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Situation Awareness in an Augmented Reality Cockpit: Design, Viewpoints and Cognitive Glue

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Abstract

The Taxiway Navigation and Situation Awareness (T-NASA) system is a prototype augmented reality commercial airline cockpit display suite developed to increase efficiency and enhance situation awareness (SA) during airport surface taxi operations. The T-NASA system consists of a head-up display (HUD) and an electronic moving map (EMM), which allow for the display of navigation information using augmented reality techniques. The T-NASA HUD, an egocentric augmented reality display, uses "scene-linked symbology" (Foyle et al., 1996), derived from a set of theoretically-derived and experimentally-validated principles to enhance local guidance and route awareness. The EMM, is an exocentric perspective display that enhances route and global awareness. The principles for enhancing situation awareness in augmented reality systems are reviewed.

1 Problem: Airport Surface Operations

The past few years in aviation have seen incredible technological advances in computing power and techniques, positioning and surveillance (e.g., Global Positioning System, GPS; ADS-B), avionics capabilities (e.g., head-up displays, HUDs; and, electronic moving maps, EMMs) and advances in display representations (e.g., "highway in the sky") that are now beginning to emerge into general aviation (GA) and commercial transport airline flight decks. Yet, many facets of our national airspace system (NAS) make little use of these technologies and suffer from issues of safety, efficiency and capacity. In its role of researching and developing advanced aviation systems to improve the efficiency and safety of the national airspace, one problem that NASA has addressed is the domain of airport surface (taxi) operations (Foyle, Andre, McCann, Wenzel, Begault & Battiste, 1996). This research and development was driven by three facts: (1) pilots have some difficulty taxiing, especially at night, or in low-visibility, or at large, unfamiliar airports (Andre, 1995); (2) airplane taxi operations are the least technologically-advanced flight phase (Kelley & Adam, 1997); and, (3) safety improvements for surface operations are needed (FAA, 2002).

In regards to technology, as Foyle et al. (1996) describes, from a pilot's perspective, taxiing between the runway and gate is done in the same manner that it has been done since the early days of passenger travel in the 1940's. The pilot contacts air traffic control (ATC) on a two-way radio, receives a verbal taxi route clearance, and then is required to follow that clearance on the airport surface. The only "tools" that the pilot has available, currently, are the airport signage denoting the taxi and runway names, and a standardized airport chart (paper hard-copy map) for reference. In regards to safety, the worst accident in aviation history, with 583 deaths, occurred on the airport surface at Tenerife airport in the Canary Islands, Spain in 1977. Recently, the FAA has targeted runway incursions (occurring when an airplane taxis onto an active runway without permission) as one of the FAA's highest priority safety issues (FAA, 2002). Clearly, many technological advances have occurred since 1940, and, in fact, these technologies are now finding their way through FAA certification into GA and airline flight decks. These new technologies pose both a challenge and an opportunity for designers of these emerging systems.

1.1 Display Information Requirements

In many augmented reality applications, the transparent media device is a helmet-mounted display (HMD), that allows for the operator to "look around" in the world. In aviation, however, no HMD has been FAA-certified for civil aviation, although HMDs are in use in military rotorcraft. HUDs, are a fixed-forward, permanently-mounted, transparent display medium, are installed in many currently-operating airline flight decks, and have been since the early 1990s. To date, however, in airline operation, these HUDs are used primarily for take-off, approach, and landing, since the current display symbology is of limited value during other flight phases such as en route, or surface operations.

