Theoretical Constructs of UAS Training

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ABSTRACT

In the 20th Century, navigation in three dimensions was largely the province of pilots. With ubiquitous deployment of Unmanned Aerial Systems, thousands of people who have not been selected or trained are now operating aircraft, developing intelligence based on the flight of these vehicles and most importantly, depending on that information to be accurate. Ironically, the ease of operation that robotics enables with UAS systems means that operators require little experience to get them in the air. However, the hours and years of flight training bring experience to pilots that remote UAS operators may not have. Further, UAS operators must mentally project themselves into the reference frame afforded by the UAS. Such projection is a difficult task. In this paper we describe the background on mental reference frames in three dimensions that will be critical for UAS operations.

Keywords: Reference Frame, Three Dimensions, Egocentric Allocentric. Operators

INTRODUCTION

Why Study Spatial Navigation?

In the early years of aviation, navigators were selected from the most highly mathematically skilled volunteers for military service. Then as now, mission success required accurate navigation. However, the low cost and ubiquity of flying platforms with cameras now means that thousands of line personnel are operating *and depending on* information gleaned from aerial vehicles they must navigate. Training personnel to operate flying platforms and to obtain reliable information from the platforms will require nimble minds that understand complex dynamic battle-spaces for situation awareness. What individual differences affect abilities to carry out spatial navigation tasks and affect individual abilities rate of training? Can we detect problems in situation awareness with electrophysiological monitoring? Can we combine theory and technology to optimize training programs to improve performance in spatial navigation and situation awareness?

Behavior and Navigation

There are multiple reference frames that the brain uses to interact with the world. Objects within arms' length are naturally in a body reference frame. Further, studies with animals show that space extended beyond arms' reach is also in a body (or head oriented) reference frame: this is called Egocentric. However, in higher primates and humans the *Allocentric* or external reference frame can be adopted. An allocentric frame is akin to a map, where objects in the world are placed relative to a frame of reference, such as a location in the world and a direction (say an intersection and a road going north). Use of an allocentric frame is important for it allows ready understanding and projection of activities of objects besides the self (the truck is going East on 4th Street to "A" Avenue). An egocentric frame forces constant recalculation of relative location of objects outside the self. However, for self navigation, egocentric and allocentric are relatively similar in computational overhead. Studies of movement in 2 dimensional spaces suggest that individuals are about equally divided as to which frame they use egocentric or allocentric. However, it is relatively unknown which frame people use when experiencing motion in 3 dimensions. The modern warrior must understand 3D battlespaces.

Training and performance for Spatial Orientation

In people required to carry out tasks requiring ongoing spatial navigation there have been two general mechanisms for training: selection and brute force. Self selection has been the beginning. Many people will not even volunteer for a pilot/navigation job because of their recognition of their own limitations or their fear of getting lost. In pilot training programs of the past, navigation tasks were trained by brute force of hundreds of hours of repetition. With the ubiquity of autonomous flying platforms, a more "virtual game"-like environment is created (you don't literally die if the vehicle crashes), but the consequences of poor navigation and target selection are still critical cases of mission failure. The common use of autonomous flying platforms means more people will be required to operate with good 3D understanding. Are there selection procedures and improved training methods that can be implemented to improve performance and reduce training times? In our project we are examining reference frames in 3D. We are determining whether people are ego or allocentric for virtual motion in pitch and yaw (3D).

Understanding reference frames may help predict performance and may predict training necessary for proficiency.

Technology Intervention for Spatial Orientation

In our ongoing project we are also examining neural markers of spatial orientation. We are a determining if we can localize sources of activity in the brain that change whether the subject is oriented or disoriented in a virtual tracking task. Brain activities could be used as feedback sources during training procedures to detect lack of orientation and direct the subject so they can recognize their loss of orientation and return to course.

WHY STUDY SPATIAL NAVIGATION?

Identifying and assessing the mental states of military personnel is of great importance in order to develop technology for improving maintenance of performance on mental tasks. There are a variety of distinct mental states known to adversely affect performance including: fatigue, sleep deprivation, stress, high workload, and motion sickness. During operations using moving platforms (land, sea or air-based) changes in states related to motion sensation occur in many personnel. Such motion related problems include spatial disorientation (SD), impaired situation awareness and even debilitating motion sickness. Even in those people who are not motion sick, disorientation can have severe effects on mission performance. Disorientation and other deleterious mental states can lead to the overall condition of loss of *situation awareness* (SA), where the individual loses perspective of their overall position and direction of action. Loss of situation awareness can lead to failure to complete mission objectives or inability to react to contingencies or anomalies.

