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Geometric Distortions in Scanned Laser Displays

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ABSTRACT: **Practically unrestricted depth of focusing, great color saturation, high contrast ratio and high resolution in combination with various video standards are the major advantages of laser projection systems compared to conventional lamp projectors. Every individual pixel is created by collinear superposition of three collimated laser beams in the image. By result, the image stays also properly focused if the distance to the projector is varying or inclined or if curved surfaces are used as a projection screen. Here the laser wavelengths used cover more than 90% of all colors which are perceptible by the human eye. The laser displays like any other system suffers from some inherent distortions. The distortions may be in shape of pincushion, barrel, parallelogram, unequal sides, non-linearity, etc.These systems use high speed scanning in horizontal direction and in vertical direction with lower speed scanning to generate the required frame rate. High acceleration forces required for high scanning frequency often causes bending of the micro mirror. The reasons for such kind of abnormalities may be disturbed biaxial scanning due to misaligned mirror, misaligned SLD module with respect to the optical system, misaligned hinge, laser source misalignment and aberration in the optical system projecting the LSD image.**

Keywords: **LSD, Distortions, MEMS, HUD**

I. Introduction

For avionics applications, CRT have been used for airborne applications like head down displays, head pdisplays (HUD) and helmet mounted displays, etc. as a light source to display the information. However, because of its higher weight, bulkiness, more power consumption, etc., various options have been used in various displays applications like Active Matrix (LCDs) and Vacuum Fluorescent Displays (VFDs) [1]-[3].Since LCD based HUD islimited by the brightnessand VFD is limited mainly by the amount of information it can display, some new emitting display technology based on OLED are also being explored worldwide which can generate a transparentdisplay on a thin layer and is brighter than LCDs [4]-[5].However, its display is limited because of its low brightness, high cost and short life span.As compared with the emitting and backlight display, laser display is an emerging technology and provides performance comparable to CRT in many aspects and in some aspects better than CRT. .

Laser is amonochromesource in which light is generated by optical amplification process. Because the light of laser is highly directional, the laser beam has high power density which can generate brighter display as compared to the conventional display methods. Laser scanned display has an edge over other conventional display technologies such as CRT, LCD and LED, etc. The properties which distinguish laser from these conventional displays are:Laser light is highly monochromatic; and Laser light is generally highly collimated which can be focused to the smallest spot size through diffraction.

II. Laser based See Through Displays

While designing a laser based display system, it is necessary to consider whichproperties of the laser radiation are important to that display system. For example, lasers is scanned in a raster pattern on a display screenfor a large-screen TV as compared to an electron beam which is scanned on the phosphor screen inside a CRT. The beam-like operation and high intensity characteristicsof laser are very useful which enables us to make a display with adequate brightness. Similarly, for avionics applications, the monochromatic character of the laser is an important parameter for an electro-optical deflection method.

In contrast to this, a direct retinal display system do not motivate the high intensity of the laser whereas it will be preferred that the laserintensity be attenuated many-fold to prevent any eye injury or discomfort. As the laser displays have the scanningnature, the laser's collimated beam may be useful for large screen TVbut it is not mandatoryfor scanning high resolution pictures on the retina.

In a directretinal display such as HMDs, thelaser display are used rather than an incoherent source because these displays use acousto-optic deflection methods and work well only with monochromatic light. Earlier, only deep red laser diodes were available in the visible spectrum but now-a-days, laser displays that operate at green and blue wavelengths are available.

Laser based HUD has a high contrast ratio, thereby provides a better visibility to the pilot in high outside luminance conditions. A contrast ratio of about 1.3 is preferred in such kind of displays whereas the contrast ratio below 1.2 will cause a dim display. The contrast ratio is governed by the display luminance and the outside world luminance. The display luminance is the luminance of the displayed light that is available to the pilot's eyes whereas the outside world luminance is the ambientluminance of the real world. An excessive contrast ratio will cause an opaque display which can be a problem when driving at night, twilight or low light conditions. The outside world luminance will be very high when driving in the sunny day and against the sun, requires a high display luminance. In such cases, the laser based HUD can achieve a good performance due to its high power density.

