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An Approach to Individual Video Camera Identification*

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ABSTRACT: This paper presents a method that can be used to determine whether or not questioned video images were recorded with a specific video camera. This type of identification can be made because the nonhomogeneous nature of dark currents in charge coupled devices (CCDs) can be detected by integrating multiple images and the distribution pattern of the nonhomogeneous dark currents is unique and intrinsic to a specific camera. The distribution patterns of the dark currents in nine cameras representing four different types were examined. In eight of the nine cameras (three types), unique detectable patterns were identified in recorded blank images, indicating that it should be possible to identify whether or not a given image had been recorded with a given camera. The method presented was used in an actual case to determine whether or not questioned video images of a criminal scene were recorded with the suspect's camera, and the results of that effort are reported.

KEYWORDS: forensic science, engineering, identification, video camera, video image, charge coupled device (CCD), dark current, camcorder

The examination of physical evidence by a forensic scientist is usually undertaken for identification or comparison (1). Identification and comparison of blood, documents, drugs, fingerprints, bullets, hair, shoe prints, took marks, etc. are widely known throughout the world. In addition, recorded voices and images are often analyzed for individual human identification, reconstruction of criminal scenes, etc. This paper presents a new method that can be used to determine whether or not questioned video images were recorded with a specific video camera. This type of identification is similar to the traditional identification of word processor models by printouts. However, the method presented in this paper can be used as an individualization technique, but cannot be used as a categorization or model estimation technique (2). Whereas this kind of individualization method is useful for examining video-recorded images of kidnapping or child pornography, or for showing the evidence of video editing, few attempts have so far been made (3,4). We focused on electrical properties of a charge coupled device (CCD) for individualizing video cameras (3). Our approach is based on the nonhomogeneous nature of dark currents in CCDs. The distribution pattern of the nonhomogeneous dark currents is unique and intrinsic to a specific camera. The principle of the method is described in the following section. The distribution patterns of the dark currents in nine cameras representing four different types will be examined in the next section. The results indicate that it should be possible to identify whether or not a given image had been recorded with a specific camera. In addition, the method presented was used in an actual case to determine whether or not questioned video images of a criminal scene were recorded with the suspect's camera. It was proven that the video image had been recorded with the camera, because coordinates of three hot pixels (i.e., pixels that have remarkably large dark current) on the images and on the camera were equal.

Principle of the Method

Charge Coupled Device (CCD)

In recent years, consumer, surveillance, and studio video cameras are equipped with Charge Coupled Devices (CCDs) as an image sensor. In order to obtain two dimensional image signals, a CCD array is made of hundreds of thousands of CCD elements that are arranged in rows and columns at regular intervals (Fig. 1). Each CCD element operates as a photo detector, which turns light quanta into electric charge carriers. Therefore, a CCD array works as a converter of a spatially distributed light pattern into a spatially distributed electric charge pattern (5). The charge pattern is read out through vertical and horizontal shift registers. The element of the conversion unit is called a pixel. The photo detectors are sensitive from the near infrared to the ultraviolet (6). However, the IR and UV rays are cut with color filters to sense only visible light.

The operation of a CCD element is described as follows (Fig. 2). Incoming light affects only a photo detector (PD), elsewhere it is blocked by an aluminum shield. Because a SiO_2 layer above the PD is transparent, it does not block the PD from detecting the incoming light. The structure of the PD is an inverse-biased PN junction, which is the same as a photodiode. When the light is absorbed in the PD, hole and electron pairs are generated. The charges are stored during exposure periods and transferred to the vertical shift register (VCCD) during read out periods through a tunneling gate (TG). To explain the principle of our individual video camera identification method, the properties of a photodiode (the inverse-biased PN junction) is very important. The typical voltage-current characteristic of photodiodes is shown in Fig. 3. The generated charges flow as a photocurrent that is almost proportional to the density of photons (i.e., the power density of incoming light). However, even though the power density of the incoming light is decreased to zero, a small current leaks in the photodiode. This current is called "dark current" (7), which decreases the performance of CCD arrays under low-level lighting conditions (5). The dark current arises from thermal energy within the inverse-biased PN

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junction, which is independent from the amount of photons arriving to the photodiode.

