Analysis of Foyle

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Enhanced/synthetic vision systems: Human factors research and implications for future systems; David C. Foyle, Albert J. Ahumada, James Larimer and Barbara Townsend Sweet; Aerospace Human Factors Research Division (MS 262-3), NASA Ames Research Center, Moffett Field, CA 94035-1000; SAE Transactions: Journal of Aerospace, 101, 1734-1741; (1992).

This paper is a good example of what the terms **Synthetic Vision** and **Enhanced/Synthetic Vision** meant 20 years ago. The term **Synthetic Vision** originally meant anything that you put up on a video display, especially forward looking infrared and radar.

For example, there is U.S. Patent 5,593,114 **Synthetic Vision Automatic Landing System** issued January 14, 1997 to Ruhl (Assignee McDonnell Douglas Corporation).

From Column 2, lines 16 - 27:

> The instant invention is an Enhanced or Synthetic Vision (also called Autonomous) Landing System (E/SV). This system allows the pilot to view the approach scene with the use of a forward looking radar or equivalent sensor which provides the means of identifying the runways and the airport and land the aircraft using the automatic landing systems on virtually all types of aircraft. A pilot effectively turns the flight task during zero visibility or other low visibility weather conditions into a synthetic "see to land" approach because the image from the forward looking sensor provides sufficient detail to turn any instrument landing into what appears to be a visual landing.

In this patent Enhanced or Synthetic Vision is a display of the data from a forward looking radar or equivalent sensor.

This was also the FAA's definition at the time, in their **Synthetic Vision Technology Demonstration, Volume 1 of 4, Executive Summary**. From PDF page 10:

> 1.1 BACKGROUND
>
> In 1988 the Federal Aviation Administration (FAA), in cooperation with industry, the United States Air Force (USAF), the Navy, and several other government organizations initiated an effort to demonstrate the capabilities of existing technologies to provide an image of the runway and surrounding environment for pilots operating aircraft in low visibility conditions. This effort was named the Synthetic Vision Technology Demonstration (SVTD) program. Its goal was to document and demonstrate aircraft sensor and system performance achieved with pilots using millimeter wave (MMW) radar sensors, a forward-looking infrared (FLIR) sensor, and a head-up display (HUD).

And from PDF pages 11,12:

> 1.2. OBJECTIVE

> The objective of the Synthetic Vision Technology Demonstration program was to develop, demonstrate, and document the performance of a low-visibility, visual-imaging aircraft landing system. The experimental Synthetic Vision System components included on-board imaging sensor systems using millimeter-wave and infrared technology to penetrate fog, and both head-up (HUD) and head-down (HDD) displays. The displays presented the processed raster image of the forward scene, combined with suitable avionics-based stroke symbology for the pilot's use during a manually flown approach and landing. The experimental system, sometimes referred to as a functional prototype system, included all the functions (in prototype form only) required to accomplish precision, non-precision, and non-instrument approaches and landings in low visibility weather conditions.

It’s the same in this 1992 Foyle paper from NASA Ames.