In order to develop a system to address the problems outlined above associated with airport surface operations, an important phase of the design process was to define the precise nature of information required by the pilots, with particular emphasis on determining the information that pilots currently have available in clear visibility but is commonly degraded in low visibility (Hooey, Foyle & Andre; 2001). Lasswell and Wickens (1995) identified two classes of information necessary for successful taxi navigation, *local guidance* and *global awareness*, and expanded the subtasks inherent in each. Additionally, when ATC issues an assigned taxi clearance, a third piece of information is required, *route awareness* (Hooey, Foyle & Andre, 2001). The local guidance task of maneuvering the aircraft is comprised of lateral loop closure (e.g., minimizing lateral deviations), directional loop closure (e.g., steering around turns), longitudinal loop closure (e.g., maintaining speed and braking), hazard detection (e.g., monitoring for traffic and obstacles), and information gathering (e.g., scanning signage and markings). Pilots must also maintain a sense of *global awareness,* which refers to knowledge of the general layout of the airport surface, the location of their destination concourse or runway, and traffic. This information is necessary to navigate to a known destination, to avoid potential hazards along the way, and to recover quickly in the event of a navigation error. Lacking any one or more of these pieces of information can cause the pilot to become spatially disoriented. The results can range from an increase in workload to catastrophic accidents. In order to maneuver the aircraft on the correct route, pilots also need *route awareness,* or knowledge of their position on the airport surface relative to their cleared route. This includes knowing the name of the next required taxiway, the distance to the turn, and the direction of the turn. Thus, the requirements for the cockpit display system were to augment the local guidance information that is degraded in low visibility, replace the global awareness information that is missing in low visibility, and provide route awareness information that is currently lacking even in clear visibility.

2 Display Representations in Aviation

In designing a display suite to provide the diverse types of information (local guidance, route awareness, and global awareness as described above), it was readily apparent that no single display could effectively portray all types of information. The design decision to allocate information across two different displays was driven by research on aviation display viewpoint placement (as summarized recently by Wickens, 2002, but also see Wickens & Prevett, 1995). Wickens characterizes the relation among the various viewpoints and has summarized the literature, display implications, as well as the advantages and disadvantages of each for aviation applications. Wickens notes that there are 4 cardinal eyepoints that can be described. Three of these are described sequentially, referring to Figure 1, beginning at the bottom and moving clockwise. First is the *egocentric* viewpoint, the nominal augmented-reality viewpoint. Here, the viewpoint is co-located with the pilot operator's real viewpoint, the eyes. The egocentric display shown is that of a "highway/tunnel in the sky" (Beringer, 2000), in which a conformal, virtual "tunnel" is shown on the display to allow the user to see an overlaid projection of the flight path. Next is an *exocentric perspective* representation. It is exocentric in that the viewpoint is no longer co-located with the operator/pilot, but is now located above and behind the aircraft with a depression angle of about 45 deg commonly used. The representative display shown allows the user to see the "ownship," the aircraft containing the user/pilot, as well as to see how one is referenced to upcoming objects in the world in front of the ownship. The final viewpoint shown in Figure 1 (top) is the *exocentric 2-D (two-dimensional) plan view*, which is a degenerative condition where the viewpoint is 90 deg to the world's plane, looking straight down in plan view. This gives rise to a 2-D representation shown in the corresponding representative display. (The fourth cardinal eyepoint described by Wickens is the exocentric 2-D side view, which is not shown here for simplicity.) At the highest level of abstraction, Wickens makes the point that as one progresses from egocentric through exocentric perspective to 2-D exocentric viewpoints, the displays associated with them become progressively less egocentric, less integrated, and are poorer ecological representations of the pilot's relation to the world.

As the display viewpoint changes in the manner shown in Figure 1, in order, from egocentric to exocentric perspective, and then to 2-D plan-view, three display format implications are determined. First, the most obvious change is that the objects in the world are represented differently on the display, consistent with the optical rules of 2-D projection (e.g., interposition, perspective, etc.). This can be seen in Figure 1 where the mountains change from a side view to a top-down view as the display changes from egocentric to plan view. Second, the display augmentations available to display designers are changed. For example, the representation of a "tunnel in the sky" flight path indicator changes from that of an immersive tunnel path, to a less useful tunnel viewed from the outside, and then to a 2-D path, as the viewpoint changes from egocentric to exocentric perspective to 2-D plan-view. Finally, as mentioned previously, the displays are progressively less egocentric, less integrated, and are poorer ecological representations of the pilot's relation to the world. Depending on one's display design philosophy and system requirements, an immersive, integrated, ecologically-natural display representation may be desired.