Individual Identification of Video Cameras

Output image signals from CCD arrays always contain noise. The noise component is categorized into two groups: random and fixed pattern noise. For example, thermal noise, transfer noise, and 1/f noise are types of random noise. One of the main factors of fixed pattern noise is the nonhomogeneous nature of dark currents in a CCD array (8). The nonhomogeneity of the dark currents is caused because some pixels have much higher dark current generation rate than the average. The locations of such pixels remain fixed, since this phenomenon is an effect that arises from contamination problems and/or crystalline defects during CCD manufacturing process (9). Because the spatial distribution of such pixels will show a statistical distribution (5) and there are numerous pixels on one CCD array, it is easily expected that the distribution pattern is quite unique. The uniqueness and stability of the pattern enable us to determine the relationship between questioned images and CCDs. Identification of a CCD array means identification of a camera because CCDs mounted on cameras are mostly unexchangeable. This is the idea of our method.

Because the fixed noise pattern is usually invisible due to the random noise and image signal components, image-processing

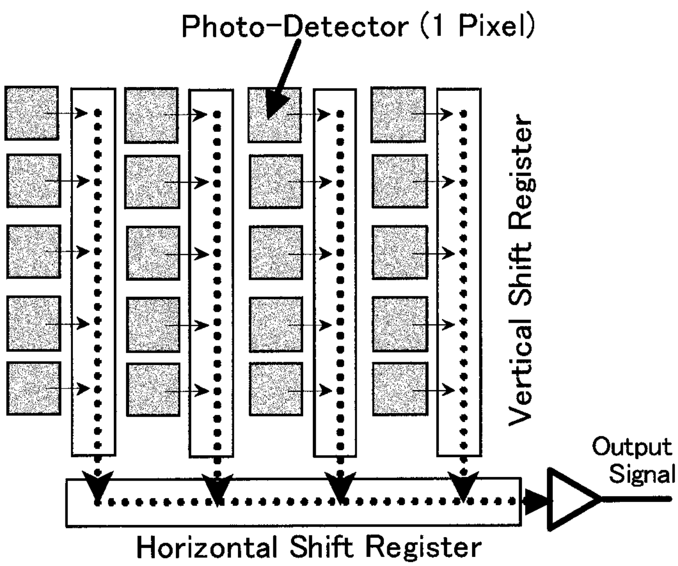

FIG. 1—*Scheme of a CCD array. It consists of CCD elements (pixels) and shift-registers. Each element works as a photo detector.*

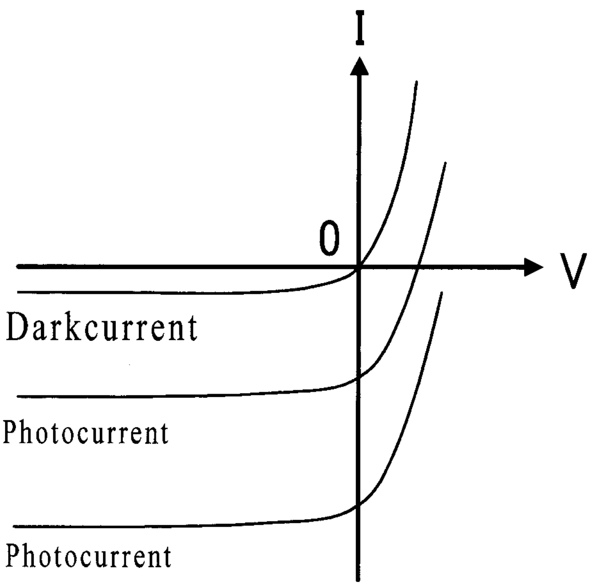

FIG. 3—*Voltage-Current property of a photo diode. The dark current leaks in a CCD element (a photodiode) even if the power of the incoming light decreases to zero.*

