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DEVELOPMENT OF TRANSMISSION TYPE PIXEL ENHANCEMENT ACTUATOR FOR DLP PROJECTION DEVICE

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Abstract

Recently, display devices become lighter and slimmer and the size of an image screen is the important issue in the development of display devices. Furthermore, display devices with a large screen are required to represent high resolution as high definition televisions are widely spread out. There are several display devices such as plasma display panel (PDP), liquid crystal display (LCD), projection with micro devices for digital light processing (DLP) and others with a large screen and high resolution. Among them, the DLP projection device realizes an image on a screen through pixels generated by micro mirrors each of which move independently on the digital micro-mirror device (DMD) chip. The number of pixel which depends on those of mirrors determines the resolution of the device and thus, it should be increased in order to enhance the resolution of the device in DLP projection. However, it has some technical problems and leads to increase in cost. Therefore, a new methodology with existing DMD chip is required for high resolution of DLP projection device. For this purpose, Texas Instruments (TI) proposed a smooth picture technique by which the resolution of DLP projection device is visually made double. First, the shape of micro mirrors is changed from square to diamond type. Second, pixels are repeatedly multiplied in the vertical direction. Consequently, the resolution of the DLP projection device is visually doubled. In this work, we propose a transmission-type pixel enhancement actuator (PEA) for pixel doubling of DLP projection device which employs the above smooth picture mechanism, where mechanical characteristics and the driving methodology are explained.

INTRODUCTION

Nowadays, display devices with a large screen and high definition (HD) are required since HD players, such as Digital Versatile Disk (DVD) and home theatre widely spread out and HD broadcasting is set off. While Flat Panel Display (FPD), for example, PDP and LCD has a large screen size and thin depth that has high cost. On the contrary, the rear projection device has an advantage of low cost in addition to a larger screen size and thinner depth than these of the Cathode Ray Tube (CRT) display device. It is generally categorized the rear projection device into four imaging systems: CRT, LCD, DLP and Liquid Crystal on Silicon (LCoS) projection device. Among these, the DLP projection device come into the spotlight on a HD display market because of a large screen and high resolution with a low cost and thin depth.

DLP is a display technology developed by TI. DLP imaging systems employ either one or three large devices which is called DMD chip. The micro-mirrors are mounted on the DMD chip and tilt in response to an electrical signal. The tilted directs light toward the screen, or into a "light trap" that eliminates unwanted light when is reproduced blacks and shadows. Figure 1 shows the configuration of DLP projection device.

DLP projection device has the several advantages of performance in comparison with other projection devices. Firstly, the beam efficiency of imaging system is extremely high because of reflection type. Therefore, contrast ratio is high and ability of colour representation is great. Secondly, the signal loss or distortion is scarcely generated because micro-mirrors of DMD chip are controlled by complete digital mechanism. Finally, DLP projection device is able to be made light and slim because DMD chip is very small and requires short optical path in the devices.

In case of DLP projection device, resolution is decided by the number of pixel which depends on those of micro-mirrors on DMD chip. Therefore, it should be increased in order to enhance the resolution of the DLP projection device. However, it has some technical problems and leads to increase in cost. Accordingly, TI suggested a smooth picture technique by which the resolution of DLP projection device is visually made double.

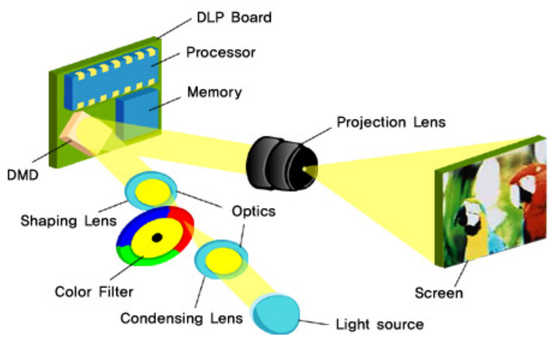
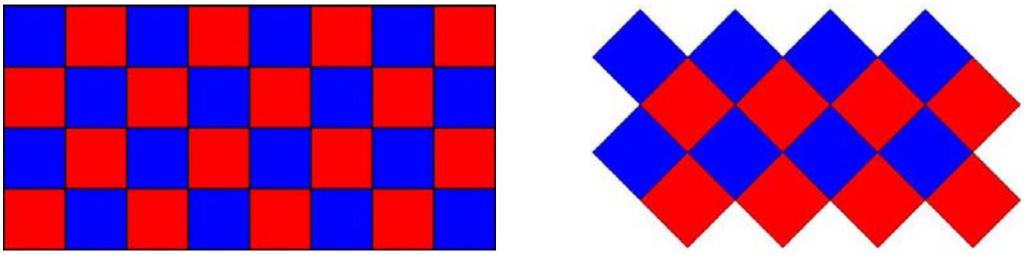