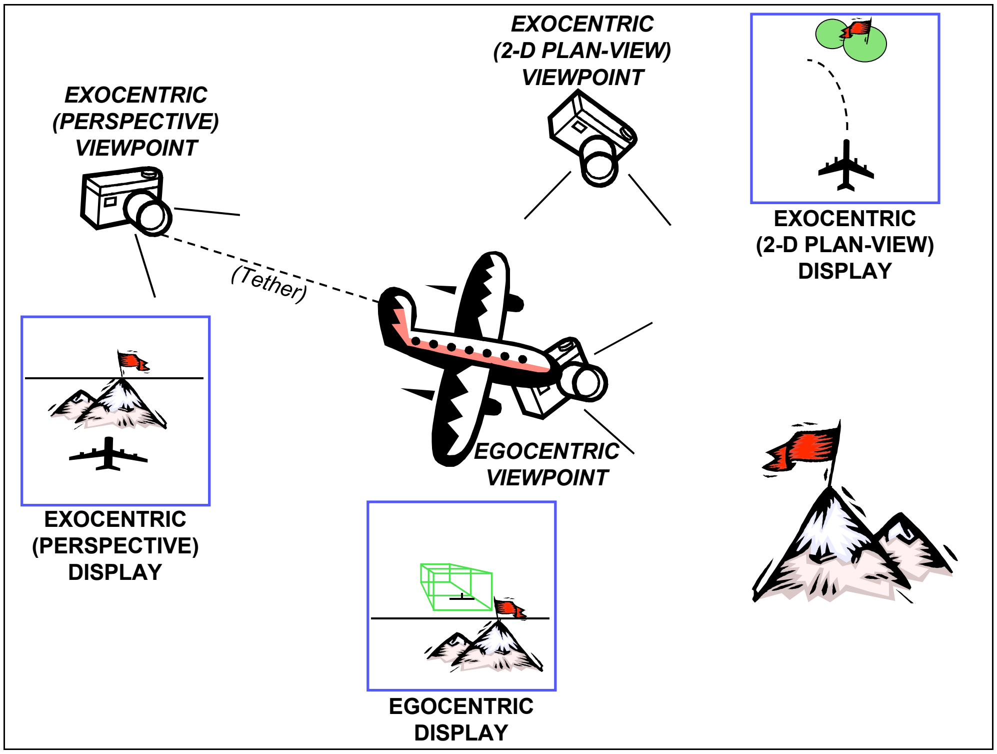

Figure 1. Schematic representation of an airplane flying toward two mountains. The three cameras shown represent three unique viewpoints, each with corresponding candidate representative displays: Egocentric, exocentric (perspective) and exocentric (2-D plan-view). (After Wickens, 2002)

3 T-NASA Description

The focus of the T-NASA (Taxiway Navigation and Situation Awareness) system project was to develop new display formats to improve surface operations, especially under degraded visibility conditions. Human factors researchers at NASA Ames Research Center developed T-NASA as a human-centered technology flight deck solution to the aforementioned problems regarding technology, efficiency, and safety for surface operations. The resulting T-NASA system is an integrated display suite consisting of an immersive, augmented-reality HUD with *scene-linked symbology* (discussed below; Foyle, Ahumada, Larimer & Sweet, 1992; McCann & Foyle, 1994; Foyle, McCann & Shelden, 1995) and a head-down, panel-mounted Electronic Moving Map (EMM). Thus, the T-NASA system combined the egocentric, augmented reality display (the T-NASA HUD with "scene-linked symbology") with that of a panel-mounted, tethered exocentric viewpoint designed to provide global awareness information (the T-NASA EMM). Through extensive part-task and full-mission simulation, T-NASA has been found to improve both surface operations efficiency and safety, as evidenced by taxi speed increases of 16%, and the virtual elimination of cleared taxi route non-conformance. For a recent overview of the human-centered methods, display format descriptions and their etiology, as well as a summary of findings of the T-NASA simulation studies, the reader is referred to Hooey, Foyle and Andre (2002).