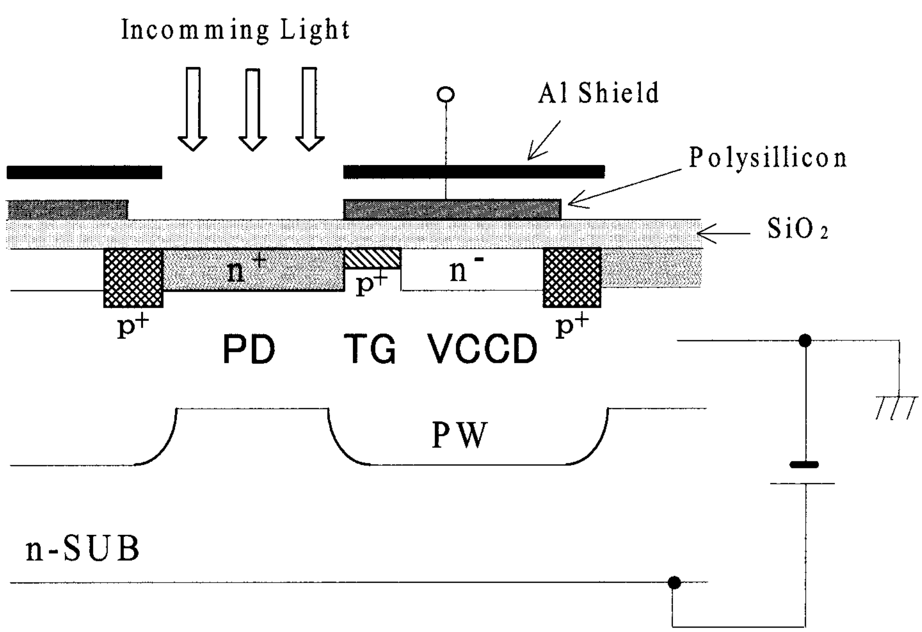

FIG. 2—*Schematic cross-section view of one pixel. A photo detector (PD) and a vertical shift-register (VCCD) are illustrated.*

procedures are required to make the patterns detectable. Multiple image integration is one of the best solutions (3).

Experimental Methods

We performed experiments whose purposes were: (a) to test whether the distribution patterns can be detected from videotaped images, (b) to examine the uniqueness of the pattern. We used nine video cameras from four models. They were DCR-VX1000 [Sony] (Serial Number 80642, 30821, 72567, 49967), CCD-TRV95K [Sony] (SN 1002655, 1002153, 1002034), CCD-TRV90 [Sony] (SN 31532), and GR-DV1 [Victor] (SN 11110805). CCD-TRV90 was an 8 mm camera. The other models were digital video cameras. We carried out the experiment as follows:

Step 1. Recording blank images on tapes.
Step 2. Capturing one hundred played back frames from each camera.
Step 3. Integrating the one hundred captured frames to improve the signal to noise ratio.

Step 1 is a recording process. In order to simplify the experimental conditions, blank (black and monotonous) images were recorded on tapes by covering the camera lens with a lens cap. This recording was carried out at room temperature. Step 2 consists of the playing back and capturing procedure. One of the DV cameras (DCR-VX1000, Serial Number 49967) for the DV medias and the 8 mm videocassette recorder (EVO-9650 [Sony], Serial Number 11694) for the 8 mm media were used as playback equipment. In order to introduce the same playback conditions, only one piece of playback equipment for each tape media was used. One hundred images for each camera were captured with a frame grabber (FINEPAC VP-1125 [Astrodesign Inc.]). All images were captured into a personal computer through an analog (Y/C) line. The resolution of each frame was 640 by 480 pixels in the 24-bit color format. The images were converted into computer image files and stored into a hard disk. Step 3 is a quality improvement procedure. Because the power of the fixed noise pattern is less than that of the random noise, the fixed pattern is hardly detected from only one frame. In order to suppress the power of the random noise component and make the fixed pattern detectable, the one hundred captured frames were integrated. This process was performed in the floating-point data format on a computer in order to avoid data loss. The integrated images were converted into the binary (black and white) images to make pattern comparison easy. The patterns were compared to examine the uniqueness of the patterns.

An additional experiment was carried out in order to confirm whether or not the signal source of the fixed pattern was inside CCDs. The ideal way for this confirmation is to observe the output signals directly from CCDs, however, in this study, the signal source was specified using a more indirect way. It was a comparison between an integrated image of the played back signals and an integrated image obtained from a lineout terminal of the camera. The result of this comparison will be mentioned in the next section.

