# ENHANCEMENT OF METHOD FOR PREVENTING ILLEGAL RECORDING OF MOVIES TO ENABLE IT TO DETECT CAMERAS WITH ATTACHED INFRARED-CUT FILTER

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# ABSTRACT

A previously proposed method for preventing the illegal recording of movies, which uses a charge-coupled device or a complementary metal oxide semiconductor device to add noise signals to the recorded content, is ineffective when the digital camera or camcorder used for the recording is equipped with an infrared-cut filter. The method has now been enhanced to make it effective even when an infrared-cut filter is used. Infrared rays specularly reflected from the filter are detected using an IR camcorder with a short-wavelength cut filter. Testing using a prototype system implemented on a 100-inch cinema screen showed that the enhanced method effectively detects in real time a camera or camcorder equipped with an infrared-cut filter.

*Index Terms*— Copyright protection, Illegal recording, Infrared-cut filter, Specular reflection

# **1. INTRODUCTION**

High-quality digital content, such as images and videos shot by individuals, is now widely available due to the rapid growth of broadband networks and the popularity of highperformance consumer audio/video equipment. Anyone these days can easily shoot videos using camcorders and make them available through the Internet. A serious problem, however, is copyright violation of content owned by others, such as images and videos, and displayed on digital signage; such content can easily be recorded using a camcorder and then made available through the Internet or sold illegally on recording media such as DVDs. The Motion Picture Association of America (MPAA) [1] estimates that the damage caused by bootleg film recordings to be three billion dollars per year [2]. This estimate takes into account the advances being made in camcorder technology that have enabled better quality recordings. Preventing the illegal recording of images and video is thus essential for copyright protection.

Digital watermarking technology can be used to trace the flow of illegally recorded digital content [3, 4], but it cannot be used to prevent a person from using a camcorder to record a film being shown in a movie theater. We previously proposed a method [5] that uses a charge-coupled device (CCD) or a complementary metal oxide semiconductor (CMOS) device to add noise signals to the recorded content, thereby corrupting it. However, it is ineffective when the digital camera or camcorder used for the recording is equipped with an infrared (IR)-cut filter.

We have now made a simple enhancement to our method so that it is effective even when the camera or camcorder is equipped with an IR-cut filter. Infrared rays reflected off the filter are detected by exploiting the IR specular reflection of the filter. We made this enhancement to our prototype system, which uses near-IR light emitting diodes (LEDs) placed on the backside of a 100-inch cinema screen, and evaluated the ability of the system to detect an IR-cut filter. The results showed that the enhanced system effectively detects in real time the use of a camcorder equipped with an IR-cut filter.

Section 2 briefly describes the original method and its shortcoming. Section 3 describes the enhancement. Section 4 describes the enhanced prototype system, and Section 5 explains how we evaluated it and presents the results. Section 6 briefly summarizes the key points.

# **2. ORIGINAL METHOD**

The method we proposed for preventing the illegal recording of images and videos is based on the difference in sensory perception between humans and devices. As mentioned above, it uses a CCD or CMOS device to add noise signals to the recorded content, thereby corrupting it [5]. The wavelength of visible light range ranges from 380 to 780 nm [6] while the wavelengths that can be detected by image sensor devices, such as the CCDs and CMOS devices used in digital cameras and camcorders, range from 200 to 1100 nm. Digital camcorders detect signals with wavelengths outside the visible range, enabling them to maintain the high level of luminous sensitivity needed for shooting in the dark. The added noise signals are in the infrared range (800 to 1000 nm), so they are invisible to the human eye but are detectable by the sensor devices. The added signals can be generated in the display (projection screen or liquid crystal display (LCD)); a new function does not need to be added to the camera used for the illegal recording. However, this

method is rendered useless by the use of an IR-cut filter on the camera.

# **3. ENHANCEMENT**

#### **3.1 Principle**

Since the camcorder used for the illegal recording must be pointed towards the screen, an IR-cut filter attached to its lens must be parallel to the screen. By placing an IR camcorder behind the screen, we can detect the IR light specularly reflected by the filter. As illustrated in Fig. 1, IR emission units for noise are used for corrupting the recorded content with noise signals that are invisible to the naked eye but are picked up by the CCDs or CMOS devices of cameras [5]. IR emission units for filter detection are newly attached at regular intervals behind the screen and an IR camcorder with a visible range cut filter is placed behind the screen at its center. A program running on a PC is used for analyzing the IR light reflected from various surfaces. The IR-cut filter is a planar filter with a dielectric multilayer, and it reflects the IR light coming from various directions in a single outgoing direction (specular reflection). The non-specular surfaces have different shapes and surface characteristics, so they reflect the incident IR light in various directions (diffuse reflection). The filter-detection algorithm can thus detect an IR-cut filter by analyzing the images of the specular reflections picked up by the IR camcorder.



Fig. 1. Principle for detecting use of camcorder equipped with IR-cut filter.