> **ABSTRACT**
>
> This paper reviews recent human factors research studies conducted in the Aerospace Human Factors Research Division at NASA Ames Research Center related to the development and usage of Enhanced or Synthetic Vision Systems. Research discussed includes studies of field of view (FOV), representational differences of infrared (IR) imagery, head-up display (HUD) symbology, HUD advanced concept designs, sensor fusion, and sensor/database fusion and evaluation. Implications for the design and usage of Enhanced or Synthetic Vision Systems are discussed.
>
> **INTRODUCTION**
>
> Enhanced/Synthetic Vision is a term used to describe a group of advanced technology systems that will present or augment out-the-window information. Near-term designs (which we term Enhanced Vision Systems) propose presenting sensor imagery with superimposed flight symbology on a head-up display (HUD), and may include such enhancements as runway outlines and other display augmentations (e.g., obstacles, taxiways, flight corridors). Longer-term designs (which we term Synthetic Vision Systems) may include complete replacement of the out-the-window scene with a combination of electro-optical and/or sensor imagery and database information (as proposed in one version of the High-Speed Civil Transport, HSCT). In these systems, the pilot would control the aircraft based on a representation of the world displayed in the cockpit, and may not see the actual outthe-window visual scene. Such systems present visual information that is needed but would not otherwise be visible (e.g., increased runway visibility in poor weather). It is likely, however, that some visual information will be lost, due to such limitations as resolution, field of view, or spectral sensitivities. Clearly, the most important and salient visual cues for pilotage must be maintained in the display. With Enhanced or Synthetic Vision Systems, the pilot no longer views the world directly; but views a representation through sensors and/or computerized databases. In these cases, it is important to determine the extent to which the Enhanced/Synthetic Vision System accurately transduces or represents the visual cues that impact flight control or taxi with such systems. If visual cues required for pilotage are not accurately or reliably represented to the pilot, system performance may suffer and safety could be compromised.
>
> Some specific studies from current research in the Aerospace Human Factors Research Division at NASA Ames Research Center related to Enhanced/Synthetic Vision System design or usage are

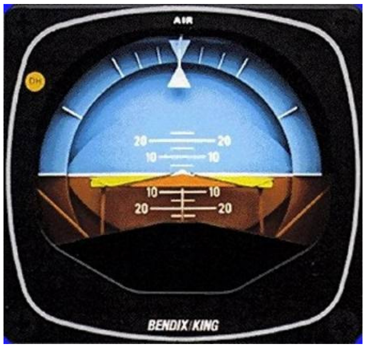
presented herein. NASA Ames Research Center and the other NASA centers have a long history of engineering and human factors research related to these topics.

The discussion in this paper is limited to the work in the Aerospace Human Factors Research Division at NASA Ames Research Center. Research topics to be discussed include: Studies of head-up display (HUD) symbology and concepts, field of view (FOV), infrared (IR) imagery, and sensor fusion algorithms and evaluation.

Conventional Head Up Displays (HUD)

Flight Guidance Information

Discusses Instrument Landing Systems (ILS) and the Flight Director, which was a mechanical instrument like this. →



HUD Symbology

Page 2, Column 2:

> Instead of using the panel-mounted ADI ball for attitude information, the HUD allows presentation of attitude information with an artificial horizon which is conformal with the outside scene, and with additional pitch and heading references. The HUD is also ideally suited for the presentation of flightpath information (the actual direction of flight, as opposed to orientation of the aircraft).

and

> An early example of a HUD using these advanced features is described as follows (Lauber, Bray, Harrison, Hemingway & Scott, 1982;'Bray, 1980).

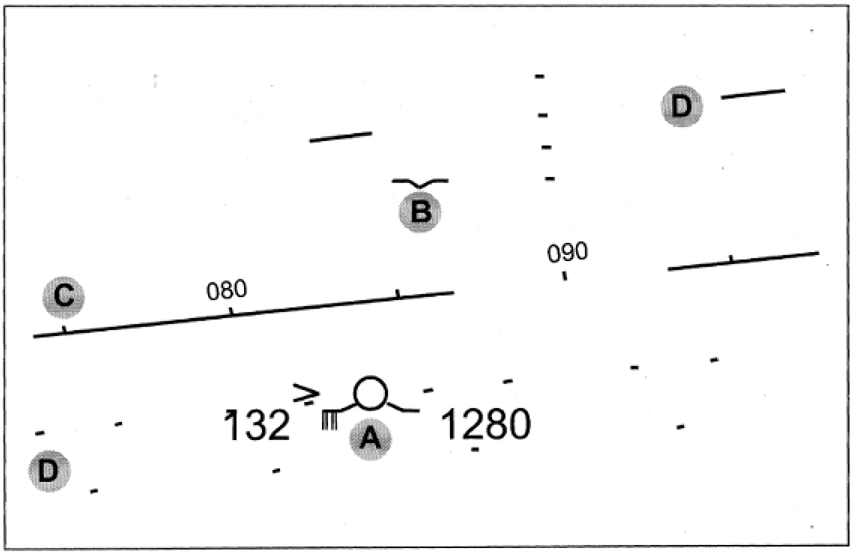
Page 3, Column 1:

> Two types of HUD formats were tested: a flight-director (FD) HUD, and a flightpath (FP) HUD. With only minor variations, the FD HUD presented the same information to the pilot as the head-down flight-director. The FP HUD was a conformal, earth-referenced display which portrayed the predicted flightpath of the aircraft, as well as navigation and aircraft state information (see Figure 1).

and

> This FP HUD display concept was later adopted and certified for use in the Boeing 727 aircraft by an avionics company. The new design incorporated a flight director element, while still featuring the flightpath symbology in the original display

And here is Foyle Figure 1:



Not Synthetic Vision as it is now defined. It is Symbology.

Superimposed Symbology Fixation

Page 3, Column 2:

> Superimposed symbology, whether on a HUD or HMD, under certain conditions, has been demonstrated to lead to visual and attentional fixation. Under visual fixation, pilots are less likely to process other symbology information, and/or the world seen through the HUD Of the imagery presented on the HUD (Fischer, Haines & Price, 1980).

Superimposed Symbology is still Symbology, not Synthetic Vision.

Scene Augmentation

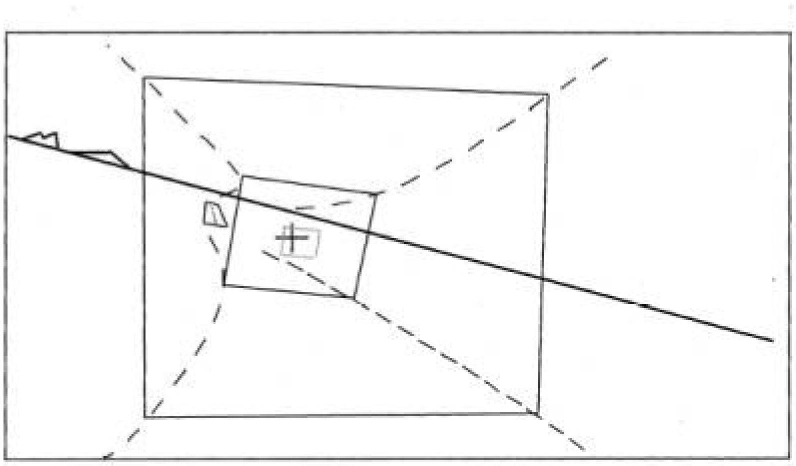
Page 4, Column 1:

> Following are two candidate examples of scene augmentation for Enhanced/Synthetic Vision Systems.

Pathway-in-the-Sky

> Grunwald and his colleagues (Grunwald, 1984; Dorighi, Ellis & Grunwald, 1991) have designed a perspective display that shows the pilot the location of the aircraft relative to a planned or assigned flight path. This display shows current flight path status, but also displays predictive information such as future position and aircraft attitude, coupled with future path and bank angle. One candidate pathway-in-the-sky design is a wire-frame tunnel as shown in Figure 2.

Here is Figure 2:



No Terrain, No Digital Elevation Database, Not Synthetic Vision.

Scene Linked HUD Displays

Page 4, bottom of Column 1 to top of Column 2:

> Advanced display media such as HUDs, in combination with highly accurate positioning systems allow for the possibility of placing information into the visual scene and stabilizing it with respect to the out-the-window scene. On the basis of the results of Foyle, Sanford and McCann (1991), this could allow for the viewing of the displayed information with reduced attentional problems mentioned above. That is, such a display may allow for the pilot to process visually both the displayed information and the out-the-window information without fixation or large attentional switching delays.
>
> Figure 3 shows an example of such a scene-linked display. In the figure, the tower and runway represent actual items in the out-the-window image (either viewed through the HUD, or via sensor imagery on the HUD). The compass rose attached to the horizon line, and the pennant indicating a distant airport (OAK) at that location, represent virtual, computer-generated imagery that is drawn as if it were "attached" to the image or world. Likewise, the Glideslope/Air Speed instruments are displayed on a virtual, computer-generated billboard, visually projected as if placed to the side of the runway alongside a nominal aimpoint. HUD symbology is already in use that presents compass rose/horizon line information in this manner.