Results

Figure 4 shows the pattern of DCR-VX1000 (Serial Number 30821). Because the original raw image contains random noise whose power is larger than that of the fixed noise pattern, no distribution pattern is observed in Fig. 4*a*. However, some bright dots are observed in the image Fig. 4*b* after 100 frames integration. This is because the random component of noise was suppressed by the procedure. The bright dots are considered to be the pixels whose dark currents are significantly larger than their neighboring pixels. In order to check whether or not the signal source of these dots was inside CCD, the results of the additional experiment is shown in Fig. 5. Both images are integrated images of DCR-VX1000 (SN 49967)—*a* the image obtained from videotape, *b* from the lineout terminal of the camera. It is obvious that coordinates of dots correspond accurately between the two images. The results indicate that the dots were generated in the circuits preceding the lineout terminal. This means that the signal source has no relation to the circuits for taping. Some dots in Fig. 5*b* are not recognized in Fig. 5*a.* We consider that the signal was smeared and made invisible during the taping or playback process. Furthermore, the dot patterns were not affected when the optical system of the camera was varied. These results demonstrate that the dots were generated after the optical

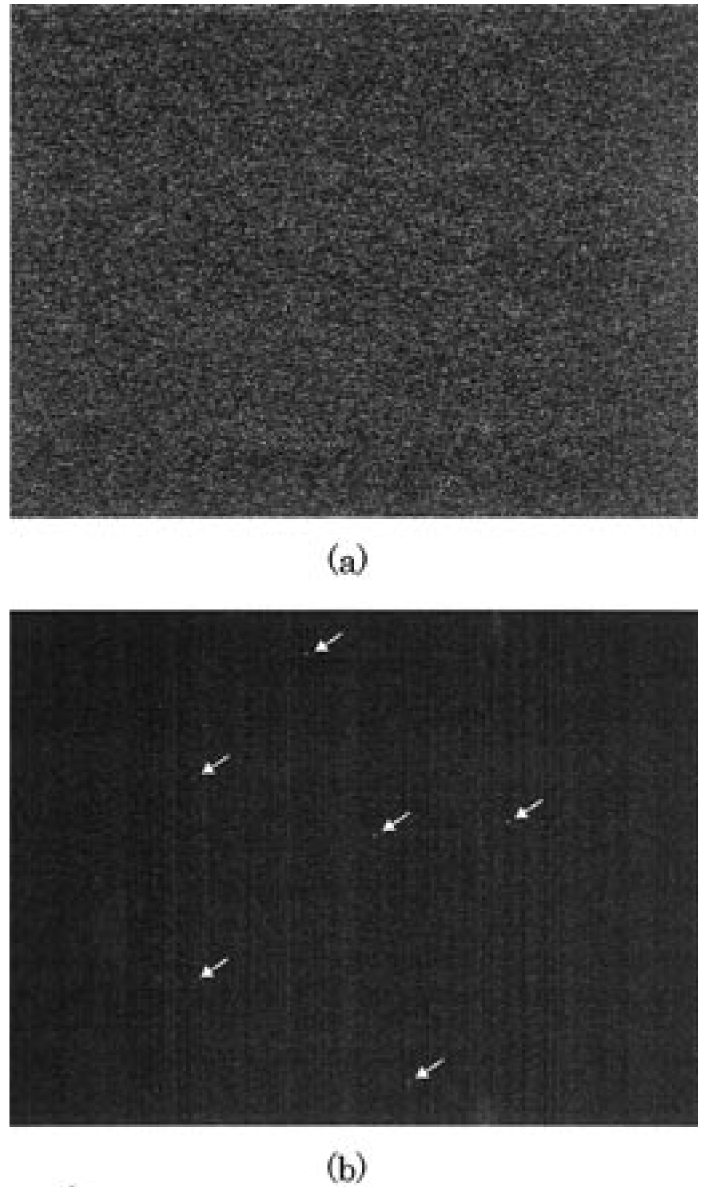

FIG. 4—*The images recorded with DCR-VX1000 (Serial Number 30821):* (a) *The original one frame (the intensity is amplified by 5),* (b) *The integrated image of 100 frames. Some bright dots are observed (with arrows).*