Figure 1 – Composition of DLP projection device

SMOOTH PICTURE TECHNIQUE

Basic Principle of Smooth Picture Technique

The smooth picture technique is to store and displace consecutive sub-frames of the image to allow the complete frame of data to be projected, generating a couple of pixel with one DMD mirror. In order to realize the principle of smooth picture technique, firstly it is necessary to change the mirror structure from square to diamond type array of pixel. Figure 2 each shows the definition of rows and columns for the mirror array for square and diamond type of DMD chip. And then, original frame is divided into two sub-frames, one of these is vertically shifted down by half pixel pitch. Therefore, the resolution of the DLP projection device is visually doubled in the horizontal direction. For example, if there are 960 rows and 1080 columns of mirrors on the DMD chip, the resolution of image in human eye is visually realized 1920 rows and 1080 columns through the use of the smooth picture technique. Figure 3 shows the effect of vertical offset by half pixel for pixel doubling on diamond type array.



(a) Square type *(b) Diamond type*

Figure 2 – Two types of pixel array

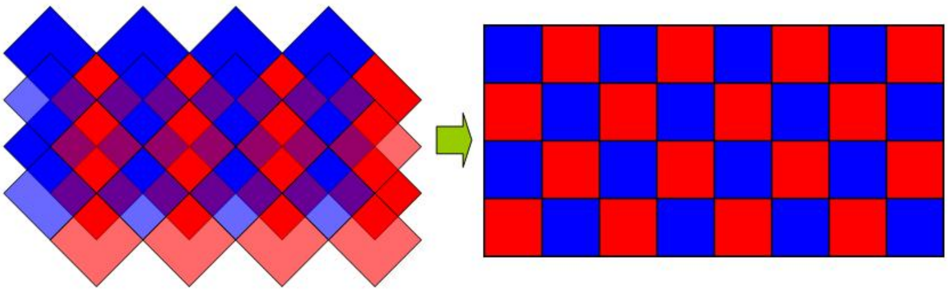
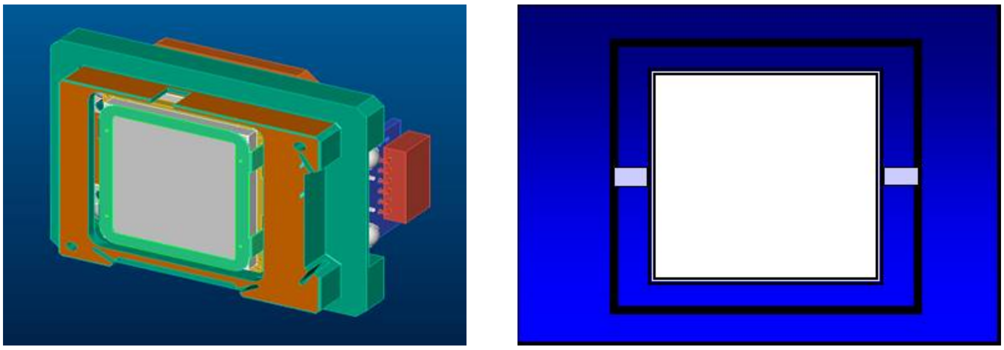


