A novel synchronous multi-intensity IR illuminator hardware implementation for nighttime surveillance

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ABSTRACT

For nighttime surveillance, it's difficult for an ordinary IR illuminator (which has a fixed light intensity) to generate a one-size-fits-all light condition for objects at different distances. Often, we will get overexposed (underexposed) image for an object which is too close to (too far from) the illuminator/camera in the nighttime. To partly resolve such problems, a multi-intensity IR illuminator was proposed which can emit periodically varying intensities of IR light toward an object. However, two major problems remain to be resolved when using such an illuminator, i.e., the "synchronization issue" for background modeling and the "viewing issue" for manual monitoring. In this paper, we propose a novel synchronous multi-intensity infrared (SMIIR) illuminator hardware design to help address these two issues. Hopefully this innovation will open the door to a new era of nighttime surveillance.

Keywords: IR illuminator, MIIR illuminator, SMIIR illuminator, nighttime surveillance

1. INTRODUCTION

Over the past few years, the research associated with the innovation of multi-intensity infrared illumination, a promising technique for nighttime surveillance, has made significant progress [1-7]. It's well known that lighting control always plays an important role on the image quality. The ability of camera system to capture informative images is greatly affected by the condition of lighting in the scene. It's difficult for an ordinary IR illuminator with a fixed light intensity to provide a one-size-fits-all light condition for all objects at different distances. Often, we get poor images in the night time where appropriate illumination condition is not available. Thus we may get an overexposed (underexposed) image if an object is too close to (too far from) the light source.

To resolve the above problems and further enhance the image quality, multi-intensity infrared (MIIR) illuminator was proposed in [1], which is capable of periodically emitting different intensities of IR light toward an object. The MIIR illumination technology for nighttime surveillance has enabled some interesting research works in the field. Lu et al. study the nighttime foreground segmentation using MIIR illuminator in [2] with special treatment for the modeling of the background of varying brightness. Chen et al. study the license plate detection in nighttime scenes using MIIR illuminator in [3] by detecting the license plate directly in images obtained from different illumination levels. Similarly, Yao et al. [4] use the MIIR illuminator to study the nighttime face detection.

While MIIR illuminator did resolve some problems due to poor illumination conditions, two critical issues remain to be addressed. Firstly, the original MIIR illuminator is based on an asynchronous design, i.e., the timing of light emitting from the illuminator is not synchronized to that for image capturing for a camera. Therefore, the levels of brightness of video frames captured by a camera may not repeat precisely, as required in general for the process of background modeling. Secondly, a video with persistent variation in the overall image intensity will be very annoying and tiresome for manual monitoring for an extended period of time.

In this paper, we propose a novel synchronous multi-intensity infrared (SMIIR) illuminator hardware design to address the above two issues. Furthermore, a number of illumination patterns are proposed to show the possibilities of using the SMIIR illuminator for various application scenarios. In the following sections, motivations for inventing the SMIIR illuminator is first elaborated, followed by a detailed description of the hardware design of the invention. Subsequently, experimental results of using the SMIIR illuminator will be provided, which include a demonstration of foreground detection which is greatly simplified from that discussed in [2]. Some concluding remarks will then be given at the end of the paper.

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2. PROBLEMS ASSOCIATED WITH ASYNCHRONOUS MIIR ILLUMINATION

2.1 Problems due to the lack of camera-illuminator synchronization

Since the previous design of the asynchronous MIIR illuminator in [1] did not take synchronization into account, i.e., the timing of light emitting from the illuminator is not synchronized to that for image capturing frame for a camera, application of such an illuminator may complicate certain image processing procedures for nighttime surveillance. For example, while many algorithms have been developed for foreground object detection in daytime scenarios, directly applying such algorithms in nighttime scenarios with asynchronous MIIR illumination may not be possible.

Figure 1 shows variations of the gray level of a typical image pixel in a sequence of image frames used in [2], using asynchronous MIIR illuminator. It is readily observable that (i) the extreme values of each cycle are relatively stable toward the two ends of figure when the pixel belongs to a background region and (ii) such values change abruptly between frame 125 and frame 750 when a foreground object shows up in the scene. Accordingly, authors of [2] propose a Max-Min background model for foreground object detection in nighttime scenario using asynchronous MIIR illuminator. Nonetheless, performance of the detection is still not as good as those achievable with foreground detection algorithms developed for daytime scenarios.