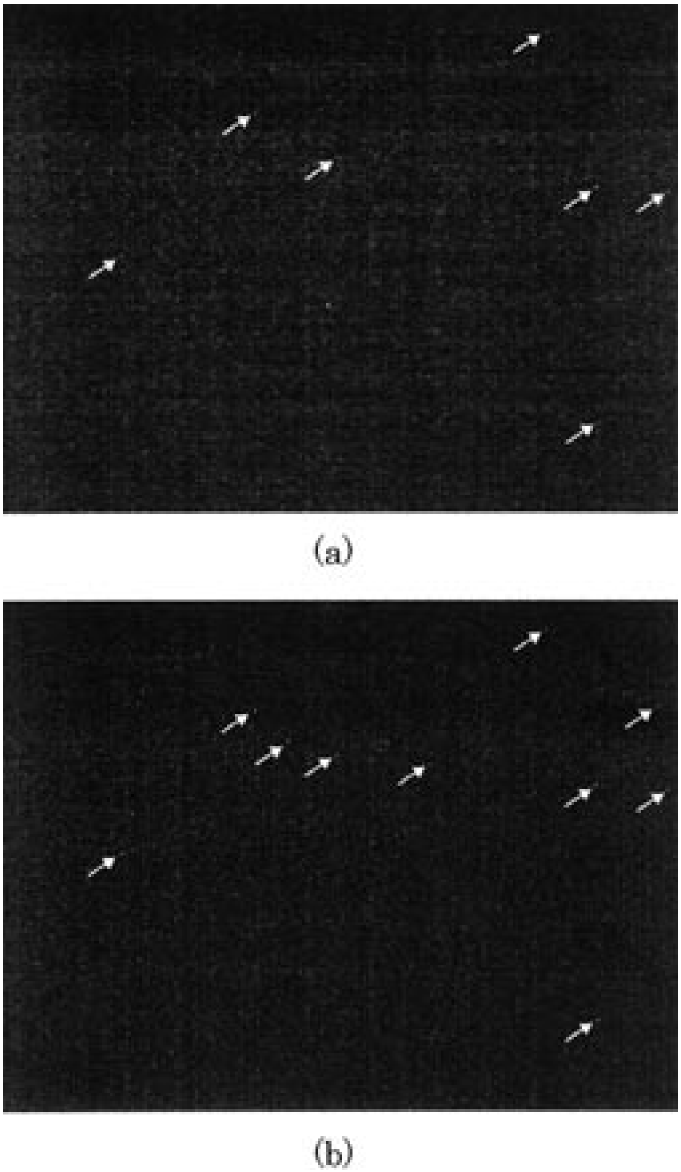

FIG. 5—*Comparison between the two integrated images (DCR-VX1000 SN49967):* (a) *The image obtained from the videotape,* (b) *The image obtained directly from the lineout terminal.*

lens system and before the taping circuits. The main components of this section are CCDs, amplifiers, encoder, and compensation circuits. Therefore, we concluded that the signal source of the dots is a CCD, since all components excluding the CCD are considered not to be able to generate such impulsive and stable dot patterns like Fig. 4*b* and Fig. 5*a,b*.

The integrated images of each DCR-VX1000 camera were converted into the binary (black and white) images and dots were dilated for enhancement. They are shown in Fig. 6. It is clear that the dot patterns are different, even if the camera models are the same. This result indicates that it should be possible to identify whether or not a given image had been recorded with a specific camera. The numerical analysis on the uniqueness of the pattern will be discussed in the following section. Only the case of CCD-TRV90 (SN 31532), no dot pattern was obtained from played back images, although bright dots appeared when 600 frames from the lineout terminal were integrated. We consider that this was caused by the signal reduction during the recording process. In the other cases (three CCD-TRV95K and one GR-DV1), the cameras also showed their unique patterns (Fig. 7). In Fig. 7*d,* whereas only two pixels are bright, a characteristic vertical thick line is observed in the left hand side of this image. Since the number of experimental sample is small, we cannot mention whether this dark line is inherent in this model or in this specific camera. However, we think that this type of feature could also be a clue to camera model identification or individual camera identification.

The results are summarized as follows: In eight of the nine cameras, unique detectable patterns were identified in recorded blank images. It was also suggested that the patterns were generated inside CCDs.

