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Analysis of Errors and Distortions in Stroke Form of Symbology for Head-up Displays

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Abstract: **In case of a Head Up Display (HUD), there are a number of other factors which are used to characterize the displays like distortion, transmittance, field of view, exit pupil diameter, parallax error, position accuracy errors, binocular disparity, linearity, vergence and field curvature. The display parameters are basically combined with human system characteristics to produce image quality metrics which are related to operator's performance as it is mostly done in present systems. The spot symbol spot positioning accuracy refers to the angular deviation of the observed spot position on the display from the exact spot position defined by the specific input data. In this paper, various issues concerning HUD distortions and errors are discussed and a method is proposed to evaluate the distortions and errors of the HUD through introduction of two patterns using which the distortions and errors could be estimated for the entire HUD screen through use of Theodolite simulating the head motion box movement in X and Z directions. The results of HUD measurements are also presented.**

Index terms: **Head Up Display, Symbol Positioning Accuracy, Parallax Error, Geometric Distortion, CRT, Optical Assembly, Theodolite.**

I. INTRODUCTION

The cockpit of modern aircraft is made revolutionary today to provide the pilot with ultra modern gadgets to maneuver civilian and jets flying at speed crossing sound barrier/velocity with high efficiency to accomplish the mission success. The cockpit is packed with display systems viz. Head-up Display, helmet mounted display, multi functional display, etc. Out of all these equipment, Head-up Display (HUD) occupies the prime location and has no redundancy [1], [2]. A Head-up Display (HUD) is a transparent display that presents data without requiring the user/pilot to look away from his or her usual viewpoint. The pilot is able to view the information with his head "up" and looking forward, instead of looking down on other instruments mounted in the cockpit. HUD essentially consists of a Cathode Ray Tube (CRT) upon which the required symbology is displayed; an Optical System along with glasses which integrates outside scene and the synthetic vision to project a collimated symbology into the pilot's field of view. The symbology on the CRT is collimated by the optical system and reflected to the pilot's eye by front glasses generally called as beam combiner glasses. Flight information with the full range of weapon aiming capabilities is displayed on the CRT with provision for either composite form or stroke form of presentation of information provided by appropriate electronics signal processing circuitry [3], [4].

In stroke form of display, only those points are scanned which are required to be displayed and the rest of the screen is blank. This form of symbology is used to display synthetic information on the display source at various writing speeds [5]-[7].

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II. MAJOR SOURCES OF ERROR GENERATION

The symbology in a Head-up Display need to be placed at correct location as it deals with the success and safety of the mission. The landing in aircraft aligns with the horizon bar. Similarly, in case of fighter aircraft, the weapon aiming is done through aiming symbology displays on HUD. Hence, the symbol spot positional accuracy requires attentions [8], [9]. The error in few milli-radians (mR) in reticles display results in weapon aiming error of several hundred of meters which is aimed at several kilometers of distance. Similarly, in case of any error in the landing information or horizon bar is not placed correctly, it may be hazardous landing. The displacement of symbols, characters and other reticles which forms the complete symbology page can be caused by five major components of a Head-up Display [1], [2], [10], [11]:

- The inaccuracies in the display driver driving the HUD.
- Electronic signal processing circuitry of HUD
- Inherent CRT properties
  - Alignment of deflection yoke
  - Convergence of electron beams: Red, Green, Blue
  - CRT deflection angle
- Optical assembly of HUD
  - Optical lens assembly which is responsible for collimating and magnifying the symbology.
  - The design which combines synthetic symbology and the outside view.
- Mechanical fitment mismatch.

In HUD applications, the CRT lengths are required to be short generally owing to the space constraints in these systems. The short length of CRT requires high deflection current due to large deflection angles for full scale deflection of the electron beam. The problem associated with high deflection current is horizontal and vertical signal distortion due to large CRT deflection angle which leads to geometric distortion of the image. However, the problem is compounded in avionics displays due to magnification and collimation of the CRT image by the optical elements [5]-[7].

The sine of the deflection angle is proportional to the deflection current in the CRT by which an undistorted rectangular pattern appears on the screen of the display if

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the radius of curvature is equal to the length of the beam when it is measuring from the center of the deflection plates. The flat HUD CRTs have got inherent geometrical distortions also known as "Pincushion". This geometric distortion in CRT image may be caused due to the minor misalignment of the CRT yoke which can be partially corrected by special design of the yoke winding or placement of the deflection yoke of the CRT. However, this methodology may cause degradation of the spot size and convergence resulting less resolution at the corners of the display [4], [12], [13].