To approach the problem of managing loss of situation awareness, we are examining problems that result in spatial disorientation. If a unique neural marker for spatial disorientation could be reliably identified, operations and training could be improved through the use of feedback to operators and training instructors. During simulated or real operations, there are multiple factors that can lead to poor performance. If supervisors or trainers can be given information as to the mental state of personnel, particularly if there are conditions that impair situation awareness, then interventions can be mounted. Thus a brain activity marker that indicates a subject is spatially disoriented could be well used by a trainer. For example, if a subject carrying out a mission in a virtual environment is consistently delivering slow performance, a marker that indicates persistent spatial disorientation would be useful to point to training in that area.

We have already demonstrated data quantitating the often observed/experienced phenomena of one’s being confident they know where they are going, when in fact they are lost (high confidence but inaccurate spatial orientation) and we have found neural activities potentially related to this state (Viirre, 2006). The current project will extend our ability to identify such neural markers in three dimensional reference frames.

BEHAVIOR AND NAVIGATION

Background Theory

In his book "The Brain's Sense of Movement", Berthoz (2000, p 99.) gives some background on body frames of reference. There is the space/frame occupied by the body itself, which is extended to the space where one can reach. Notably, the reaching space can be extended by tools and even artifacts like brake peddles where drivers or pilots located far above the ground can "extend" their feet to it. The reference frame that develops coordinates relative to the body is the "egocentric" frame. It can extend to the reaching space and indeed far beyond the body itself. Lower animals use egocentric space. However, higher primates and humans can carry out the mental transformations to "allocentric" or external space. The allocentric space develops coordinates relative to a fixed object and direction, such as a street going north from an intersection. The allocentric space is thus map-like and importantly, its non-moving constituents maintain a constant reference pattern. In contrast, a person who is using an egocentric space and is moving in a room, has constantly changing coordinates relative to all constituents, like doors, windows and furniture. Turns are even more problematic in egocentric space. However, the use of allocentric space requires the subject to carry out the mental transformation of their body position and motion into the map space. The use of allocentric space does readily allow mental simulation of self motion, and also motion of other objects in the environment. The ability to mentally handle allocentric space probably develops in late childhood and reverts back to egocentric in times of stress. Athletes in confrontational running sports such as hockey and football probably take advantage of errant mental projections when "faking out" (or "deking") opposing players when rushing towards them. Animal studies suggest that allocentric mapping activities take place in Occipito-temporal cortex and para-hippocampal areas Galati (2000).

Reference Frames in 3 Dimensions.

Gravity is an external reference frame and provides an "External plumb-line" that can be described as geo-centric. Indeed neurophysiologic studies suggest that the head in mammals (including humans) is stabilized relative to gravity. "It's as if the brain creates a stabilized platform to coordinate movements of the limbs", according to Berthoz (p 101). However, in complex movements, (such as dance) feet rarely touch the ground, thus the ground may be a poor reference frame. Further, there is the gravito-inertial differentiation problem, where linear motion is indistinguishable from gravity. Optic flow is a powerful driver of the sense of the vertical, as illusions in tilted rooms can demonstrate. Thus while it might appear that gravity would provide a solid reference to the vertical, it appears not to be the case.

Reference Frame Descriptions.