Case Report

The method presented was used in an actual case to determine whether or not questioned video images of a criminal scene were recorded with the suspect's camera. We were asked to examine the crime scene recorded on the 8 mm videotape and the suspect's camera (CCD-TR3 [SONY]). We could detect three hot pixels (i.e., pixels that have remarkably large dark current) from the images on the tape by integrating 400 frames (Fig. 8*a*). The camera showed its pattern as shown in Fig. 8*b.* The coordinates of three pixels in Fig. 8*a* are completely equal to corresponding pixels in Fig. 8*b.* Therefore, we could make a positive conclusion on the basis of statistics. To calculate statistically, we need some assumptions. The first one is that the distribution of the pixels whose dark currents are significantly larger than the other pixels is random. Such pixels that have large dark current are introduced by contamination and/or crystalline defects during CCD manufacturing process (9). The other condition we took into account was the resolution of the video image. Although the CCD mounted on the camera has 300 000 pixels and images can be captured in the resolution of 640 by 480 pixels with a frame grabber (FINEPAC VP-1125 [Astrodesign Inc.]), we believed that the image resolution was 160 by 240 pixels, which makes 38 400 pixels in one frame. This is because the spatial resolution is degraded when images are recorded on tapes due to the limitation of the frequency range. This assumption makes our conclusion safer. The last assumption is the number of hot pixels. From Fig. 8*a,* we believed that the camera had three detectable hot pixels among the whole 38 400 pixels. The probability p that two different cameras have the same distribution pattern by chance is calculated as follows.

$$p = 1/({}_{38\,400}C_3) = (38\,400 - 3)! \times 3!/38\,400! = 1.1 \times 10^{-13}$$

Compared with the number of video cameras shipped in Japan (1.4×10^6 cameras in 1999 (10)), the probability p is so small that the relationship between the image and the camera was attested; the criminal scene must have been recorded with the suspect's camera.

Discussion

The method presented here can be a strong tool for video camera identification. However, not every video image can be examined with this method because there are some fundamental limitations. For example, when incoming light into CCD is strong enough to generate much more electrical charges than that arisen from dark currents, the pattern is undetectable. Some recording conditions are required for successful identification. For example, images on tapes must be recorded in dark places, or dark objects must be

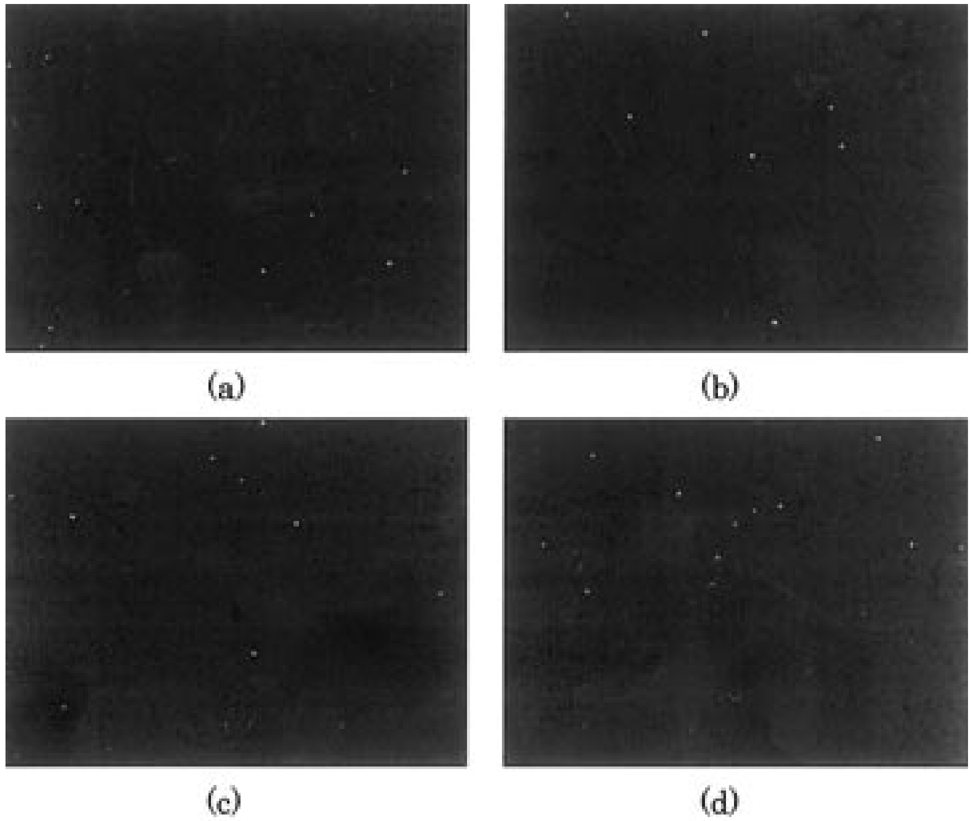

FIG. 6—*Patterns of DCR-VX1000 cameras. The integrated images were transformed into the binary (black and white) images, and dots were enhanced. Serial Numbers are* (a) *80642,* (b) *30821,* (c) *72567, and* (d) *49967.*