As is evident from Figure 2, the T-NASA system is an augmented reality display suite, where the HUD is an egocentric augmented reality display, and the EMM is an exocentric perspective display. The two display components, the T-NASA HUD and the T-NASA EMM represent two separate viewpoints of the world around the aircraft and pilot. It should be noted that they are not only just two unique viewpoint placements into a common visual database, but, in fact, represent views into two different, complementary, cross-referenced world representations. In the T-NASA system, all three defined information sources described above, local guidance, route awareness, and global awareness, are supported in both the egocentric HUD and the exocentric perspective EMM. These are represented in the two displays in varying degrees, since, as discussed above, different viewpoints afford different display formats. In T-NASA, local guidance information is supported primarily via the egocentric HUD scene-linked symbology, route awareness is supported by both the HUD and EMM displays, and global awareness is supported primarily by the exocentric perspective EMM.

Figure 2. The T-NASA (Taxiway Navigation and Situation Awareness) system is composed of a transparent head-up display (HUD) using augmented-reality scene-linked symbology (top); and a panel-mounted electronic moving map (EMM, bottom middle-right).

3.1 Display Elements Promoting Situation Awareness

In this section, the display elements that promote situation awareness in the HUD and in the EMM of the T-NASA system are described.

3.1.1 T-NASA HUD Scene-linked Symbology

Previous HUD research (see McCann & Foyle, 1995 for a review) has determined that HUD elements that have differential motion from objects in the world (i.e., a fixed HUD location overlaying a moving world) demand inappropriate attention. The resulting "cognitive/attentional tunneling" may not allow for appropriate attention to be allocated to the real world objects appearing behind that HUD symbology. Inappropriate cognitive/visual attention to displays clearly do not allow for good situation awareness when using a system. Two display solutions to eliminate the problem of HUD cognitive tunneling, and promote situation awareness, have been determined.

The first display solution is to move any fixed-location HUD symbology away from real world objects that the user must view and process. Moving fixed-location HUD symbology more than 8 deg visual angle from relevant world objects eliminates cognitive/attentional tunneling, possibly because of the required visual saccade between the world objects and the fixed-location HUD symbology (for a review, see Dowell, Foyle, Hooey & Williams, 2002). In Figure 3, in T-NASA, this display design solution was used for the HUD text elements of Ground Speed and Taxiway Labels. These fixed-location HUD elements were placed as far away as possible on the HUD from the relevant real-world taxiway that was being followed, and in fact overlaid the sky.

The second display solution to reduce cognitive/attentional tunneling is the display concept of *scene-linked symbology*, an augmented reality display taxonomy developed throughout the 1990s, and first described in Foyle, Ahumada, Larimer and Sweet (1992) and tested in McCann & Foyle (1994) and Foyle, McCann and Shelden (1995). Since the primary cause of cognitive/attentional tunneling is the differential motion between the HUD symbology and the world, then removing the differential motion cues should minimize or eliminate the problem. This design option achieves this goal by replacing conventional HUD symbols with virtual symbols that appear to be physically part of the world (Foyle, Ahumada, Larimer & Sweet, 1992; McCann & Foyle, 1994). Although rendered in graphics on the HUD, these "scene-linked" symbols are drawn, and move, as virtual objects in the out-the-window scene. As the aircraft moves through the world, the scene-linked symbols undergo the same positional and perspective visual transformations as real objects, that is, they are represented via augmented reality. Since there are no differential motion cues to cause the visual system to interpret the virtual symbols as separate from the world, cognitive/attentional tunneling should be prevented, enhancing the ability to process scene-linked HUD symbology and real-world information efficiently and simultaneously.

