

Rugged Eye Tracker for Fighter Jet Pilots

Background and Need

Pilots need eye trackers that can be used in conjunction with head trackers for combat and virtual reality environments. There are two major applications: First is to increase the speed and accuracy of pilot targeting using look and click cueing. Second is to support an immersive display system with true 20/20 resolution for pilot training simulators based on foveal eye tracking. A small, lightweight, non-contact, head-mounted eye tracker that is capable of operating in a high-G airborne environment is needed to meet these demands.

Aggressive maneuvers of the jet result in both buffeting as well as substantial G loading. G loading causes visual acuity loss, in part due to loss of blood flow and in part due to the displacement of the eye's lens in the direction of the g-force vector (generally the direction opposite of motion). Additionally, the pilot's (upper) eyelids droop and the lower eyelids, which are not designed to hold themselves down, partially cover the eye during negative acceleration. Moreover, the shaking can cause most standard commercial off-the-shelf (COTS) trackers to lose track because they must track reflections from inside the eye and through the pupil.

Besides having to be immune to G loading and buffeting, the eye tracker for the jet fighter pilot is subject to the usual constraints and requirements of weight size and speed. This specification can be summed up as a non-contact eye tracker with fast operation and low latency (less than 30 ms), very light weight (tens of grams) and small volume (less than a cubic inch). The form factor should allow secure mounting to the head or a helmet, since the eye tracker needs to operate in cooperation with a head mounted display and head tracker. Furthermore, the design should not interfere with the pilot's vision or the ejection process or risk any harm to the pilot including during the ejection process.

A design that meets all of the stated requirements cannot be found today, and new technology development is required.

Technology Highlights and Status

Under the SBIR Phase I project sponsored by the Air Force, Optical Physics Company (OPC) completed the design of an eye tracker design suitable for high G environments. The ability to meet the above requirements of small volume light weight and low latency were demonstrated. The accuracy is 1 mrad (1 milliradian = 3.44 arc minutes = 0.057 °) in both the horizontal and the vertical direction. The detailed specifications and how they compare with the threshold and objective requirements are included in Table 1 below.

REQUIREMENT	THRESHOLD	OBJECTIVE	PERFORMANCE	COMMENT
HORIZONTAL RANGE (DEG)	+/-25	+/-50	+/-50	Requires two eye trackers
VERTICAL RANGE (DEG)	+/-20	+/-30	+/-30	Either eye tracker is sufficient
HORIZ ACCURACY (MRAD)	+/-4	+/-1	1 RMS	0.1% of 60 degree range
VERT ACCURACY (MRAD)	+/-4	+/-1	1 RMS	0.1% of 60 degree range
UPDATE RATE (HZ)	100	200	200	Easy
LATENCY (MSEC)	50	20	7.5	1.5 frames latency
NUMBER OF EYES TRACKED	1	2	2	Need both eyes for full range of motion
UP G-LOAD	1	1	FULL	Helmet motion measured + corrected
DOWN G-LOAD	10	10	FULL	Helmet motion measured + corrected
BACK G-LOAD	1	1	FULL	Helmet motion measured + corrected
HELMET ROTATION RANGE	TBD	TBD	5 mm	Horizontal and Vertical range
HELMET ROTATION ACCURACY	TBD	TBD	0.5 mrad	Uses second source for each eye
SIZE	TBD	TBD	0.3 cu.in.	Embedded in the helmet
WEIGHT	TBD	TBD	22 gm	Includes IrDA data link and helmet track
POWER	TBD	TBD	0.63 watt	Includes IrDA data link and helmet track

Table 1. Summary of eye tracker requirements and performance

Phase II baseline flight design is helmet mounted with no interference to the pilot's vision area. The design allows not only eye tracking but also helmet-to-head tracking for maintaining accuracy during maneuvers that cause the helmet to slip.

Total weight impact on helmet is about 22 grams; total power impact is <0.65 watt. The load is small enough that the eye tracker can use the helmet power.

Experimental Test Results

The breadboard constructed during the project yielded excellent track data shown in Figure 1. Both the horizontal and the vertical track angles were measured, and the data was smooth enough to be fit by a fourth order polynomial (as predicted) to 0.55 mrad rms (horizontal) and 0.26 mrad (vertical) – 2-4X better than the objective accuracy requirement.