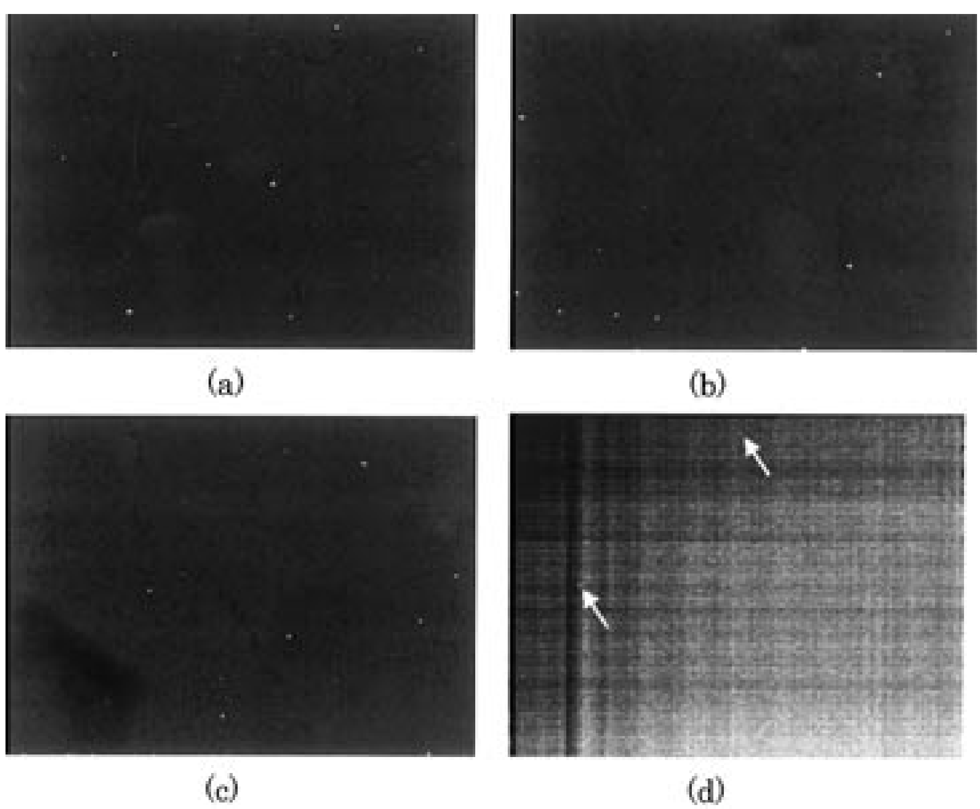

FIG. 7—*Patterns of CCD-TRV95K cameras* (a), (b), (c) *and GR-DV1* (d). *The serial numbers are:* (a) *1002655,* (b) *1002153, and* (c) *1002034. The images were transformed into the binary images, and dots were enhanced,* (d) *the pattern of GR-DV1 (SN11110805). Two dots (with arrows) and vertical dark line (in the left-hand side) are observed.*

