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Dynamic infrared scene simulation using grayscale modulation of digital micro-mirror device

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Abstract Dynamic infrared scene simulation is for discovering and solving the problems encountered in designing, developing and manufacturing infrared imaging guidance weapons. The infrared scene simulation is explored by using the digital grayscale modulation method. The infrared image modulation model of a digital micro-mirror device (DMD) is established and then the infrared scene simulator prototype which is based on DMD grayscale modulation is developed. To evaluate its main parameters such as resolution, contrast, minimum temperature difference, gray scale, various DMD subsystems such as signal decoding, image normalization, synchronization drive, pulse width modulation (PWM) and DMD chips are designed. The infrared scene simulator is tested on a certain infrared missile seeker. The test results show preliminarily that the infrared scene simulator has high gray scale, small geometrical distortion and highly resolvable imaging resolution and contrast and yields high-fidelity images, thus being able to meet the requirements for the infrared scene simulation inside a laboratory.

1. Introduction

As the infrared imaging technology develops and innovates rapidly, beyond-visual-range combat and precise strike will become the main modes of air combat in the future. Infrared imaging guidance weapons play a major role in taking battlefield initiatives, night attack and precise strike. During the design, development, test and finalization of infrared imaging guidance weapons, it is essential to conduct hardware-in-the-loop simulation, in which the infrared scene simulation is of the most importance.[1–3]

During recent years, China has made remarkable progress in studying infrared imaging guidance. However, as the performance of infrared imaging guidance weapons improves, the existing infrared scene simulation capacity cannot meet the requirements for simulation and cannot greatly enhance the contrast, grayscale resolution and spatial resolution as required by simulation. Furthermore, the highly dynamic condition and high frame rate encountered in the air-shooting infrared guidance weapons development present new requirements for infrared scene simulation.[4,5]

The engineering applications at the laboratory abroad during recent years show that a typical infrared scene simulation system mainly uses MOS resistor array,[6–9] laser diode,[10] IR-CRT, IR liquid crystal light valve,[11] micro-mirror[12–14] and

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so on. The IR liquid crystal light valve and the IR-CRT have their constraints in frame rate, temperature range and dynamic range. The space uniformity and imaging quality of a laser diode are not so satisfactory and require a large encapsulation; both are not extensively applied.[10] For the limitations above, IR liquid crystal light valve, IR-CRT and laser diode are not extensively applied.[10,11] The temperature range of the MOS resistor array is rather wide and its infrared property concentrates on the high-temperature section; the resolution of its pixels is rather low. Currently, other countries have developed 1024×1024 pixels,[6] but only 512×512 pixels are put into engineering application.[7,8] China has only 256×256 pixels.[9] The imaging resolution of MOS resistor array is too low and its non-uniformity and non-linearity have not been well tackled,[8,9] thus having big constraints for engineering application. The digital micro-mirror device (DMD)[12–14] has high resolution (up to 1920×1080 pixels),[15,16] concentrated energy output, image stabilization, small non-uniformity of brightness, small geometric distortion, small resolvable temperature difference, good dynamic special effects and other merits. Therefore, it has come to be applied to the hardware-in-the-loop simulation of weapons.

Based on the DMD system, this paper explored the binary and time-sharing pulse width modulation (PWM) method, so as to solve the key technical problems existing in the aerial target simulation, such as high frame rate, highly dynamic condition and high contrast, thus laying a solid foundation for the application of infrared image simulation to the hardware-in-the-loop simulation of air-shooting weapons.

2. The grayscale modulation model

2.1. The DMD grayscale modulation principles

For an infrared scene simulator, gray scale refers to the number of gray scales or shades of gray of an image that is projected by simulator. It represents the capacity of the simulator to display images with many gray scales, and is related to spatial resolution, contrast and temperature resolution. The more the gray scales are, the more the changes in the shade of an image are and then the more exquisite the image is. The grayscale modulation is a major method for raising the grayscale of the DMD scene simulator. The digital grayscale modulation method which is similar to the PWM is used to carry out the high-precision control of grayscale in order to realize image grayscale modulation of DMD.[17]

From the perspective of light modulation mode, DMD is a light intensity modulator which reflects light passively, relying on the angle at which the pixel mirror reflects light to produce brightness or darkness and to change gray scales by controlling the length of reset time. The DMD display technology uses the binary time-sharing PWM method to conduct image processing, the PWM of binary drive data and the high-precision control of the length of time for switching on or off the lens of each unit, thus producing the gray scale of an image.

The DMD inputs image data representing brightness gray scales; the color information of each pixel is expressed by using 24 bits of RGB (Red, Green, Blue) information with 8 bits per color, namely 256 gray scales. Each bit of information represents the time interval of turning on or off (1 or 0), its interval value being 2^0, 2^1, …, 2^7 correspondingly. The time domain (255) of each image is divided into eight independent time slices, with the length of a time slice being proportional to the weighted binary value of the bit and the frame time allocated to each time slice being $2^0/255$, $2^1/255$, …, $2^7/255$. The bit separation method is used to disassemble one image into eight bit-plane images from the least significant bit (LSB) to the most significant bit (MSB), continuously creating the light-started time intervals that correspond to each bit-plane image and thus obtaining the gray scales that correspond to the original image. Fig. 1 shows the principles of the pulse sequence modulated by the pulse width of a 4-bit binary image.

Pixels are updated by PWM signal under multichannel serial mode, that is to say, the line shift register selects a line of DMD pixel arrays and updates them line by line. Within the time of one frame of image, the DMD pixel array may be updated many a time and the gray-scale image is displayed with the light integral effect of the infrared detector.

2.2. The DMD-modulated imaging model

The analysis of the DMD modulation principles shows that, for an image projected by DMD, the intensity of light incident upon image detectors is different at time slice with respect to data bits, namely the light intensity distribution is a function of time. The modulation imaging model is established according to the time cumulative effect of the light intensity of the transient imaging of multiple images generated by DMD.

Under the PWM controller, there is a mutual exclusion between frame rate and intensity level. The higher the frame rate of a single pixel is, the less the gray scales are; on the other hand, if the frame rate for controlling the switching is lower, then the gray scales are more.

With the flexible controller, a wide range of frame rates and intensity depth can be achieved. Fig. 2[17] describes the maximum achievable frame rate as a function of PWM bits that can be displayed within one frame. The 0.7 XGA DDR DMD is organized into 16 mirror sections, allowing each mirror section to be latched independently. The diagram gives the curve that clearly describes the relationship between gray scale and frame rate.

Define the distribution function of an input grayscale image as $f(x,y)$, and the number of bits of its gray scale is N. The display of each grayscale image in DMD can be divided into $\log_2 N$ number of time slices of data bits, whereas the PWM signal is a binarized signal. Therefore, within each time slice of a data bit, the DMD display is actually a binarized black and white image, and each data bit is exposed in a revolving manner. Then, $f(x,y)$ is expressed as:

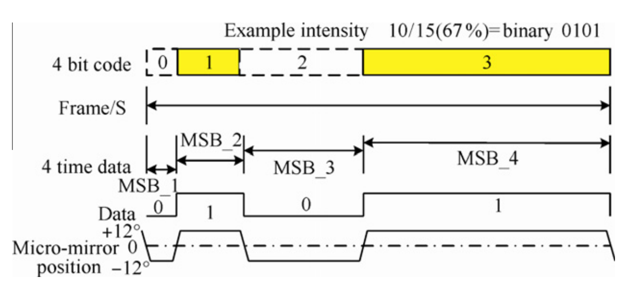

Fig. 1 Principles of the pulse sequence modulation with the pulse width of a 4-bit binary image.