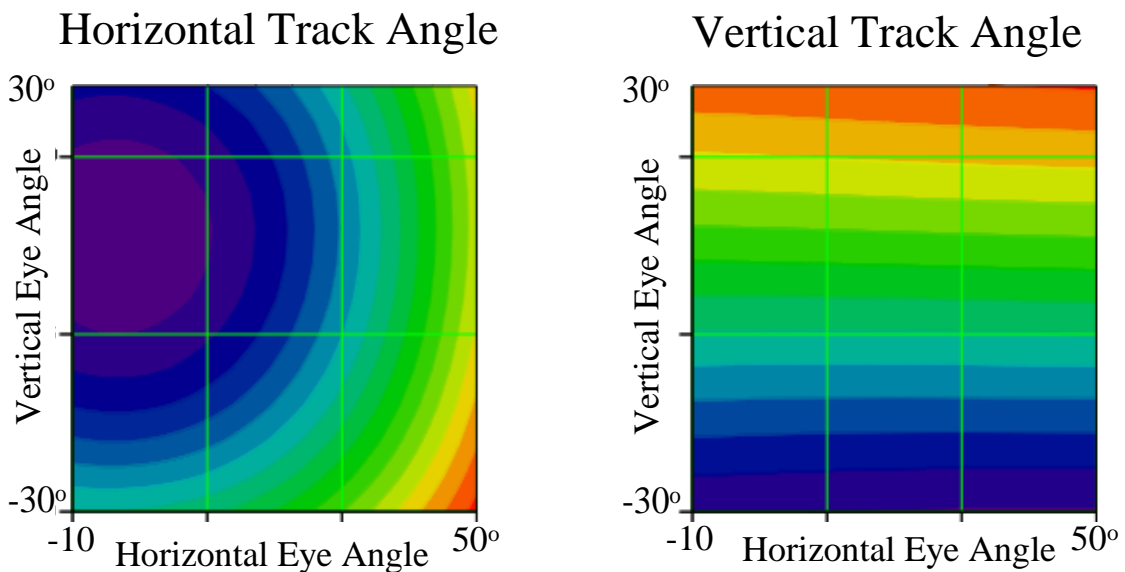


Figure 1. Contour plots of the measured eye tracker response over the full field of view matched theory well. The eye tracker breadboard gave excellent track data, smooth enough to be fit to 0.55 mrad rms (horizontal) and 0.26 mrad (Vertical) – better than the objective accuracy requirement of 1 mrad.

These plots show the position incident on the sensor (color contours) as a function of actual horizontal and vertical eye position. The vertical position signal (right plot) is quite linear in vertical eye angle and almost independent of the horizontal eye motion. The horizontal position (left plot) is a quadratic function of both vertical and horizontal eye motion. The center of the quadratic function can be placed at a desirable position by adjusting the design geometry. In the final design, optimally this center will be moved beyond the left edge of the eye track range so that one can obtain track signals over the entire objective eye range.

The horizontal and vertical experimental data was fit by a fourth order polynomial to 0.5 and 0.25 milliradians accuracy respectively (as predicted by the theory). This provided excellent confirmation that the desired track accuracy can be practically achieved in real hardware.

Technology Transition Target: Joint Helmet-Mounted Cueing System (JHMCS)

The technology transition target platform for the OPC eye tracker is the Joint Helmet-Mounted Cueing System (JHMCS). The JHMCS helmet designed for use with its helmet mounted display (HMD) and with a cockpit head tracking system. Current tracking mechanism on JHMCS does not include eye tracking. Instead, the JHMCS has a magnetic helmet-mounted tracker that determines where the pilot's head is pointed, combined with a miniature display system that projects information onto the pilot's visor. The head tracker and visor display act as a targeting device that can aim sensors and weapons wherever the pilot is looking. This coordination between the pilot and the JHMCS display which lets the pilot look at a threat, place the sighting symbol over it, and command the plane's sensors and weapons to look there consists of a head tracker. The system uses a magnetic transmitter unit fixed to the pilot's seat and a magnetic field probe mounted on the helmet under the visor to define helmet pointing positioning. Thus, in a sense, this is a "turn and shoot" mechanism and not a "look and shoot" mechanism. This helmet mounted electronic head tracker is small (the size of a sugar cube). By reading a low-power magnetic field transmitted in the cockpit, it registers the precise positioning of the helmet at every moment [1] [2].

The eye tracker mechanism is most useful during aggressive maneuvers of the jet which result in substantial G loading that makes it difficult for the pilot to make precise head movements. Since it is highly likely that the look and shoot capability will be used during these aggressive maneuvers, it makes sense to have an alternate mechanism using the pilot's eyes.

References

- [1] www.globalsecurity.org/military/systems/aircraft/systems/jhmcs.htm
- [2] www.boeing.com/news/frontiers/archive/2005/august/i_tt.html