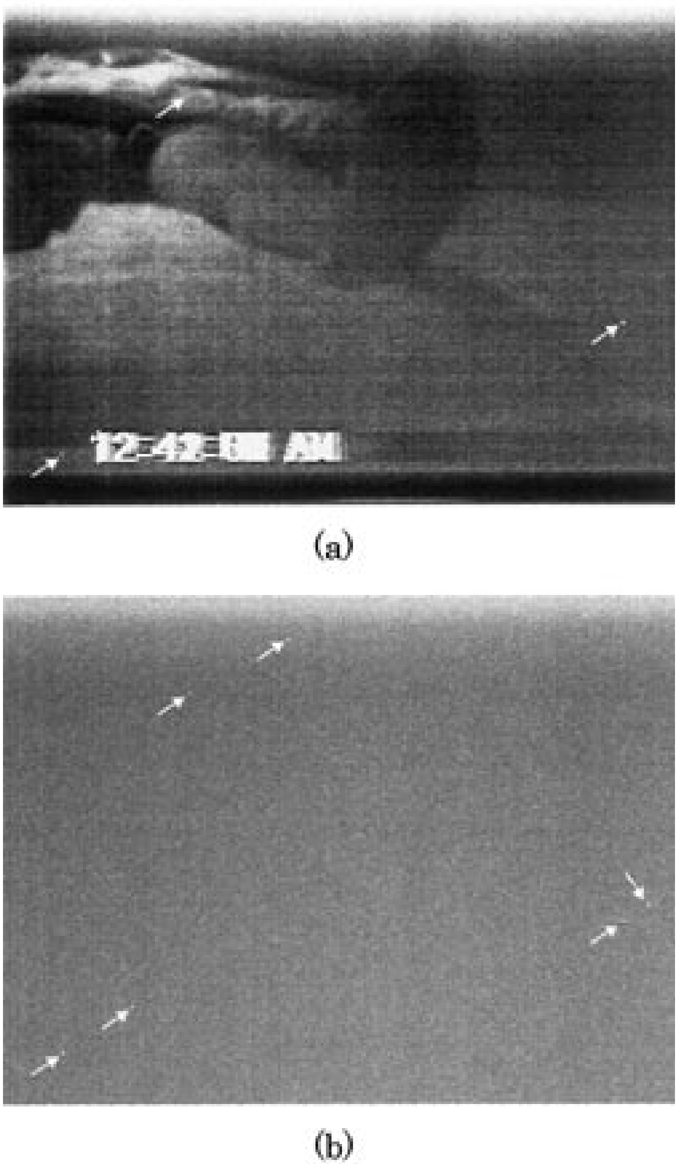

FIG. 8—*An example of actual individual video camera identification:* (a) *The integrated image of 400 frames. These frames contains the criminal scene. The images were recorded on the 8 mm tape.* (b) *The integrated image of 400 frames obtained from the lineout terminal of the suspect's camera. The coordinates of three pixels (with bright arrows) are accurately correspond to the pixels in* (a).

recorded on tapes. The other obstacles for applying this method to questioned images are camera functions such as an image stabilizer that compensates for unwanted camera movement and digital zoom function. Both functions shift the coordinates of the hot pixels in the recorded frames. The detailed analysis on these factors that affect the method has been an subject of further study.

As shown in Fig. 7*d,* some CCDs have characteristic structures in their patterns. One analog video camera we examined had a rectangular form in its pattern. Because CCD manufacturing process heavily affects the generation of the patterns and the number of hot pixels, there must be a correlation between the quality of CCDs and their dark current patterns.

Although some technical limitations exist, we conclude that our new approach will become a new effective tool for crime investigation.

References

1. Saferstein R. Criminalistics—An introduction to forensic science, 6th ed. New Jersey: Prentice Hall, 1998.
2. Kurosawa K, Kuroki K, Saitoh N. Basic study on identification of video camera models by videotaped images. Proceedings of 6th Indo Pacific Congress on Legal Medicine and Forensic Sciences; 1998 Jul 26–30; Kobe. 1999;1029–32.
3. Kurosawa K, Kuroki K, Saitoh N. CCD fingerprint method—Identification of a video camera from videotaped images. Proceedings of IEEE International Conference on Image Processing'99; 1999 Oct 24–28; Kobe. 1999;3:537–40.
4. Geradht Z, Bijhold J, Kieft M. Methods for identification of images acquired with digital cameras. Proceedings of AAFS annual meeting; 2000 Feb 21–26; Reno. 2000;VI:68.
5. Van Santen JG. Invited: solid state image sensors using the charge transfer principle. Proceedings of the 8th conference (1976 International) on Solid State Devices; 1976 Sep 1–3; Tokyo. Tokyo: Japanese J Applied Physics, 1977; 16 Suppl 16-1:365–71.
6. Yu PY, Cardona M. Fundamentals of semiconductors: physics and materials properties; with 50 tables and 105 problems, 2nd ed. Berlin: Springer, 1999.
7. Chuang SL. Physics of optoelectronic devices. New York: John Wiley and Sons, 1995;583–622.
8. IEICE. Handbook for electronics, information and communication engineers. Tokyo: Ohmsha, 1988.
9. Amerasekera EA, Najm FN. Failure mechanisms in semiconductor devices 2nd ed. Chichester: John Wiley & Sons, 1997;87–185.
10. http://www.jeita.or.jp/eiaj/

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