Figure 3 – Effect of vertical offset by half pixel on diamond type

Optical Methods for Smooth Picture Technique

There are two optical methods for shifting the half pixel in the image. One is the use of reflection type PEA and the other is the use of transmission type. Figure 4 is shows the reflection type actuator and transmission type actuator. The reflection type PEA takes much less energy to move the mirror because the rotation angle is very small (as little as 0.015 degrees). However, because of this, that is always required the feedback system and has high cost. On the contrary, the transmission type PEA takes much energy more than the reflection type PEA because the rotation angle is very larger (about 0.5~1 degrees). However, if there is the reliable square wave solution for driving, feedback system is eliminated and thus has the simple structure and very low cost. Besides, transmission type PEA has the another advantage that is more insensitive to noise than reflection type PEA because rotating angle is very large although tolerance of rotating angle is same. Table 1 shows the compared properties of two optical methods.



(a) Reflection type PEA *(b) Transmission type PEA*

Figure 4 – Two optical methods for shifting the half pixel in the image

Table 1 – Characteristics comparison between reflection and transmission type PEA

	Reflection type	Transmission type
Rotation angle (Peak to Peak)	As little as 0.015 degrees	About 0.5~1 degrees
Tolerance	20%	20%
Feedback system	Yes	Yes or No
Cost	High	Low
Driving voltage (energy)	Low	High

TRANSMISSION TYPE PEA

Overview of Proposed Transmission Type PEA

The transmission type PEA is installed between an image screen and the DMD chip and composed of the fixed part, moving part with a transparent glass which is rotated by regular input signal to shift half pixel, a rotating axis, and a magnetic part for generating of driving force. Figure 5 shows the structure of the transmission type PEA.

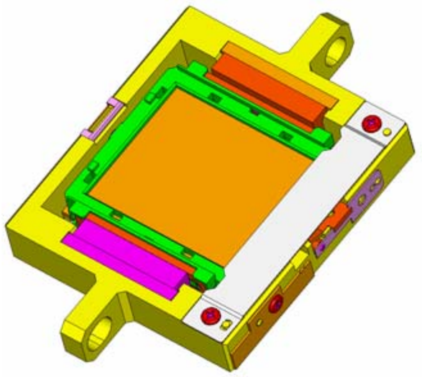


Figure 5 – Construction of Transmission type PEA

Square Wave Solution for Proposed Transmission Type PEA

For pixel doubling, it is desirable that the rotation angle of the transparent glass coincides with Figure 6. Hence it is the next step to obtain input waveform for this square wave output, reflecting the characteristics of the system. Actually square wave in Figure 6 can be described as a linear combination of infinite terms by Fourier series. If the input corresponding to each term is obtained, it is apparent that a linear combination of each input is input waveform for square wave output.

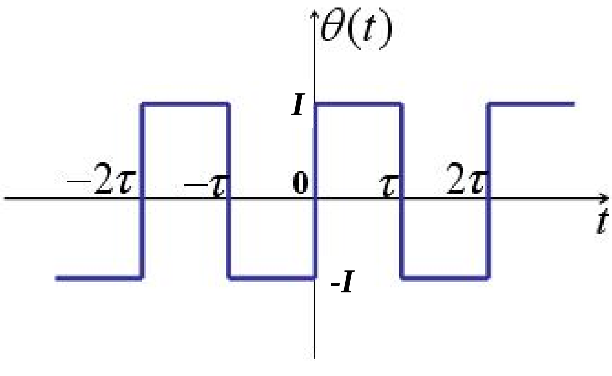


Figure 6 – Ideal output of transmission type PEA

An ideal output of transmission type PEA is expressed as follows:

$$\theta(t)=\begin{cases} I & 0\le t\le \tau \\ -I & -\tau \le t\le 0 \\ and & \theta(t+2\tau)=\theta(t) \end{cases} \tag{1}$$

And, (1) is mathematically represented using Fourier series, such that

$$\theta(t)=\frac{4I}{\pi}\left(\frac{\sin\frac{\pi}{\tau}t}{1}+\frac{\sin\frac{3\pi}{\tau}t}{3}+\frac{\sin\frac{5\pi}{\tau}t}{5}+\cdots\right)=\sum_{n=1}^{\infty}\frac{4I}{\pi n}\sin\frac{n\pi}{\tau}t=\sum_{n=1}^{\infty}\Theta_n\sin\frac{n\pi}{\tau}t \quad (2)$$

$$\textit{where, } n=2m-1 \quad (m \textit{ is natural number}) \textit{ and } \Theta_n=\frac{4I}{\pi n}$$