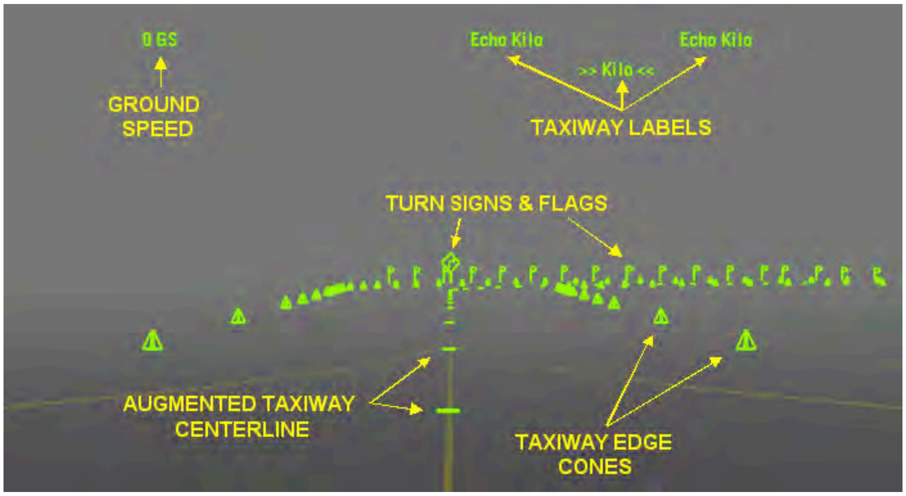

Figure 3. T-NASA HUD egocentric symbology overlaid on a foggy, low-visibility airport taxiway. Individual symbology elements are labeled with arrows.

Scene-linked symbology can take three forms. *Scene enhancements* entail the outlining in symbology of existing objects, so as to enhance the visibility or salience of those real-world objects. The symbolic runway used in airline HUDs, where a HUD runway outline overlays the actual runway, is an example. *Scene augmentations* represent the addition of virtual, non-real, three-dimensional objects drawn on the HUD as if they existed at a location in the real world. An example of this would be the depiction on a HUD of "virtual traffic lights," which could inform the pilot of clearance to cross an active runway during taxi. *Virtual instruments* are the depiction of aircraft instrumentation and aircraft data values drawn on a "virtual billboard" or similar representation. An example of this might be a digital or tape readout of actual and current glideslope on a virtual billboard to the side of an approaching runway. In the T-NASA system (see Figure 3), the HUD centerline overlaying the actual centerline paint was an example of "scene enhancements", and the taxiway edge cones were examples of "scene augmentations." (A "virtual instrument" example is presented in a later section.) Experiments with this augmented reality concept of scene-linked symbology has shown that it does, indeed, reduce cognitive/attentional tunneling and improve situation awareness. A recent study by Foyle, Hooey, Wilson and Johnson (2002) showed that, compared to more traditional

HUD guidance displays, scene-linked symbology formats produced better situation awareness subjective ratings, and improved the detection of off-nominal situation awareness probe events that occurred in the environment while also improving taxi accuracy and speed.

3.1.2 T-NASA EMM Elements

On the T-NASA panel-mounted EMM (see Figure 4), there are multiple display elements that were included to promote situation awareness (see Tu & Andre, 1996; Mejdal & Andre, 1996). The most obvious is that the EMM contains representations of world landmarks. These include all of the runways, taxiways, and airport terminals and their names labeled, necessary for airport navigation. Possibly even more obvious, since it is the defining feature of EMMs, is that there is an ownship representation showing the location of the pilot's ownship relative to the world landmarks. Also included on the T-NASA EMM is other airport traffic, which is represented in real-time in their appropriate location on the airport surface and in relationship to the pilot's ownship.

Figure 4. T-NASA panel-mounted, exocentric perspective EMM, with display elements labeled. Shown is the ownship aircraft taxiing at Chicago's O'Hare airport; the ownship is holding for another aircraft, with planned route curving to the left. The "wedge" is the large, triangular highlighted area with apex at the top of the ownship icon.