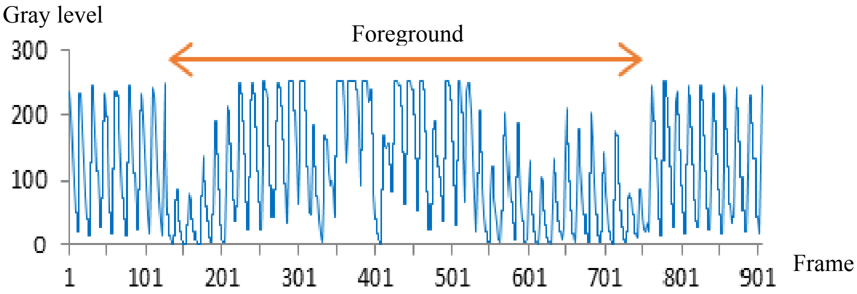


Figure 1. Variations of the gray level of a typical image pixel in a sequence of image frames.

2.2 Problems associated with manual monitoring

The second issue arising from the utilization of the asynchronous MIIR illuminator is associated with manual monitoring of surveillance videos. Figure 2 shows some consecutive image frames of a video captured with asynchronous MIIR illumination. Since the overall image brightness changes in a frequency of about 7.5 Hertz, manual monitoring of such a "blinking" video will be extremely annoying and tiresome. In fact, viewing such videos for an extended period of time is practically impossible.

Figure 2. Consecutive image frames of a video captured with asynchronous MIIR illumination.

3. HARDWARE DESIGN OF SMIIR ILLUMINATOR

In order to address the two issues discussed in the previous section, a novel synchronous SMIIR illuminator is developed in this paper. The SMIIR illuminator plays the key role to enable the camera to capture a sequence of image frames with a repeatedly pattern of illumination intensity and thus more information of image of object can be retained. Figure 3 shows the hardware architecture of SMIIR illuminator which consists of (i) a sync separator, (ii) a pattern generator, (iii) the DAC/PWM driver, and (iv) an IR LED array, as will be described in detail in the following. Note that without (i), as with the asynchronous MIIR, (ii) will have little effect of improving the illumination condition since the illuminator will asynchronously generate an unlimited number of uncontrollable illumination levels.

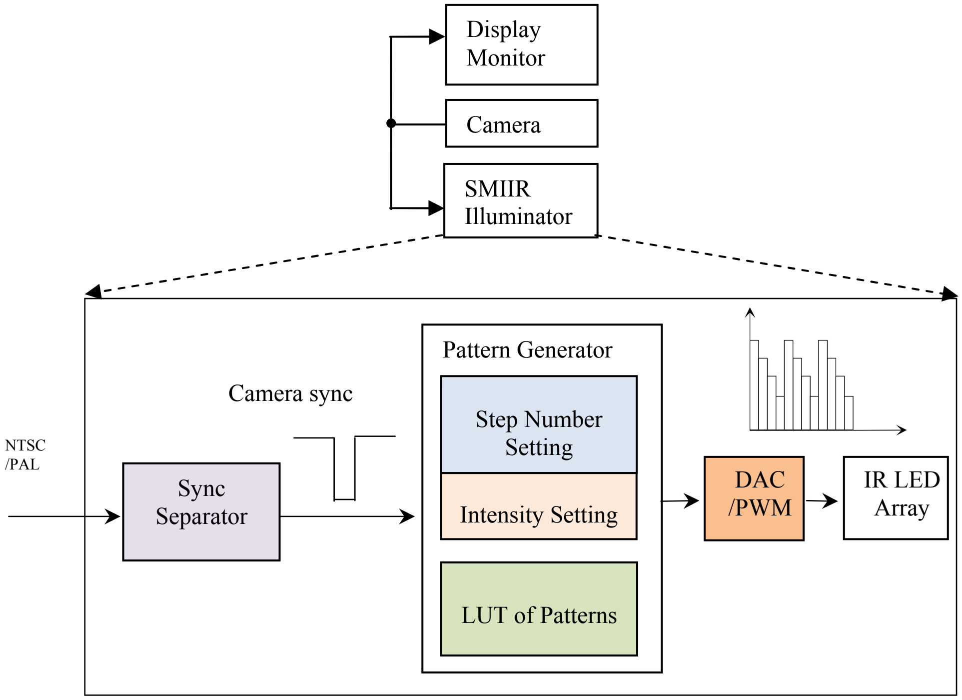


Figure 3. Hardware architecture of the SMIIR illuminator.

3.1 Sync separator

In Figure 3, the sync separator is designed to strip the synchronization signals from composite video sources in the NTSC or PAL format. With the sync pulse available as the output of the sync separator, the IR illuminator can change light intensity synchronously with the timing of exposure for each image frame. Figure 4 shows the relationship between camera sync, illuminator output and the exposure time wherein the IR light is emitted with timing offsets from the rising/falling edges of camera sync. Thus, a limited number of preset illumination levels can be employed to capture an image frame.

