t

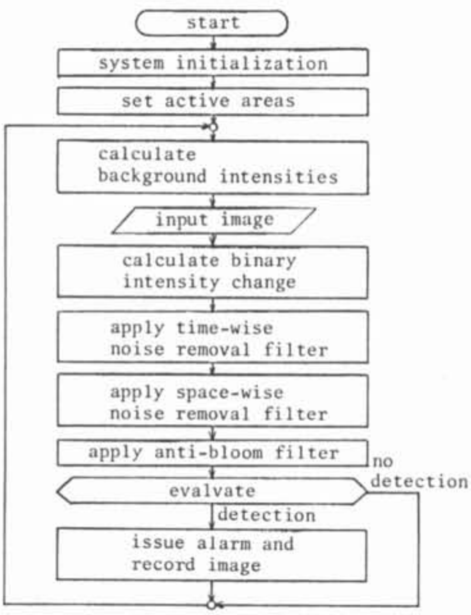

Fig. 3 Process flow chart

The intensity change of the sampling pixel is small unless an intruder passes through on the sampling pixel or the weather changes rapidly. In order to neglect slight changes of in intensity, it is converted to binary values by introducing an allowable limit to the background intensity. The binary intensity change is defined by the following equation:

$$I_{i,t} = \begin{cases} 1 & (|f_{i,t} - I_{AVi}| > L) \\ 0 & (|f_{i,t} - I_{AVi}| \leqq L) \end{cases} \qquad (2)$$

$I_{i,t}$: intensity change of sampling pixel i at time t
L : allowable limit (detecting parameter)

(3) Time domain noise removal filter

Not all the optical and/or electric noise can be removed by converting to binary values. According to experimental experience, noise does not occur consecutively but in isolation along the time axis. Taking account of this characteristic, isolated intensity changes of sampling pixels are modified along the time axis:

$$\begin{aligned} &\text{if } I_{i,T-\Delta} = I_{i,T-\Delta-1} = \cdots = I_{i,T-2} = I_{i,T} = 0 \\ &\text{and } I_{i,T-1} = 1 \text{ then } I_{i,T-1} = 0, \\ &\text{if } I_{i,T-\Delta} = I_{i,T-\Delta-1} = \cdots = I_{i,T-2} = I_{i,T} = 1 \\ &\text{and } I_{i,T-1} = 0 \text{ then } I_{i,T-1} = 1. \end{aligned} \qquad (3)$$

Δ : time threshold

(4) Space domain noise removal filter

If the detection occurs only when an intensity change occurs at every sampling pixel of an active area, the detection sensitivity is quite low. The principle of decision by majority is introduced to measure the intensity change of an active area. The intensity change of active area j at time t is defined by the following equation:

$$S_{Gj,t} = \begin{cases} 1 & (\sum_{i=k}^{p_j+k-1} I_{i,t} \geqq \frac{p_j}{2}) \\ 0 & (\sum_{i=k}^{p_j+k-1} I_{i,t} < \frac{p_j}{2}) \end{cases} \qquad (4)$$

$$k = 1 + \sum_{\ell=1}^{j-1} p_\ell$$

p_j : number of sampling pixels in active area j that consist of consecutive sampling pixels

(5) Anti-blooming filter

When a high intensity light source, such as an automobile head light, comes into the field of view of a CCD video camera at night, a high intensity vertical line passing through the center of the light appears, and can cause spurious detections. The problem is addressed by some dummy observing pixels. If the intensity change of a dummy observing pixel continues for longer than the time threshold, the intensity change of the active area is reset to zero:

$$\text{if there exist } D_x \ (x=1,2,\cdots,n_j) \text{ which satisfy } \sum_{t=T-1}^{T-2\Delta'-1} I_{Dx,t} \ge c, \quad (5)$$

$$\text{then } S_{Gj,T-\Delta'-1} = 0 .$$

D_x : dummy observing pixel
n_j : number of dummy observing pixels for active area j
$I_{Dx,t}$: intensity change of D_x at time t
$2\Delta'$: time threshold

(6) Recognizing intruder detection

When the weather changes rapidly, intensity changes occur simultaneously at almost all the active areas on a screen. When an intruder enters, intensity changes occur locally. Taking account of these facts, detecting criterion is defined as:

$$N_{min} \le F_{T-\Delta'-1} \le N_{max} \quad (6)$$

N_{min}, N_{max} : minimum and maximum number of intensity changes

where F_t is the sum of $S_{Gj,t}$ over all active areas at time t, and is defined by the following equation:

$$F_t = \sum_{j=1}^{m} S_{Gj,t} \quad (7)$$

m : number of active areas

Each slave CPU repeats the forementioned process every 1/60 second to detect intruders in real time.