Here is Figure 3 showing the state of the art of virtual computer-generated imagery used by NASA in 1992 to draw the tower and the runway (and the pennant):

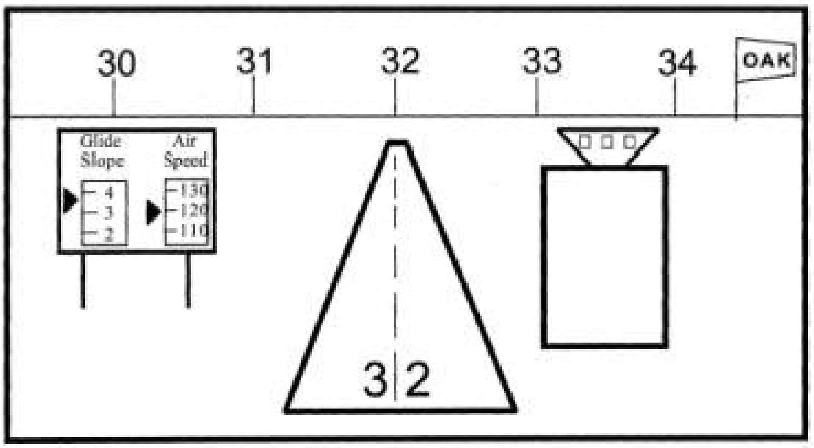


Figure 3. Schematic of a runway landing area demonstrating the "scene-linked HUD display" concept. The tower and runway represent real objects in the out-the-window scene. The compass rose attached to the horizon, distant airport (OAK) pennant and the billboard with instrument displays represent virtual, computer-generated images.

Sensor Systems Characteristics

Page 5, Column 1:

> New sensor systems in the near future will undoubtedly have relatively narrow field of views (FOV), along with other limitations (possibly low spatial and temporal resolution, as well as other specific attributes).

Field of View

> Brickner and Foyle (1990) conducted a simulation of a helicopter slalom course flight task with a forward-looking imaging sensor. Three FOV values were tested: 25, 40 and 55 deg. Slalom course performance was measured by tallying number of slalom course pylon hits and averaging altitude and course deviations. Not surprisingly, the data indicated that flight control was best (and approximately equal) in the 40 and 55 deg FOV conditions, with an increased number of pylon hits occurred in the 25 deg FOV condition.

and

> For Synthetic Vision Systems, one design that could overcome this problem is to inset, using sensor fusion techniques, a narrow FOV sensor into a graphical database image, effectively increasing the system FOV.

We have seen in the previous section (**Scene Linked HUD Displays**) what Foyle considers Synthetic Vision and Graphical Database Images – the tower and the runway (and the pennant).

Infrared (IR) Imagery

Page 5, Column 1:

> Infrared imagery transduces thermal energy into a visible image on a display.

Page 5, Column 2:

> This inherent difference between the appearance of IR imagery and direct vision or TV may have impact on the use of Enhanced/Synthetic Vision Systems. Runways and taxiways may have a quite different appearance under IR imagery (and presumably other non-visible wavelength passive imaging systems, such as passive millimeter wave, PMMW).

In the next section Foyle mentions active millimeter wave systems (Forward Looking Radar) which were also considered part of Enhanced/Synthetic Vision before Synthetic Vision acquired its current meaning.

Sensor Fusion

Page 6, Column 1:

> The goal of sensor fusion algorithms is to combine different sources of information into a single display, both to reduce the number of displays required and to reduce the workload of the pilot attempting to integrate rapidly the information from the different sources. Here we briefly describe an approach to sensor fusion described in more detail elsewhere (Pavel, Larimer & Ahumada, 1991; 1992). Although the approach is generalizable to other sensors and other tasks, this discussion will focus on the task of deciding whether to land or execute a missed-approach in low visibility based on the information from an active or passive millimeter wave sensor and from position information that allows an image of the scene to be rendered from a graphical data base of the terminal environment.