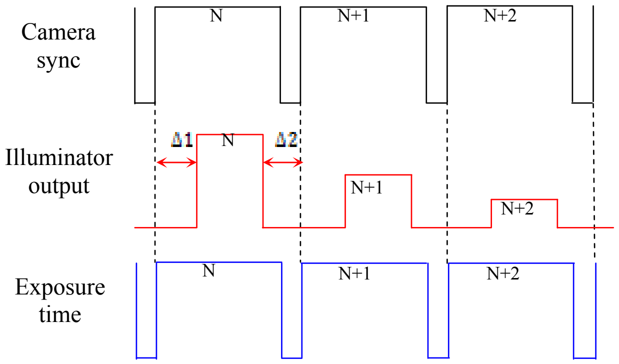


Figure 4. The relationship between camera sync, illuminator output, and the exposure time.

3.2 Pattern generator

The pattern generator contains switches for settings the number (m) of steps (image frames or illumination levels) in each period of illumination change, as shown in Figure 5 for m = 4, as well as the intensity of each illumination level. In addition, a look-up table (LUT) of a pre-defined illumination patterns can be stored in a memory unit. Outputs of the pattern generator will then be used to control other parts of the SMIIR so that the timing of light intensity change will be synchronized with the exposure timing of the camera.

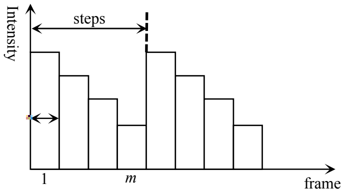
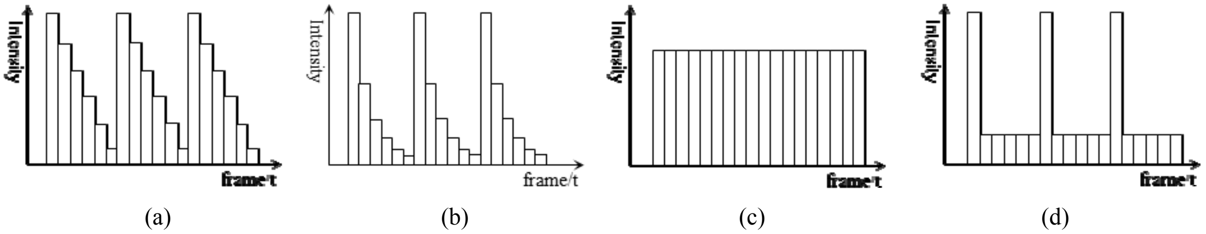


Figure 5. An illumination pattern for $m = 4$.

Owing to the above synchronization scheme, overall brightness of consecutive image frames captured by the proposed system, as shown in Figure 3, will directly reflect the repeated pattern of illumination levels generated by the SMIIR. Therefore, different illumination patterns, e.g., those stored in the above LUT, can be designed to provide different lighting conditions for various application scenarios. For example, Figures 6(a) and (b) show linearly and exponentially decreasing intensities for $m = 6$ to cover a wide range of locations of (multiple) objects in the scene. The selection between them may depend on speed, trajectory, etc. of the objects. Other possible patterns are shown in Figures 6(c) and (d). While Figure 6(c) can be used as an ordinary illuminator with adjustable intensity level, Figure 6(d) can also be used to fulfill certain power saving requirements.



(a) (b) (c) (d)

Figure 6. Various illumination patterns.

3.3 Hardware realization of SMIIR illuminator

Figure 7 shows a printed circuit board (PCB) realization of the SMIIR illuminator discussed in this section. While the NS LM1881 Video sync separator is used to extracts the sync signal from the composite NTSC/PAL video signal entering from the upper left corner of the PCB, the pattern generator is implemented with Lattice LCMXO256C IC and the PWM driver is implemented with LT3755 IC. As for the IR LED array, 84 pieces of IR LEDs are wired with 6 LEDs in series and then 14 strings in parallel to emit IR light of 850nm in wavelength.

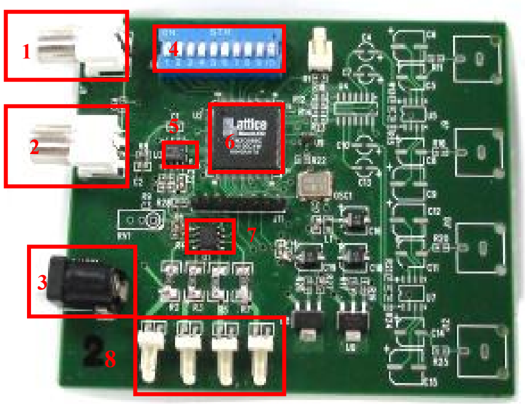


Figure 7. The hardware realization of the SMIIR illuminator. (1) Video IN, (2) Video OUT, (3) DC 12V Power Jack, (4) LUT Setting Switch, (5) Sync Separator, (6) Pattern Generator, (7) PWM driver, (8) IR LED Array Module Connectors.