The optical lenses are curved in nature and the distortions can not be eliminated in totality especially after fabrication. The errors due to optics are generally more at edges then at center locations. The optical errors are of various types [14], [15]:

- Parallax
- Binocular parallax
- Optical aberrations

These three errors results in overall displacement of the symbology from its original desired spot position. This means that a particular character, symbol or reticle will be placed at some other place than the desired place when seen from one single place or when seen from different locations. The former two corresponds to parallax and binocular disparity (parallax) errors while the latter leads to error in spot positional accuracy. The Beam Combiner (BC) Glasses which combine the synthetic display symbology with the outside view also contribute to the spot positional accuracy error. This occurs due to non-parallelism between the two surfaces of BC glass, due to non-parallelism between the pair of glasses or due to error in the coating thickness uniformity. The non-alignment of CRT plane with the focal plane of the optical lens assembly results in the parallax error. The parallax error due to mechanical misalignment can be corrected by bringing the CRT place into optical lenses plane. But the spot positional displacement error can be corrected only through electronics and not through optics once it has been fabricated. For a fixed field point, the accuracy is numerically equal to the angular difference between the actual spot position of a real world feature as seen through the combiner glasses, and the projected symbology on the display [1], [14]-[17].

III. DISCUSSIONS ON CRT DISTORTIONS

During the manufacturing and assembling of CRT based electronic display devices such as computer monitors, TV sets; precise mechanical, optical and electronic color and geometric adjustments are required to ensure a display system with optimum reproduction of image quality. These adjustments are performed manually with the help of testing and alignment systems to precisely alignment of CRT based display devices. Since the placement accuracy is not that important in these display devices as the viewer basically looks for the information content and positional accuracy is not of importance. However, in case of medical application, the display accuracy is of prime importance as the physician is dependent on its output image accuracy for performing surgery and similar other procedures [18].

In case of symbology display for avionics application, there is universal standard for military application - MIL-D-81641(AS) according to which size and placement of each character, reticle or symbol is defined along with the continuous display of character or flashing with warning signals. However, slight variation according to requirement may be there in terms of optional or permanent symbol display. The orientation and location of scales, reticles, characters and symbols used for avionics is defined, hence, the error limit of each of the displays parameters also various from position of symbol to symbol. The reason for this variation is that errors at the edges are more due to electronics – CRT, deflection amplifiers, conditioning circuitry, etc. and due to curved surface of the optical elements at the edges resulting in large error margins. The errors at centre or its vicinity is lesser due to lesser deflection movement of the beam and less curvature in the optical elements. Accordingly, worldwide it is a standard to keep the symbol positioning accuracy errors in the display area field to less than 1.5mR from centre to 5º field; less than 2.0mR from 5º to 10º field; and less than 3.6mR for the display area field greater than 10º [18], [19].

IV. METHODOLOGY TO CORRECT GEOMETRIC DISTORTIONS IN HUD

In monochrome TVs in earlier days, a pair of magnets was used on the neck of the CRT to correct the geometric distortions appearing on image. The colour TVs employ incorporation of dedicated electronic circuitry where each kind of distortion like pincushion, barrel, vertical and horizontal linearity, centering, right-left, top-bottom sizes, curvature balance errors etc were accounted for. The correction methodology started with use of analog methods using a series of trim potentiometers which basically incorporated a circular mathematical function. This, however, resulted in more of coarse correction of the geometric distortion.

There are limitations associated with the existing measurement and correction methods which are listed below:

i. The method employed for monochrome television systems using pair of magnets is quite crude in nature and results in quite coarse adjustment of geometrical distortion correction. The resultant adjustment does not result in good results especially at the edges. However, this method is quite simple and highly cost effective and serves the purpose for normal home television applications. As the distortions at the edges are hidden under the chassis of the television system, hence we do not notice them.

ii. The conventional method of using magnets for distortion correction is not used for the colour CRTS as a magnetic field will cause the wrong beam to strike the dot and affect the colour. Moreover the effect of magnetic field on CRT can be permanent by magnetizing the shadow mask to permanently distort the colour. Hence, the correction mechanism in colour television systems is employed using a dedicated electronic circuitry. This mechanism employed all over the world for colour television systems again results only in coarse adjustment only.