In a previous section (**Scene Linked HUD Displays**) we have seen the images from the graphic data base of the terminal environment - the tower and the runway (and the pennant).

Multiresolution Image Analysis

Page 6, bottom of Column 2 to Page 7, top of Column 1:

> Noting the success of Toet and his colleagues (Toet, van Ruyven, & Valeton, 1989; Toet, 1989; 1990; 1992) in fusing visual and IR imagery, we have taken the multiresolution image analysis approach pioneered by Burt and Adelson (Burt & Adelson, 1985; Burt, 1984; 1992). In this approach the image is first decomposed into bandpassed component images in a manner analogous to the generation of separate bandpassed audio signals by a stereo system graphic equalizer. The fusion algorithm combines two corresponding bandpass component images, one from each· source, and then these fused bandpass component images are combined. There are two major benefits from this approach. One benefit is that the high-spatial resolution image component of the position-based image is not subjected to the fusion algorithm at all. Only the low-resolution part of the position-based image; which is represented by the same small number of image values as the low-spatial resolution radar image, participates in the combination. This results in large computational savings. This ability of the multiresolution approach to match images of different resolutions also allows it to work easily with variable resolution sensor data. A second advantage is that combination of images in the different spatial frequency bands results in little cross-masking between the different bands. Information in one band can be seen relatively transparently through the other bands. This may explain in part the success of the fusion of visual and IR imagery despite the lack of any concern for contrast polarity.

Fusion of sensor imagery. No digital elevation database. Not Synthetic Vision in the modern definition.

Noise Analysis

Page 7, Column 1:

> Much of the total contrast energy of low-signal, high-noise image is just noise.

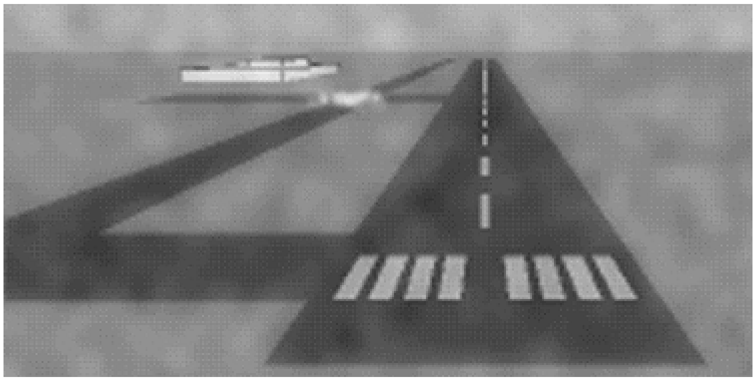
The images are from sensors, not a digital elevation database.

Sensor Fusion Image

Page 7, Column 2:

> Figure 5 shows the result of fusing a simulated PMMW image with the corresponding graphical database image. In this example, the PMMW sensor has imaged the scene with an aircraft taxiing towards the runway during approach. The position-based image has the same scene information without the obstacle. In the fused image, the intruding aircraft is essentially as visible as it was in the original sensor image, although it is lacking the detail of objects that are also in the database. Hopefully, the pilot seeing such a blob approaching the runway would decide to go around.

Here is Figure 5. The image in the copy provided by {the Company} was degraded and useless. I found a better copy at http://human-factors.arc.nasa.gov/ihi/hcsl/publications/Foyle_SAE92_syntheticvision.pdf



The blob is presumably the simulated PMMW image. The remainder is presumably the corresponding graphical database image.

It looks a lot more sophisticated than the graphical database image in Figure 3, but it still does not have a digital elevation database. And they left out the pennant.

I wonder if this was a realtime system, or just a pretty picture. It is probably irrelevant to the question of prior art but I wonder if Figure 3 was realtime and Figure 5 was just for show.