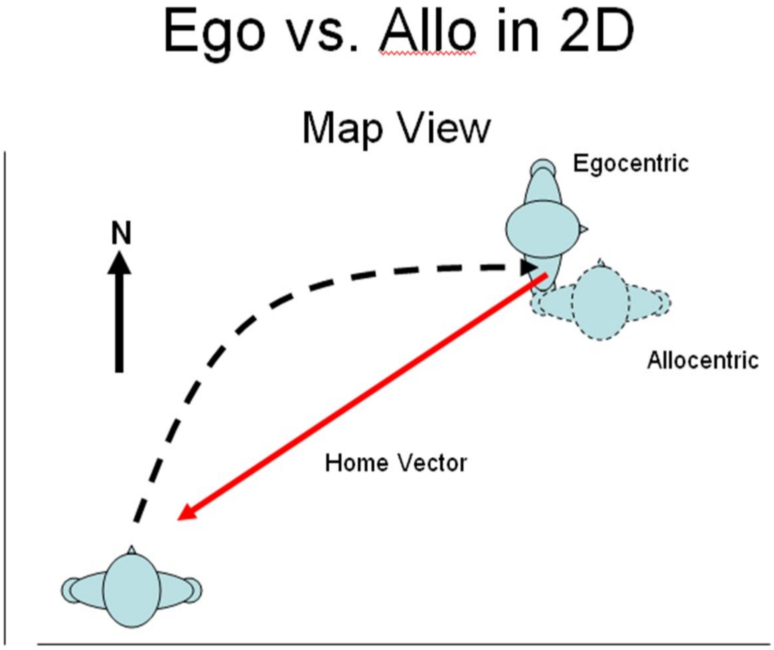

Figure 1. Egocentric vs. Allocentric mental navigation

As described above there are two general possibilities of means of navigation: reference to the self or reference to the environment being navigated. Navigation by reference to the self ("egocentric") means that the movement of the body is monitored by the nervous system with a reference frame which is fixed in relation to the body. This frame usually has "straight ahead" as a vector directed from the face or torso. In contrast, navigation by reference to the environment, ("Allocentric") uses a reference frame related to the local environment. The local environment could be a room, building with references like the door or windows or a geographic area with conventional compass directions. In figure 1 above, we can see a schematization of egocentric vs. allocentric navigation methods.

The graphic is an overhead view of motion of person through an environment. The subject starts moving forward and then turns to the right and stops. In the egocentric mode, the "Straight ahead" position is relative to the nose or chest of the subject, and thus the straight-ahead axis of the body turns 90 degrees. However, in the allocentric mode, the mental reference frame of the subject is fixed to the environment (in this case facing North). At the completion of the motion, the allocentric reference frame is still with the subject facing north. Critically, the vector to point of origination ("home") is very different in the two frames. It is over the right shoulder in the egocentric frame and over the left in the allocentric.

In allocentric navigation, movements are tracked with reference to the environment. Particularly when subjects are navigating *virtually* through an environment, mental imagery of motion and location become critical in representations of motion. Importantly, studies of navigation through 2 dimensional virtual environments show that mental representations by subjects are about equally divided between egocentric and allocentric representations (Gramann, 2006). Further, Gramann has seen that subjects are very fixed in their modes of navigation.

Importantly, egocentric versus allocentric modes of navigation have not been well examined in three dimensions. In the figure below, we demonstrate a motion in the pitch plane and the egocentric versus allocentric frame references.

As with motion in the horizontal plane, we can see the two possibilities of mental orientation after a virtual forward motion with a pitch down. In the Egocentric case, the subject has pitched forward relative to the reference frame, whereas in the allocentric case the body orientation is still oriented erect to the reference frame. As with movement in the horizontal plane, the vector pointing to the original position is different. The egocentric subject has a vector pointing behind and below the head and the allocentric homing vector is pointing back and up. Understanding the divisions of the population that are egocentric and allocentric in the pitch plane is important. Incredibly (including one of the authors and to his surprise), motion in the horizontal plane may be egocentric *and may be allocentric in the pitch plane.* The relative incidence of egocentric and allocentric modes in pitch and yaw is not known.

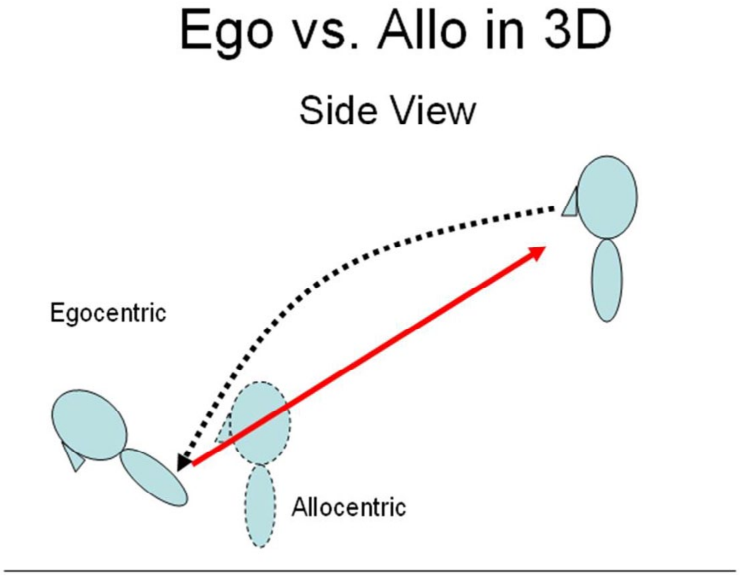

Figure 2. Reference frames in pitch motion.