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Moreover, it is quite tricky to correct the geometric distortion on the overall image. Further, the distortion correction is seldom achieved at the edges. The image never acquires a straight line shape at all the four sides of the image.

iii. In some cases, due to implementation of complex function and hence increase in computational time, the time taken to compute and implement the correction is not in real time. This result in delay in resultant correction from the actual instance of the correction applied.

iv. The digital method employed worldwide does not fully take care of optical and windshield errors. Hence though the measurement and the correction methodology employed is automatic, the resultant accuracy is not as desired. Further, the need of frequent alignment confirmation periodically adds to the complexity and the inaccuracy of measurements.

During the course of development of HUD for LCA, a method was evolved to completely evaluate the distortions and error performance such that accuracy levels of order of 0.1 - 0.2mR may be achieved.

Figure 1 shows two square patterns with First Square being +/- 3° centrally symmetric with the horizontal and the vertical axis which makes the diagonal field of 8°29’7”. The diagonal field for the smaller square on either side of the x and y axis is 4°14’34”. The bigger outer square is +/-6° centrally symmetric with the horizontal and the vertical axis which makes the diagonal field of 16°58’14”. The diagonal field for the outer square on either side of the x and y axis in this case is 8°29’7”. The patterns are in stroke form and generated through simulator at the desired writing speed.

The vertical and the horizontal sides of the square are made equal through electronics correction mechanism. This pattern ensures the coarse correction of small to large deflection excursions and is meant to provide coarse correction electronically to the square patterns. When measurement for this pattern is taken, the Theodolite is kept near (about 100m from the combiner’s edge to eliminate the error possibilities due to parallax error of optical system.

Other distortions and errors like positional accuracy, parallax, binocular disparity, linearity etc are evaluated using the grid pattern as shown in figure 2. The grid consists of eight rectangular patterns which results in total eight points separated by 1°30’, thus covering a field of 12° on each quadrant. The pattern covers the entire HUD screen and thus provides a comprehensive idea of distortions and errors and also the means to minimize the errors.

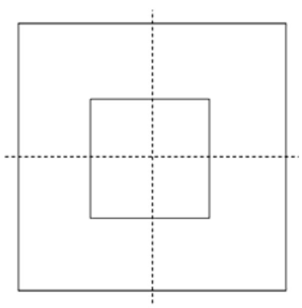

Figure 1: Square Pattern for coarse adjustments of distortions

When the coordinate measuring optical instrument like a Theodolite is moved simulating the head motion box movement, which typical is +/-65mm from the center, the parallax error for each point of the display is estimated. For example, say if the point A (left most point on x axis in figure 2) is being measured, the measurement through the Theodolite could be taken at -65mm, -32.5mm, 0mm, +32.5mm and +65mm which mould mean that point A has been measured from 5 different locations thus simulating the parallax error condition. Similarly, in the vertical direction, HMB movement of +25mm up and -45mm down is simulated through taking measurements from +25mm up, center and -45mm down for each point of the pattern. Thus when the measurement for each point of the pattern from A to A’ through O point, and from I to I’ through O point and other points located on locations other than x & y axis are taken the parallax error for the entire screen could be estimated.

The correction of parallax error is the starting point of measuring and subsequent correction of HUD distortions. The geometric distortions due to CRT and optical elements are lower near the center location and increases from center to the peripheries. Due this vary fact, the measuring points are equally spaced with a reasonable spacing so that the entire screen measurements could be covered. While HUD CRT is generally circularly symmetric, the optical errors are significantly more at the edges. The combined effect may be enhanced errors or the reduced errors depending on the direction of distortions on CRT and optical system.