The map has both a fixed position, *north-up overview* mode and a multiple zoom, *track-up navigation* mode. The overview mode provides a fixed north-up representation of the entire airport. This mode supplies a standard airport representation that can be used for arrival/departure planning. In navigation mode, the EMM is an exocentric perspective view, tethered above and behind the aircraft looking in the direction of the aircraft's heading, and moving with the aircraft's motion. The EMM, then, is a track-up representation with the top of the display being the direction that the pilot and aircraft are facing. Research has shown (e.g., Aretz, 1991) that a track-up representation better supports situation awareness, since no mental rotations are required to map the display to the world. In track-up maps, an objects' display position (on the pilot's left or right) directly corresponds to the relative relation to the pilot in the world.

The exocentric perspective mode provides an interesting capability, when compared to what might be considered the nominal designer's view, the plan view. One criticism that can be levied against exocentric perspective maps is that they do not provide uniform scaling across the entire display, so that they do not provide precise distance estimation. The corollary of that, however, is that there is increased display resolution near the pilot's ownship, providing necessary detail while still providing a view (albeit less detailed) of more distant world objects. Although the scaling across the display is not constant, for a given zoom level, a given point at a constant distance on the EMM always represents a constant distance in the real world. Designers can capitalize on this feature, therefore, to enable distance estimation, at least for near-by objects, as was done by incorporating "the wedge" on the EMM (as shown in Figure 4; Aretz, 1991). The top of the "wedge" might represent a distance of 2000 ft in front of the aircraft. Pilots can then use this information, for example, to roughly estimate their distance to the next turn.

Since the EMM in navigation mode is track-up, the display provides only relative positional relationships. Pilots may need to cross-reference to the overview north-up map, or to a paper chart, or to a compass-referenced instruction (e.g., "depart to the north"). This is provided on the track-up, exocentric perspective map by the use of compass heading bars that surround the outer edge of the display. The compass heading bars always provide the cardinal compass positions (i.e., north, east, south, west) around the outside of the display. In this manner, a pilot can quickly ascertain the compass direction from the EMM, and then correlate it to the world.

3.2 Visual Momentum

Since the T-NASA system is comprised of two coordinated displays, each with their own viewpoint, world representation, and augmentations, rather than one integrated display there is a need to keep the pilot oriented when scanning among the out-the-window real world, the augmented reality of the HUD, and the map-like display of the panel-mounted EMM. The design concept of *visual momentum* (Woods, 1984; as applied by Aretz, 1991) was used to enable these transitions: Corresponding display elements appear in both the EMM and HUD, and correspond to the real world elements. In a sense, visual momentum supplies the "cognitive glue" that cognitively bonds the visible real world, the HUD, and the EMM.

Some of the specific display elements included in the T-NASA HUD and EMM to provide visual momentum are now described. The EMM "wedge" (see Figure 4) was added (after Aretz, 1991) to allow the pilot to correlate among the narrow field of view (FOV) HUD, the wider FOV out-the-window world, and the very wide FOV EMM. The EMM wedge is the highlighted triangular-shaped "wedge" extending forward from the aircraft, representing the approximate forward view (roughly corresponding to the forward view on the HUD and when looking out the forward window). An additional feature providing visual momentum is that both the EMM and HUD, and the real world, of course, have graphical representations of the forward taxi route (with the cleared route highlighted on the EMM and HUD). Although not a display element per se, but the choice of a perspective exocentric view for the EMM has been argued to allow for better correspondence among the EMM, HUD and world, which are all perspective views (see Tu & Andre, 1996; Mejdal & Andre, 1996).

3.3 Behavior-based Design

Adding redundant representations of elements to visual displays so as to provide visual momentum must be done cautiously and in regard to the affordances described above (Figure 1, and Wickens, 2002). As mentioned previously, the HUD is best suited for local guidance, and not for global awareness, and conversely, the EMM is best suited for global awareness, and not for local guidance. In that regard, then, there are specific elements that are missing from the HUD and the EMM because they would lead the pilot to use the display in a manner for which it is not well suited (that is, to misuse the HUD for global awareness and the EMM for local guidance).