The equation of motion of transmission type PEA is given by

$$J\ddot{\theta}(t)+c_\theta\dot{\theta}(t)+k_\theta\theta(t)=T(t) \quad (3)$$

If the rotating angle $\theta(t)$ is $\Theta\sin\omega t$ and the input torque $T(t)$ is $\mathbf{T}\sin(\omega t+\phi)$, frequency response is obtained by

$$\frac{\Theta}{\mathbf{T}}=\frac{\frac{1}{k_\theta}}{\sqrt{\left\{1-\left(\frac{\omega}{\omega_0}\right)^2\right\}^2+\left(2\zeta\frac{\omega}{\omega_0}\right)^2}} \quad , \quad \phi=\tan^{-1}\frac{2\zeta\frac{\omega}{\omega_0}}{1-\left(\frac{\omega}{\omega_0}\right)^2} \quad (4)$$

$$\textit{where, } \omega_0=\sqrt{\frac{k_\theta}{J}}\sqrt{1-\zeta^2} \quad \textit{is damped natural frequency}$$

$$\zeta=\frac{c_\theta}{2\sqrt{Jk_\theta}} \quad \textit{is damping ratio.}$$

Input torque $T(t)$ is generated by voice coil motor installed in this system. Therefore, this input torque is proportional to the input voltage.

It was shown that the output of the system was be able to be defined as a linear combination as shown (2). Thus, corresponding to each output term of (2), input term is obtained by applying (4)

$$T_n(t)=\mathbf{T}_n\sin(\omega_n t+\phi_n) \quad (5)$$

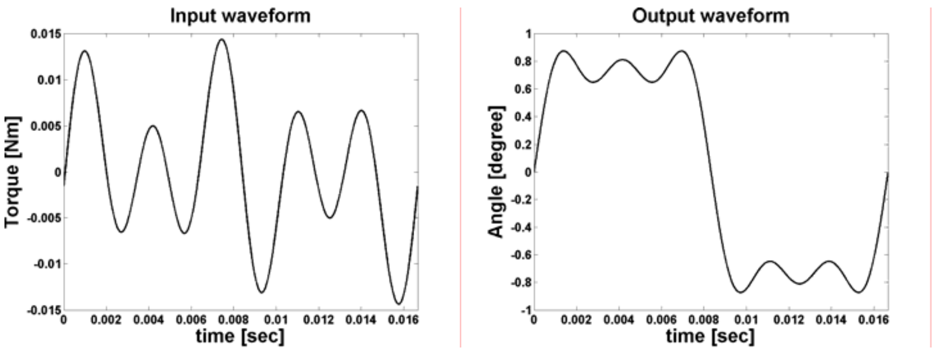
$$\textit{where, } \mathbf{T}_n=k_\theta\sqrt{\left\{1-\left(\frac{\omega}{\omega_0}\right)^2\right\}^2+\left(2\zeta\frac{\omega}{\omega_0}\right)^2}\,\Theta_n \,,\ \phi_n=\tan^{-1}\frac{2\zeta\frac{\omega_n}{\omega_0}}{1-\left(\frac{\omega_n}{\omega_0}\right)^2}\,, \textit{ and } \omega_n=\frac{n\pi}{\tau}$$