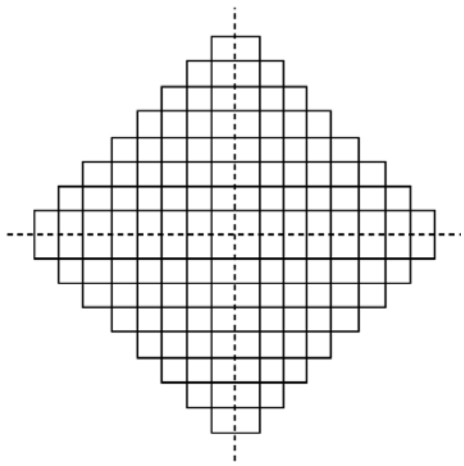

Figure 2: Grid Pattern for Complete Measurement and Correction of distortions and errors

By taking measurements through Theodolite from 15 different placement locations of Theodolite, all the errors and distortions measurements are covered. The measurements are made through Theodolite from the 5 horizontal locations i.e. 65mm extreme left, 32.5mm left, Center, 32.5mm right and 65mm extreme right each for three different locations in the vertical direction i.e. 25mm up, center, and 45mm down, thus simulating the Head Motion Box (HMB) of the cockpit. Hence a total 15 sets of measurements ensure the exhaustive analysis of the errors and distortions over the entire surface of the display screen for the entire HMB. Since for each point, both horizontal

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and the vertical coordinates are measured, the linearity errors in both the axis are also measured. The final measurements through Theodolite are taken from the design eye position. Thus with two patterns, the all the measurements and corrections could be made. The figure 3 shows the Setup used for measurement directly on Optics.

Figure 3: Setup used for measurement on Optics

The following table shows the measurement readings for positional accuracy taken for four different HUDs before and after the correction. In this system, the correction factor applied for horizontal and the vertical deflection follows the function $x(x^2+y^2)$ and $y(x^2+y^2)$ respectively.

Table 1: Errors (in mR) from the nominal positions before and after correction

	HUD-1		**HUD-2**		**HUD-3**	
Points	Before correction (mR)	After correction (mR)	Before correction (mR)	After correction (mR)	Before correction (mR)	After correction (mR)
D’	+ 0.93	+ 0.11	- 1.52	- 0.02	- 1.24	+ 0.12
C’	+ 1.75	+ 0.08	- 1.81	- 0.04	- 1.81	+ 0.18
B’	- 2.75	- 0.14	+ 2.99	- 0.13	- 2.19	- 0.10
A’	- 3.35	- 0.19	+ 3.98	- 0.09	- 2.46	- 0.13
E’	+ 0.97	- 0.02	- 1.52	- 0.12	+ 1.29	- 0.04
F’	+ 1.72	- 0.07	- 2.12	- 0.14	+ 1.98	- 0.01
G’	- 2.99	- 0.09	+ 3.19	+ 0.13	+ 2.39	- 0.10
H’	- 4.63	- 0.11	+ 4.83	+ 0.07	+ 2.88	- 0.12
L’	+ 1.25	+ 0.01	- 1.55	+ 0.11	- 0.98	+ 0.07
K’	+ 1.81	+ 0.03	- 2.05	+ 0.17	- 1.55	+ 0.06
J’	- 3.13	- 0.09	+ 3.27	- 0.21	- 1.78	- 0.19
I’	- 4.62	- 0.12	+ 5.17	- 0.22	- 2.16	- 0.11
M’	+ 1.41	- 0.02	- 1.64	- 0.06	+ 0.87	- 0.04
N’	+ 2.17	- 0.06	- 2.89	- 0.06	+ 1.57	- 0.07
P’	- 3.21	+ 0.16	+ 4.31	- 0.11	+ 2.39	+ 0.21
Q’	- 5.09	+ 0.17	+ 5.49	- 0.11	+ 3.89	+ 0.17

The second column shows a pincushion error, fourth column shows a barrel type of distortion while sixth column shows a rhombus type of geometric distortion.

V. CONCLUSIONS

Since a Head-up Display is used during takeoffs, landing and during weapon aiming, the geometric correction mechanism should result in nearly zero errors in the symbol positioning. The error of few mR in reticles display results in weapon aiming error of several hundred of meters which is aimed at several kilometers of distance. The study discussed various aspects of geometric distortions in HUD used for avionics applications. The major contributors in geometric distortions are the coil drivers, Electronic signal processing circuitry, Inherent CRT properties, CRT deflection angle, Optical assembly of HUD, and Mechanical fitment mismatch. The distortions and errors in optics and mechanical assembly can not be corrected once they are fabricated and assembled. The only error which could be reduced in optics after fabrication is parallax error which could be optimized by bringing CRT and optics in the same focal plane by using spacer shims. Hence, corrective action through electronics in deflection (coil driver) amplifier circuit is the only means through which distortions and errors could be minimized. The measurements made using the two evolved patterns described above ensure that the errors and distortions over the entire display area are analyzed in totality.

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