Although Lasswell and Wickens (1995) considered traffic as information necessary for local guidance, traffic is not represented on the HUD. Since the HUD is fixed forward, has a limited field of view, and because traffic may be very close and subtend large visual angles and would clutter the HUD, it is not well suited for traffic awareness on the surface. Traffic, therefore, is represented on the head-down EMM (Figure 4). It should be noted that the T-NASA system was designed to operate under no worse than 600 ft visibility, and not zero visibility. Any traffic close enough to affect local guidance control (i.e., initiate a brake response) would be directly visible in the real world.

To support route awareness, the cleared taxi route was depicted on the HUD via scene-linked taxiway edge cones, and on the EMM by coloring the entire cleared taxiway magenta (the aviation standard for the flight path). The taxiway centerline, the painted line down the center of all airport taxiways, was represented in an augmented-reality fashion on the HUD as a dashed line overlaying the real-world painted centerline to support the pilot’s task of maintaining their position on the centerline. It was not, however, represented on the EMM since it would not have the display resolution to support this same task. This was done deliberately so that the EMM would be used to support global awareness only, and so that it could not be used to support local guidance, which would require the pilot to taxi the aircraft in an "eyes-in, head-down" mode, instead of in a safer, "eyes-out" manner (Graeber & Andre, 1999). Other “control” augmentations, such as speed and turn predictors, were purposely not added to the EMM, again to prevent the pilot from taxiing in a head-down position and from attempting to make closed-loop control decisions with a low-resolution, non-conformal display.

Similarly, there was no attempt made to add global awareness information to the HUD. Doing so would likely require the format to be non-conformal in nature. Non-conformal HUD symbology is graphical HUD symbology that is superimposed on the world, does not overlay real-world objects, and does not preserve angular measurements (in contrast to augmented-reality displays). Studies (Fischer, Haines & Price, 1980; Wickens & Long, 1995) have shown that non-conformal graphical HUD landing displays lead to cognitive/attentional tunneling, causing pilots to miss unexpected environmental events, and inducing higher workload to cognitively switch between the world and the symbology. In its worst-case implementation, non-conformal symbology not only incorporates non-unity scaling of angular measurements (i.e., compression or expansion of scale), but might involve completely different spatial or response mappings and representations. For example if a plan-view representation were placed on a HUD or HMD, the superimposed plan-view map yields a 90-deg viewpoint mismatch from the visual view (see Figure 1). If that same plan-view map were on an HMD, when one looks directly to the right or left, this would add yet another orthogonal 90-deg axis mismatch. Although we are not aware of any formal studies, anecdotal evidence from video game designs, and certain HMD military rotorcraft applications, where a plan-view HUD overview map is superimposed on a forward egocentric view, suggests that the user cannot efficiently process the two views and, at best, would have increased workload (see Neisser & Becklen, 1975, for a related study). Thus, consistent with the basic tenet of Wickens (2002) shown in Figure 1, the egocentric viewpoint of the HUD puts limitations on the display augmentations available to designers (generally precluding non-conformal graphical representations).

4 Other Applications

The concepts explored above, and used in the development of the T-NASA flight deck display, can be applied to other advanced navigational display applications, especially telerobotics. Underwater telerobotic operations, telerobotic repair operations in space, unmanned air vehicles (UAV) applications, and teleoperations of exploration "rovers" on lunar or Martian surfaces (see Figure 5) all have the potential problem of being disorienting to an operator because of the lack of familiar visual cues and landmarks. As in the T-NASA system, an egocentric (that is, if the vehicle had a pilot on board) camera view with superimposed "scene-linked symbology" can provide the operator with local guidance information, and an exocentric perspective view can provide global awareness.