Finally, the input of the system is expressed the linear combination of (5), such that

$$T_n(t) = \sum_{n=1}^{\infty} T_n \sin(\omega_n t + \phi_n) \qquad (6)$$

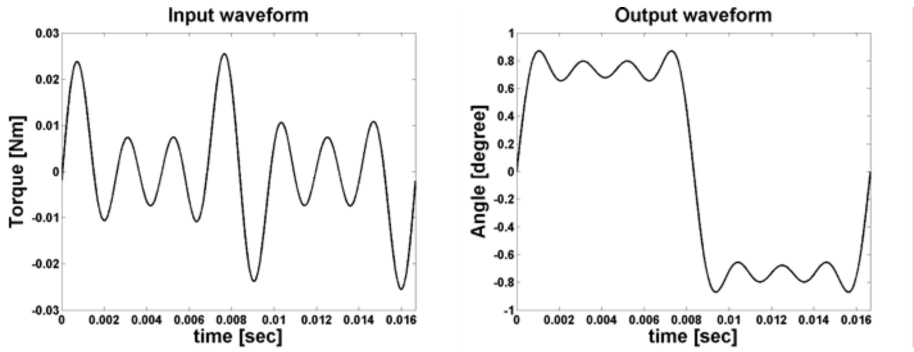
$where,\ n = 2m - 1\ (m\ is\ natural\ number)$

In order to obtain the ideal square wave solution, the linear combination of infinite terms in (6) should be composed. However, high order terms in (6) are properly eliminated based on maximum input voltage which can be supplied from DLP projection device, because input voltage should be abnormally raised to make use of high order terms.



(a) Input *(b) Output*

Figure 7 – The 3rd order driving waveform

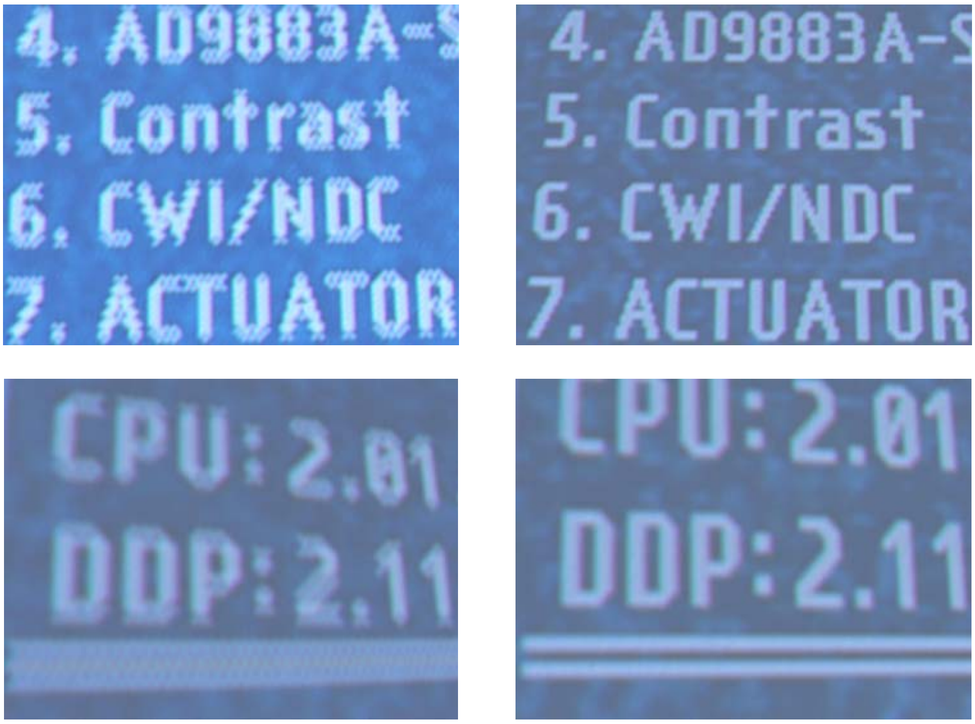


(a) Input *(b) Output*

Figure 8 – The 4th order driving waveform

Applying Results of Quasi-Square Wave Solution for Proposed Transmission Type PEA

Figure 9 shows the screen quality between image before using the proposed transmission type PEA and after using it. Through the results, pixel doubling effect by the proposed transmission type PEA with derived quasi-square wave solution is verified.



(a)Before using the proposed PEA *(b) After using the proposed PEA*

Figure 9 – Comparison of the image quality

CONCLUSION

We newly propose the transmission type PEA with the derived quasi-square wave solution, which can be obtained without feedback system with the very low cost. We prove the high image quality by proposed transmission type PEA in spite of using the present DMD chip.

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