#### 3.2. Object surface reflection

The reflections from all object surfaces in the detection area must be measured in order to distinguish the reflection from an IR-cut filter from those of other objects. We use the Phong shading model [7] to do this. In this model, there is a light source, an object, and a camcorder, and the spectral radiance  $L_O(\lambda)$  for one pixel is expressed as follows.

The first term in Eq. (1) is called the diffuse reflection element, and it shows that the light reflects randomly and diffuses equally. The second term is called the specular reflection element, and it shows that the light reflects more strongly on object surfaces. The n is the decrease in reflection intensity; when the value is large, the object has properties of specular reflection, and when it is small, the object has those of diffuse reflection. The third term is called the ambient light element, and it shows that it constantly gives brightness to the surface of the object where the light is not directly from a light source.

$$L_{\varrho}(\lambda) = I_{e}(\lambda)K_{d}(\lambda)\cos\theta/r^{2} + I_{e}(\lambda)K_{s}(\lambda)(\cos\varphi)^{n} + I_{d}(\lambda)K_{a}(\lambda)$$
(1)

*r*:Distancefromlight source

 $\theta$ : Angle between light source and normal vector of object surface  $\varphi$ : Angle between camcorderand regular reflection  $I_{c}(\lambda)$ : Radiant intensity of light source  $I_{a}(\lambda)$ : Radiant intensity of ambient light  $K_{d}(\lambda)$ : Diffuse reflectance of light source  $K_{s}(\lambda)$ : Specular reflectance of light source  $K_{a}(\lambda)$ : Reflectance of ambient light  $(0 \le K_{d}(\lambda), K_{s}(\lambda), K_{a}(\lambda) \le 1)$ 

We consider the light source to be the IR emission units for filter detection, the object to be the IR-cut filter, and the camcorder to be the IR camcorder. An IR-cut filter has specular reflection; i.e., it reflects IR light received from various directions back in one direction. In the enhanced method, a short-wavelength cut filter is attached to an IR camcorder to remove the effects of visible range light, thereby excluding the influence of visible light. Specular reflection from an IR-cut filter at any location in the detection area can be observed with multiple IR light sources positioned at regular intervals to the range whose detection is possible. From the information presented above,  $K_d$ ,  $K_a$ , and  $\varphi$  are

$$K_d(\lambda) \cong 0, K_d(\lambda) \cong 0, \ \varphi \cong 0,$$
 (2)

and Equation (1) becomes

$$L_{\varrho}(\lambda) \cong I_{\ell}(\lambda). \tag{3}$$

When the case where the object sharpens is the curved surface or the object surface is not the specular surface of the above mentioned model, the decrease in specular reflection and the increase in diffuse reflection are created. Since the increment of a diffuse reflection element is inversely proportional to the square of the distance from the light source, it is smaller than the spectral radiance when the object is an IR-cut filter. That is found by measuring the IR reflection, making it possible to distinguish between an IRcut filter and other objects.

#### 3.3 IR camcorder position

People try to illegally record a displayed screen image as large as possible, and try to record a less-distorted image. Therefore, the normal vector of the surface of an IR-cut filter attached to a camcorder is fixed for a certain time while turning it towards the center of the screen. Thus, we can efficiently detect the reflected IR light by placing the IR camcorder at the center of the screen. A cinema screen has many holes, about 1 mm in diameter, to enable sound from the speakers behind it to pass through. The IR camcorder can detect the reflected IR light through these holes.

#### 3.4 IR emission unit placement

As shown in Fig. 1, IR emission units for filter detection are placed at regular intervals around the center of the screen. They can thus respond to the size of the filter. The relative position of the screen and IR-cut filter are illustrated in Fig. 2. The IR emission units are placed on the screen. The IR camcorder (point O) detects the IR light reflected from the filter, with diameter d (line *OP*). From the property of specular reflection, since the incident angle and reflection angle of IR light are equal to segment *QP*, we must segment SR (line 2d) to determine the placement of the IR emission units. Since a cinema screen is generally flat, it is necessary to appropriately place the IR emission units on the detection plane. Generally, there is a square lattice and a triangular lattice in the lattice arrangement of a plane, as shown in Fig. 3. Since the placement interval of the IR emission units depends on the size of the IR-cut filter. With the two general filter shapes (square and circle), when the length of one side of a square filter or the diameter of a circle filter are set to d, we can derive the placement interval  $l_s$  for a square lattice and  $l_t$  for a triangular lattice. Therefore, for a square area with a side length of 2d and for a circle area with a diameter of 2d, it is necessary to determine the placement interval of the square lattice and triangular lattice so that there is at least one IR light source. A circle with a diameter of 2d can be inscribed in a square with a side length of 2d, so we simply need to determine the placement interval on the basis of a circle area with a diameter of 2d. Since we have to make the intervals of the square lattice  $(l_s)$  and triangular lattice  $(l_t)$ shorter than the length of one side of the square and triangle t inscribed in a circle with a diameter of 2d, as shown in Fig. 3, we can derive

$$l_s \le \sqrt{2}d \tag{4}$$



 $l_{\star} \leq \sqrt{3}d$ .