IMPLEMENTATION

The detection sensitivity is set by the detecting parameters K and L. If the detection sensitivity is selected too high, the rate of spurious detections increases. On the other hand, if it is too low, the system will fail to detect intruders. First, we determined appropriate detection parameters K and L. These parameters were tested under conditions of frequent weather change, and the result offers standard values for K and L for other conditions.

Table 1 shows the relationship between detecting parameter K and the rate of spurious detections. When the parameter K was set less than or equal to 6a (a: a constant value), no spurious detections were observed.

Detecting parameter L dominates the detecting sensitivity rather than the spurious detection rate. The relationship between parameter L and the detection sensitivity was investigated. (See Figure 4)

The system was examined under various outdoor conditions. One video camera was used, and the parameter K was set to 3a. Two active areas were set on each target, and the parameter L was set to 3b (b: a constant value.) Furthermore, three active areas were located on the road with the parameter L set to 5b. The detecting sensitivity of these supplemental active areas was set to a low value in order to prevent spurious detections. Table 2 shows the results. The system exhibits high detection sensitivity. A few spurious detections were obtained during a snowfall; a lot of spurious detections occurred because of a grain of snow near the video camera that passed through all the sampling pixels of one active area. The problem may be solved by suitably changing the locations of sampling pixels.

parameter K	2a	3a	4a	5a	6a	7a	8a	9a	12a
spurious detection count	0	0	0	0	0	2	5	5	12

(a : a constant value)

Table 1 Relationship between parameter K and spurious detection rate

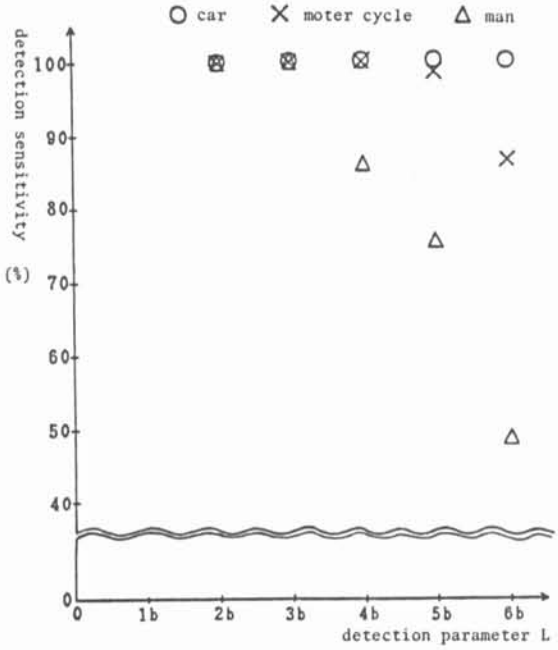

Fig. 4 Relationship between parameter L and detection sensitivity

		weather condition				
		clear	cloudy	rainy	snowy	windy
correct detection count		21	228	226	7	185
spurious detection count	target	0	0	0	103	0
	road	0	1	0	0	1
missed detection count	target	0	1	1	0	2
	road	0	5	5	3	8
spurious detection (%)		0	0.44	0	96.3	0.54
detection sensitivity (%)		100	97.4	97.4	70.0	94.9

Table 2 Result under various environmental conditions

The system was also tested under video blooming caused by automobile head lights at night. The blooming phenomenon occurred 21 times, but no spurious detection was observed.

Finally, the system was examined under indoor conditions (a passage and a room in our case.) All intruders were detected with no spurious detections.

CONCLUSIONS

An unmanned watching system to detect intruders in real time without spurious detections is proposed, and the experimental results of the system under various environmental conditions are demonstrated. The system exhibits the following features:

(1) Intruders can be detected in real time by checking the intensity levels at selected active areas which are set beforehand based on possible intruder paths.

(2) Shapes and locations of each active area can be selected depending on the type of objects to be detected and the watching purpose.

(3) Spurious detections caused by changes of the weather and video camera blooming are prevented by using noise removal filters. These filters are functions of time and space. Dummy observing pixels are also utilized.

(4) High sensitivity of detection is guaranteed under any environmental condition if the detecting parameters are set to appropriate values.

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