III. Discussion on Image Formation and Distortions in LSD on HUD

Head up displays is a promising application for scanning laser beam displays due to their high contrast and color saturation. In HUD, the image is viewed under a large range of environmental luminance conditions. The high contrast makes scanning laser beam technology very well suited for applications where a high contrast is important. LED illuminated LCD based HUDs have a relatively low contrast. Under dark illumination conditions, this contrast causes a background glow around the image content. A scanning laser beam head up display will not show anything else than the intended image content, even under the lowest environmental lighting conditions. In addition, the saturated colors from the laser illumination make the content stand out from the environment. As a result, the display increases situational awareness, which can improve the safety of an operator.

As compared to all of the other HUD displays techniques which use LCD and OLED as a display source, the micromirror based vector HUD has some advantages.The laser display can generate higher brightness images compared to the LCD and OLED display. The brightness is usually 5-10 times of the LCD and OLED. For laser vector display, the laser beam just focus on the desired trajectories which can generate even brighter display than the laser raster display.The micromirror based laser scanned display has a bigger angle of view which is 5-10 time bigger than the traditional HUD such as LCD HUD and OLED HUD.The micromirror based HUD can form both real image and virtual image which makes it flexible whereas the LCD HUD can only generate virtual image display which cannot be used for some vehicle such as trucks as the windshield for the truck is almost flat and vertical.So micromirror based HUD has more flexibility. The micromirror based HUD module has a much smaller volume than the LCD HUD. Because of the curvature of the windshield, a compensational optics is needed to generate an undistorted image on the windshield which increases the volume of the HUD module. For the micromirror based vector HUD, a pre-distorted image can be produced by compensating in the control signal, which does not need the compensational optics. The small size of the electrostatic micrormirror can largely reduce the volume of complete HUD system.The poly-silicon multiuser MEMS process (PolyMuMps) fabrication process of the micromirror can make low coat production which results a relative low cost of the HUD system.

The laser based HUD has the ability to display a large amount of information. They uses rotational micromirror which is a micro-electro-mechanical system (MEMS)to control the laser beam to scan a certain two-dimensional area.There are two types of display method of laser scanned display, i.e., vector display and raster displaywhich corresponding to two types of micromirror, non-resonant micromirror and resonantmicromirror respectively. In laser vector display, the laser spot keeps scanning arbitrary points whichform the patterns periodically. If the scan speed is fast enough, stable shapes can be formed. In case of laser raster display, the laser spot scans a certain area line by line. In this, each point is one pixel on the image. Laser brightness is modulated in different pixel togenerate the desired image. The disadvantage of the vector display is that it only can display theoutline of the objects and the amount of the displayed content is limited by the scan speed. Presently, most of the commonly used display equipment such as the TV and projector areusing the raster display which can provide more image information.

For the HUD application, vector display had been widely used in the aircraft. It has got several advantages. In this, a brighter display can be achieved because limited information needs to be displayed as simple shapes and the vector display allows a slower scan, consequently a brighter image. Then, transparency of the display region is an important safety factor. Raster display in preferred HUD display ratio may cause an opaque region. However, this can be avoided by turning off the laser in the regions which do not contain the useful information. In this point, the vector display and raster display don't have a big difference in HUD. In addition, the laser based raster display requires a higher power laser which consumes more power and has a potential safety problem. In this case the vector based display is more suitable for HUD.The micromirror used for vector HUD and raster HUD have the common character that they are both rotational and can steer the laser beam to scan through a two dimensional area.

LSD mainly employs a laser deflection mechanism which can be implemented using either a bi-axial mirror or a set of two uni-axial mirrors. The objective is to move the beam both in horizontal direction with a fast scan rate and in vertical direction with a slow scan rate to produce the required frame rate in a raster scan image. The bi-axial mirror tilts in orthogonal directions whereas in case of uni-axial mirrors, one mirror moves in the horizontal direction and the other in vertical direction to effectively produce deflections in both the directions. The micro mirrors are usually actuated through electrostatic or electromagnetic means which enable sufficient deflection of the mirrors to achieve the required resolution. Using a fisheye lens in front of the micro mirror, a projection angle of over 100° can be achieved. LSDs using electromagnetic actuator consume significant current as well as have increased weight and size of the scanner engine. They are capable of providing greater torque than the electrostatic actuators at small voltage.