4. EXPERIMENTAL RESULTS

4.1 Illuminating both far and near object with SMIIR illumination

In order to demonstrate the capability of the proposed SMIIR illuminator, the PCB implementation shown in Figure 7 is tested. The test environments include both indoor and outdoor scenes, with placards placed in the former to mark the distance (in meter) to illuminator/camera, as shown in Figure 2. A SONY 981 camera is used to provide the NTSC video output format, which has a 6mm lens with aperture set at F2.0, shutter fixed at 1/120s, and the gain fixed at 6dB. An illumination pattern similar to that shown in Figure 6(b), with relative light intensities of {32, 16, 8, 4, 2, 1}, is adopted for the SMIIR illuminator to cover a wide range of people locations. Figure 8 shows a series of images of a person at three different distances (10, 5, and 3 meters) from the camera under the above six illumination conditions. Regardless of the specific distance, a clear and well exposed image of the person (circled in red) can always be found, e.g., for acceptable face or appearance recognition. In general, this is not possible for an ordinary IR illuminator with fixed light intensity since underexposure (overexposure) may occur for far away (nearby) object that details of its appearance will be lost completely.

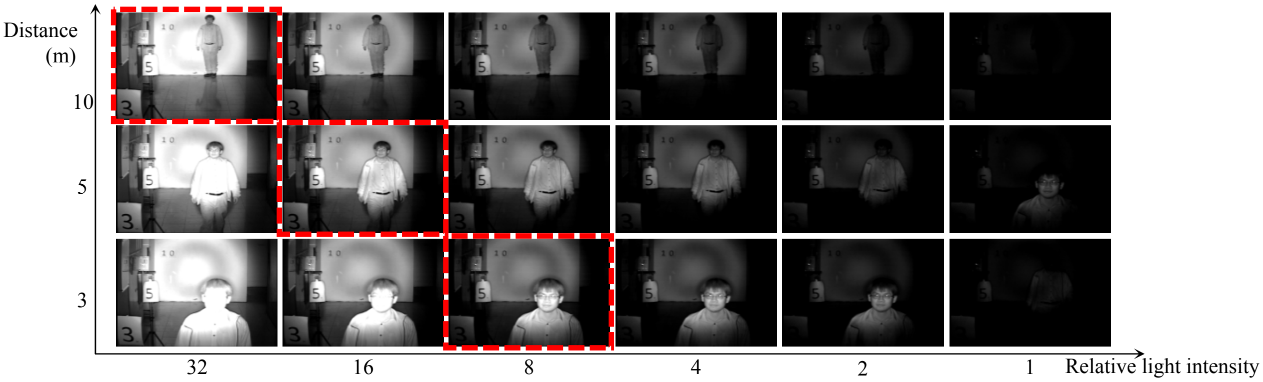


Figure 8. A series of images of a person at three different distances from the camera, and under six illumination conditions. Well exposed images of the person are circled in red.

In addition to enriching the information content of the video data, the effective range of surveillance can also be extended with the SMIIR illumination. For example, assuming the image shown in Figure 9(a) correspond to the maximum distance that an ordinary IR illuminator can cover. It is quite possible that such a distance can be further extended by using the SMIIR illuminator since the (maximum) IR light can be emitted for only 1/*N* of the complete cycle of illumination change.

4.2 Nighttime foreground detection with SMIIR illumination

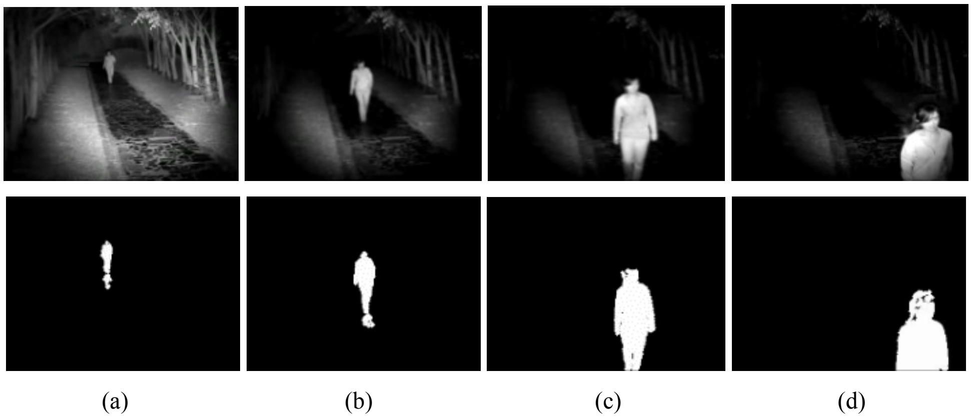


Figure 9. Images obtained with the SMIIR illuminator for a person walking along a pathway (upper), and the corresponding foreground detection results (lower).