TRAINING AND PERFORMANCE FOR SPATIAL ORIENTATION

Situation awareness and spatial orientation have historic and current military importance in manned aviation. All three US military branches have carried out research on recovery from unusual attitudes, displays for orientation and post-accident reviews in spatial disorientation incidents. Training programs for avoidance and recovery from SD are part of the traditional military and civilian flight syllabus. That said, there have been no programs for determining *cognitive components* of flight orientation and recovery. Aviation programs have depended on self selection (only people who want to be pilots apply), selection based on basic cognitive skills and training, such as recovery from unusual attitudes. Finally, hundreds of hours of classroom, simulator and supervised flight training are the basis for operational flight safety. Unmanned aerial vehicles take away the risk of loss of pilots, but maintain the risk of spatial disorientation. The risk however, is loss of situation awareness. “Where is my target and what is it doing (relative to me)” is the problem (Navathe, 1994). Training programs for inexpensive (i.e. expendable) UAV platforms are less than a week in duration. Do cognitive capabilities make a difference in the operation and use of intelligence of capabilities of UAV platforms? Are there means to select individuals as good operators (model airplane pilots?) and are there means to optimally train most people to be operators, depending on their individual differences?

It would appear that the egocentric vs. allocentric orientation for subjects would have an influence on their performance on orientation tasks, or at least on their orientation training. Tests, such as those developed by Gramman (2006), where an individual watches optic flow displays on a computer screen and then gives estimates of starting positions, are easy to implement. Other tests of spatial abilities, such as mental rotation tasks can be used to assess cognitive abilities of spatial orientation.

Virtual versus Real Navigation

If *virtual navigation* is mapped onto activity in the *real world*, the mapping modes used by subjects become critical. For example, for piloting an aircraft by instruments and not having visual reference to the ground, we can use egocentric and allocentric reference displays. Indeed, western navigational instruments and Russian navigational instruments are completely different: Western is Egocentric and Russian is allocentric. Tragically, the difference in convention appears to have lead to a fatal commercial jet accident in 2008 near Perm, Russia. A Russian pilot, with long experience with Russian instrumentation was flying an American jet during instrument conditions. Through analysis of the black box recordings, it is believed that the pilot reverted to the interpretation of the flight instrument as he learning in Russian aircraft and inadvertently tipped the aircraft into an unrecoverable attitude Interstate Aviation Committee (2009). Clearly, extensive training does not preclude disorientation if the instrumentation is in a different reference frame.

Common Virtual Navigation Tasks

Fortunately, transition accidents between different primary flight instruments are very rare as flying by instruments is completed safely in tens of thousands of flights every day. However, there are common circumstances where mental or virtual navigation occur and operators must perceive correctly their orientation and motion for critical activities such as targeting and way-finding for remote personnel or systems. Further, training for virtual navigation is a time-intensive and mission critical task. Very commonly, military personnel use 3 dimensional map representations of activity in their daily planning and execution of missions. For example, Falconview^{TM} is software commonly used by the Marines for mission planning. Users must project the motion of themselves and other actors into the virtual mission they create.

Perhaps the most common real-time activity involving complex virtual 3D activity is piloting a UAV. Unlike a piloted aircraft, the UAV operator depends solely on the visual displays for operation of the vehicle and for understanding of their spatial situation: position, orientation and movement. Further, the most common UAV platforms have simple displays and impoverished information. The system used in our study is a simple air vehicle with a fixed camera and a video display with some numeric information (RAVEN B). Training operators to maneuver the vehicles, keep track of the vehicle's position and keep track of objects of interest on the ground can be difficult (Becker, personal communication). UAV operation will be described further below.

TECHNOLOGY INTERVENTION FOR SPATIAL ORIENTATION TASKS

Operation of a remotely piloted Unmanned Aerial Vehicle (UAV) has been selected as a task where situation awareness and spatial orientation are critical to mission success and where intensive, prolonged training is required for successful operation. Operation of an aerial vehicle is inherently more difficult than ground vehicles because of movements in an additional dimension. Our overall research program includes:

1) Simulation of spatially disorientating tasks in UAV training software.

2) Measurement of neural markers of disorientation during simulations.

3.) Planning for engineering implementation of neural marker usage.

The Raven Unmanned Aerial Vehicle (UAV) is a semi-autonomous aircraft. It is used for observation of terrain and "over-the-hill" objects within a few miles of its operator. Raven operations are intended for line personnel, not specially trained pilots. Thus a wide variety of skill levels and experience and abilities will appear in people who are expected to use this platform. Using the simulation of the Raven system from Lockheed Martin Corporation, we are re-creating disorienting vehicle activities and with existing electro-encephalographic (EEG) recording systems, we are recording brain activity during simulated operations where subjects are in control and where subjects show loss of spatial orientation. Using similar techniques as were used in the analysis of the previous experiments, we will examine the brain activity for signature identifiers of loss of situation awareness. Loss of situation awareness is demonstrated in the figure below.