The MEMS scanning mirror consists of a reflector suspended in a gimbal frame containing a micro fabricated electrical coil. Permanent magnets are collected around the MEMS die to supply a magnetic field. Providing electrical current to the MEMS coil generates a magnetic torque on the gimbal frame with components along both of the desired axes of rotation. One component of the torque is oriented to cause rotation of the gimbal frame about its flexure suspension. The torque component is used to convert the frequency content of the mirror drive signal below any resonant frequencies of the MEMS to a saw tooth ramp mirror rotation corresponding to the vertical display axis. A second torque component activates rotation of the gimbal frame about an axis normal to its flexure suspension. Such a component is used to activate the scanning mirror on a resonant mode of vibration consisting mainly of rotation of the reflector about its flexure suspension to the gimbal frame, and analogous to the horizontal display axis. There is only one drive signal input to MEMS. To create the biaxial motion, the waveforms for both the vertical and horizontal motion are simply superimposed. The frequency response characteristics of the MEMS dynamic system intrinsically filter the composite drive waveform such that a 2-dimensional raster display pattern results. The design allows for large scan angles with reasonable power consumption operating at atmospheric pressure. Position feedback for both desired scan angles is implemented using PZR strain sensors micro fabricated on both the reflector suspension flexures and the gimbal frame suspension flexures. Such feedback improves the stability of the projected display over time and environmental conditions.[7]

In case of LSDs, the micro mirror should operate at high scanning frequency and with a wide projection angle to achieve required resolution and frame rate. High acceleration forces required for high scanning frequency often causes bending of the micro mirror. Even a small deformation of the mirror flatness can lead to pixel and image distortion. The resolution of LSD system depends upon the scan angle and mirror size. Taking into account the required resolution, frame rate, mechanical and space constraints, the mirror size and scan angles are optimized to meet the application needs.[6]

Image distortion in LSD may be a result of the bi-axial scanning of a single beam. This can be understood geometrically by imagining that the mirror is at the center of a globe, and scanning the image on the interior of the globe between longitudinal lines. The steeper the input angle of the beams relative to the mirror normal, the higher the latitude at which the image is drawn. This image is then projected onto a surface which can be either curved or flat. In both cases distortion is created. Distortions in scanned laser displays may have a shape of pincushion, barrel, parallelogram, unequal sides, non-linearity, etc.The normal distortions like barrel, pincushion distortion, unequal sides, etc. are normal in such displays and they need to be studied and quantified. In barrel and pincushion distortion, image magnification process increases with distance from the optical axis. The seen effect is that lines that do not go through the centre of the image are inclined inwardstowards the centre of the image.The size related distortions are generally linked to the positioning of the SLD source with respect to target optics system or the opaque surface on which it is projected.Thedistortions may be due to various factors like:

- Disturbed biaxial scanning of the single beam due to misaligned mirror
- Improper positioning of the SLD vis-à-vis optical lens system or the surface on which is image is being projected.
- Misaligned hinge on which the mirror is mounted which may be due to vibration or due to vibration-temperature combined effect.
- Laser source misalignment.

These distortions results in overall displacement of the symbology from its original desired spot position. Thismeans that a particular character, symbol or reticle has placed at some other location other than the desired location. However, these distortions can be removed using 2-D interpolation techniques.

IV. Conclusions

MEMS displays offer many advantages like miniaturization, reliability, cost and weight reduction in addition to the fact that they can be ruggedized to meet military standards for air-borne applications viz. avionics displays. LSD based RSDs has revolutionized the head-worn display technology with better resolution and full color capability.These systems are realized on either a bi-axial mirror or a set of two uni-axial mirrors which deflect the beam in horizontal direction with high speed scanning in horizontal and with lower speed scanning in vertical direction to generate the required frame rate. Thehigher scanning frequency coupled with a wide projection angle is required to achieve required resolution and frame rate. High acceleration forces required for high scanning frequency often causes bending of the micro mirror. Even a small deformation of the mirror flatness can lead to pixel and image distortion. The LSD image distortion could be in shape of pincushion, barrel, parallelogram, unequal sides, non-linearity, etc.The reasons for such kind of abnormalities may be disturbed biaxial scanning of the single beam due to misaligned mirror, improper positioning of the SLD with respect to the optical lens system or the surface on which is image is being projected, misaligned hinge on which the mirror is mounted which may be due to vibration or due to the combined effect of vibration and temperature, laser source misalignment and aberration in the optical system projecting the LSD image.

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