Fig. 2. Relationship between Cinema screen and IR-cut filter.



(a) Square lattice (b) Triangular lattice **Fig. 3.** Arrangement of infrared light emission units for filter detection.

Once the IR camcorder has been positioned at the center of the video display device, it is necessary to arrange the IR emission units in a certain area centering on the IR camcorder using the placement interval described above. Since the size of the area and the number of the IR emission units depend on the size of the screen or record environment, we determined the size of the area by conducting a preliminary evaluation using the prototype system described in Section 4.

#### 3.5 Filter detection algorithm

Figure 4 shows the flow of the IR-cut filter detection algorithm. The inputs are two videos shot using the IR camcorder:

Video (a): shot in room without audience

Video (b): shot in same room with audience.

Video (a) is used for eliminating the reflections of the objects in the room that also appear in video (b).



Fig. 4. IR-cut filter detection algorithm.

# **Detection procedure**

**Step 1.** Input picture frames of video (a) and eliminate effect of flashing noise (from IR emission units).

Step 2. Average processed frames and generate one averaged frame.

**Step 3.** Do steps 4 through 8 for each series of the frames for video (b).

Step 4. Input the frames and eliminate the effect of flashing noise.

**Step 5.** Subtract the pixel values of the averaged frame for video (a) generated in step 2 from those of each frame for video (b) processed in step 4.

**Step 6.** Estimate motion areas in frames for video (b) from frames processed in step 4.

**Step 7.** Eliminate motion areas in frames for video (b) by using results of motion estimation (step 6) and eliminate diffuse reflection objects in frames for video (b).

**Step 8.** Calculate size of each reflection area, S, for video (b) and compare each one with threshold T. If S is greater than T, decide that object in reflection area is IR-cut filter and determine location of filter.

(5)

#### **4. PROTOTYPE**

We implemented this enhancement in our prototype system installed on a 100-inch cinema screen. Figure 5 shows an image displayed on the screen and an overview of the system. It has an IR camcorder with a short-wavelength cut filter (cut-on wavelength of 870 nm), 48 IR emission units for filter detection (IR LEDs with a peak wavelength of 940 nm) arranged in a 6 by 8 grid, and 9 IR emission units for noise (IR LEDs with a peak wavelength of 870 nm and a shortwavelength cut filter (cut-on wavelength of 870 nm)). The camcorder is placed behind the screen in the center, and the LEDs for filter detection are arranged at regular intervals around it. The IR light reflected from the IR-cut filter passes through the sound holes in the screen and is detected by the IR camcorder. The IR-cut filters used were a square filter with side length d of 50 mm and a circular filter with diameter d of 50 mm. The distance between the IR LEDs for detection was 70 mm as determined using Eq. (4).



(a) Displayed image (b) Backside Fig. 5. System overview.

# 5. EVALUATION

# 5.1 Method

We evaluated the ability of the prototype system to detect an IR-cut filter. As shown in Figure 6, we placed objects that would normally be in a movie theater at distances of  $\sim$ 4.5 m from the screen. We classified the objects into four groups, as shown in Table 1. The camcorders (Group D) were placed one at a time at nine different locations and, at each position, they were oriented so that they captured the whole screen at maximum size.

Table 1. Reflection objects.

	Group	Object Type	Objects
	Α	Theater facilities	(1) Beam projector (2) Chair
	В	Audiences' belongings (moving)	(3) Eyeglasses(4) Watch(5) Tie clip(6) ID card(7) Pen(8) Mobile phone(9) Plastic bottle(10) Snack package
	С	Things audience carry into theaters (static)	(11) Plastic bottle(12) Eyeglasses (13) Watch(14) Drinking glass (15) Pen(16) Nylon bag
	D	Things pirates carry into theaters	(17) Camcorder with attached IR-cut filter (18) Normal camcorder (without filter)

### 5.2 Results

Figure 7 shows an example image after processing using the filter detection algorithm when threshold T was set to 50 (pixels). The area circled in red is the area for which an IR-cut filter was detected. It corresponds to the camcorder with an IR-cut filter attached (no. (17)). The beam projector light

source (no. (1)) was eliminated in the background difference step (5) in the algorithm, and the reflections from the audience's belongings (no. (3) to (10)) were eliminated in the motion estimation step (6). The filter was detected in about one second, so real-time detection is possible. The enhanced method can thus be used to detect camcorders illegally used in movie theaters even when they are equipped with an IR-cut filter.





Fig. 6. Evaluated objects.

Fig. 7. Evaluation results.

### 6. CONCLUSION

Preventing people from illegally recording movies displayed in movie theaters is essential for enforcing copyright laws. Laws prohibiting such recording are being better enforced, and methods using watermarking to detect illegally recorded videos have been developed. However, a method is still needed to detect illegal recording. We previously proposed such a method, but it was ineffective when the camcorder used for the recording was equipped with an IR-cut filter. We have now enhanced the method so that it can detect the IR specular reflection from an IR-cut filter. Testing using our prototype system showed this enhancement enables our method to can detect camcorders with an attached IR-cut filter.

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