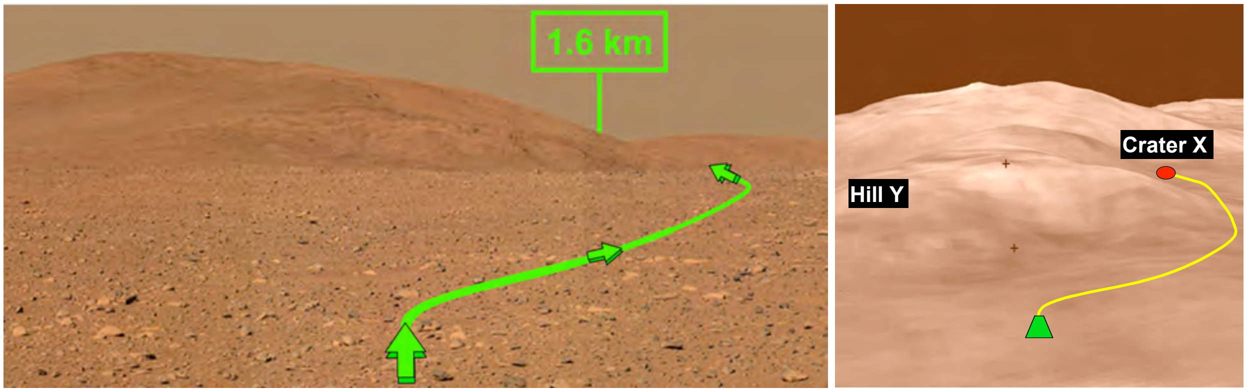

Figure 5. Notional representative displays to support situation awareness in Mars-based teleoperations. Egocentric forward-looking camera view with superimposed "scene-linked symbology" for local guidance (left), and an exocentric EMM for global awareness (right). (Images from NASA's Mars Rover, "Spirit")

Figure 5 shows notional representations of two displays for conducting telerobotic, crew-centered operations from a Mars-based outpost. The egocentric view (left panel) shows potential "scene-linked symbology" with a planned path, and a "virtual instrument": An augmented-reality object embedded in the forward view, optically registered and "attached" to a geographical point, containing vehicle instrument status information. In the above case, the numbers represent the dynamic, continuously-varying distance (currently 1.6 km) from the vehicle's current location to the destination, represented by the virtual, scene-linked object. Note that in the egocentric view (left) the actual destination, Crater X, is occluded by the intervening hill. Scene-linked virtual instruments have been found to be an efficient way to both maintain navigational awareness while providing vehicle state information (Foyle, McCann & Shelden, 1995). The right panel is the corresponding exocentric perspective view, showing current location, planned route, and the destination, Crater X. This view provides global awareness of terrain, route awareness, rover position relative to landmarks and the destination (which was not directly visible in the egocentric view).

5 Conclusions and Recommendations

Augmented reality systems are inherently egocentric systems, allowing the user to view both the real world and display augmentations to the world. When used for navigation, an augmented reality display can support local guidance, closed-loop control. However, egocentric systems do not support global awareness well. The solution presented in the design of the T-NASA system was to combine the egocentric, augmented reality display (the T-NASA HUD with "scene-linked symbology") with that of a panel-mounted, tethered exocentric viewpoint designed to provide global awareness information (the T-NASA EMM). In addition, the EMM global awareness display was not only an exocentric viewpoint different from the HUD egocentric viewpoint, but was also based on a different database, one that was designed specifically to support global awareness and to complement the egocentric HUD display.

Display elements incorporating the concept of visual momentum were used to act as "cognitive glue" allowing system users to view sequentially the two displays and the real world, and still maintain a correlation between features. As discussed, elements supporting visual momentum must be cautiously added to the component displays, consistent with the natural display augmentations that each viewpoint affords (see Figure 1 and Wickens, 2002). In the modern era of cockpit display design and augmented reality technology, it is tempting for the systems designer to render as many real or virtual information elements as possible. However, adding representations that do not map directly to the intended use of the display can have negative consequences.

6 Acknowledgments

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