While the previously developed asynchronous MIIR illuminator can also provide IR light of various intensities, its asynchronous nature greatly complicates image processing procedures, e.g., background modeling in [2], commonly employed for visible-light applications. Figure 9 shows images of a person at a number of locations along a pathway obtained with the proposed SMIIR illuminator (upper) and the corresponding foreground detection results (lower) obtained by the background modeling scheme presented in [5][6]. It is easy to see that with additional shadow/reflection removal procedure, such detection results can be used effectively for subsequent image processing tasks such as human activity analysis, gesture recognition, and face recognition. Figure 10 shows another experimental result of foreground detection with SMIIR video. After foreground detection and channel selection procedure in [6], the best foreground image can be extracted among the various channels.

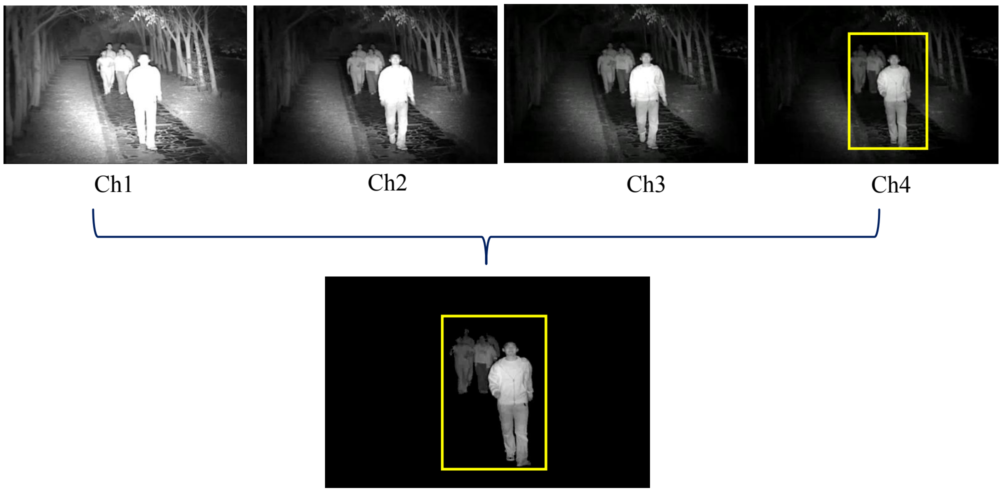


Figure 10. Another foreground detection result with SMIIR illumination.

4.3 Viewing the SMIIR videos

As mentioned in section 2.2, the blinking videos generated by asynchronous MIIR illumination are unendurable for human viewing. On the other hand, due to the synchronous nature of the SMIIR illumination, we may split the original video into several subsequences of video clips each consists of image frames with the same illumination level and can be recorded or compressed efficiently as an ordinary video. Moreover, for comfortable viewing experience, these split videos can be played back concurrently, as shown in Video1 for $m = 6$. In general, for $m = N$, the split videos can be arranged into N "channels" of video streams which can be concurrently played back with $1/N$ of the original frame rate. Some videos recorded with the SMIIR illuminators can be found in [7]. With SMIIR videos, the viewing problem associated with asynchronous MIIR illumination can be addressed perfectly.

Video1. Raw video is on the left side, then it's played back concurrently on the right side.
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5. CONCLUSIONS

In this paper, a novel synchronous multi-intensity infrared illuminator is proposed and implemented as a hardware module. This new illuminator is an improvement over a previous multi-intensity illuminator design which is capable of enriching the information content of video data for nighttime surveillance, but in an asynchronous fashion. The new (synchronous) design not only simply the viewing and recording of the video data, different illumination patterns can also be adopted for various application scenarios. Experimental results show that (i) images of good quality can be obtained for objects located in different locations in the scene with different illumination intensities and (ii) with synchronous implementation of the illuminator, traditional, single illumination level-based image processing algorithms, such as background modeling, may perform equally well for each illumination intensity.

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