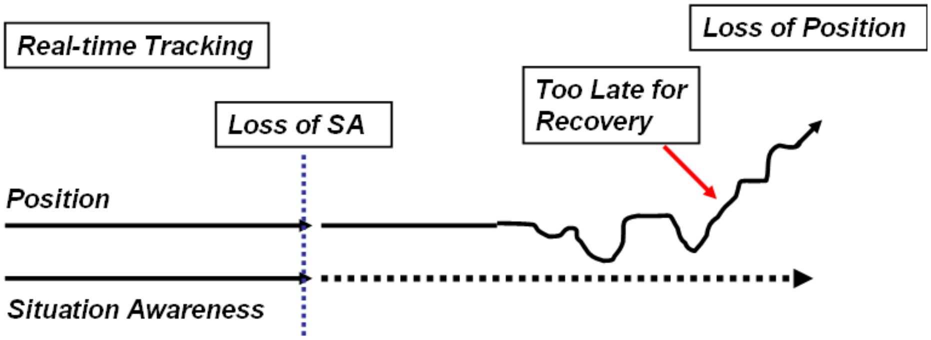

Figure 3. Schematic of loss of situation awareness (SA) during a tracking operation. Undetected deviation from the projected path results in loss of recovery of position information.

The intended program for use of the signature brain markers of loss of situation awareness is shown in figure 4 below. When the system that monitors neural activity determines loss of situation awareness, a signal is sent to the operator warning of the disoriented state, the operator then responds ("checks instruments") and regains control before significant deviation from planned path occurs.

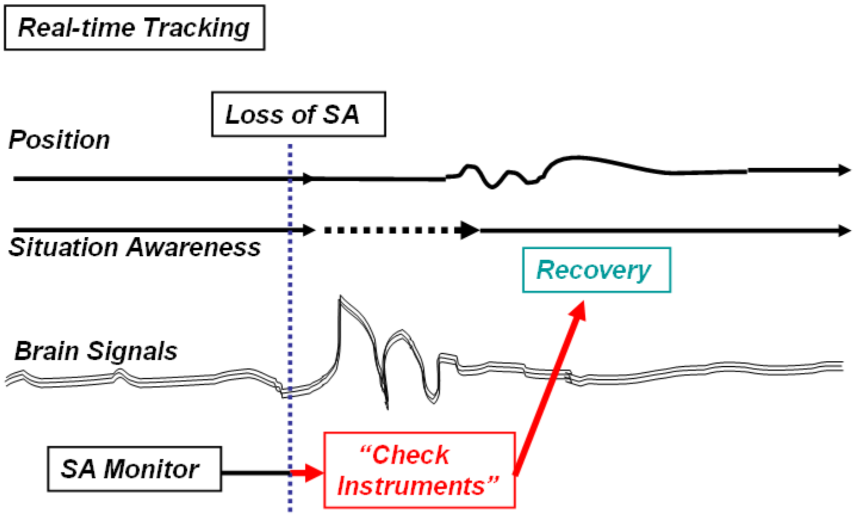

Figure 4. Use of a monitor assessing situation awareness to intervene and recover.

CONCLUSIONS

Unlike many conditions for ground based personnel, UAS platforms offer the unique opportunity and the unique challenges of views of operations from the air in real-time. The operators of such systems need to not only know their location and orientation, but also the location and orientation of the UAS platform and then the location and orientation of targets being viewed via the platform. The mental mathematical transformations for such monitoring are complex.

Compounding the complexity is the variation of mental reference frames that individuals use to navigate: body-centered, environment centered, or a mixture of both in different planes of orientation, as found in our current research. It is unknown what the implications of this individual variability to performance and training requirements are. Selection of individuals to operate UAS systems may require typing as to orientation skills and modes of action. Training could then be individually modified to optimize skill acquisition. For example, subjects that do not typically use an allocentric (map) reference frame could be given extra training on orientation through instruments and simulations. Finally, advanced technologies could go beyond performance monitoring to monitoring of actual neuro-physiologic status. Systems that can detect lack of attention, reduction of situation awareness and even spatial disorientation could be integrated into training systems. Trainees and instructors could be alerted if a student is no maintaining awareness of relevant spatial information.

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