Understanding cognitive processes of helicopter navigation by characterizing visual scan patterns:

What they see vs. whay they believe

Ji Hyun Yang [1, *], Bradley Cowden [2], Quinn Kennedy [2], Harrison Schramm[2] and Joseph Sullivan [1]

[1]The MOVES Institute, Naval Postgraduate School, Monterey, U.S.A.
[2]Operational Research Department, Naval Postgraduate School, Monterey, U.S.A.

[*]jyan1@nps.edu

Abstract— **This paper aims to provide a framework to model human belief and misperception in helicopter overland navigation. Helicopter overland navigation is known to be a challenging cognitive task, and understanding the cognitive processes associated with it is non-trivial. Two sets of human-in-the-loop experiments were conducted to investigate pilot misperception during simulated overland navigation by analyzing actual navigation trajectory, pilots' alleged location, and corresponding confidence levels. No significant correlation between perceived and actual location of the aircraft was found, indicating that confidence is not a good indicator of performance. There is however some evidence that there is a negative correlation between perceived location and intended route of flight, suggesting that there is a perception bias towards the intended flight route. Observed visual misperception can be summarized into: 1) confusion between inference and evidence, 2) incorrect mutually exclusive assumptions on the data, and 3) biased sampling. Simulation results on two cases observed in the experiments are given. Quantitative differences in dynamic perceptions between a Bayesian agent and misperceiving humans are presented with the suggested modeling framework.**

Keywords- mispercetion; visual perception; Bayesian modeling; cognition; navigation

I. INTRODUCTION

In many different disciplines such as psychology, neuroscience, and cognitive engineering, research efforts have been focused on understanding human perception. Overland navigation is made up of a number of sub-skills that require continuous visual cue perception and decision making. "The Pilot Not At the Controls (PNAC) is primarily responsible for accurate navigation. He must remain oriented at all times, monitor cockpit instruments and perform assigned cockpit duties as briefed. Because of the complex cognitive task placed on the nonflying aviator, it is easy to deviate from course. Among the four different awareness states of a navigating pilot, the most concerning area is marked "Dangerous" [1], where the crew believes that they are on course when they are not. This type of misperception can lead to both mission failure by the aircraft not reaching its intended destination on time and also mishaps due to the pilot flying into obstacles in the terrain. This extended abstract is an excerpt from [1], [2] and [3].

II. MODELING OF VISUAL MISPERCEPTION IN A HELICOPTER OVERLAND NAVIGATION TASK

Twelve military officers who varied in flight expertise as defined by total flight hours participated in the first experiment. Their gaze parameters were tracked via two eye tracking systems while subjects were looking at out-the-window (OTW) and topographic map views in a fixed based helicopter simulator. Flight performance measures were not predicted by the expertise level of pilots. However, gaze parameters and scan management skills were predicted by the expertise level. For every additional 1000 flight hours, on average, the model predicted the median dwell will decrease 28 msec and the number of view changes will increase 33 times. However, more experienced pilots scanned more OTW than novice pilots, which was contrary to our expectation. A visualization tool (FEST: Flight and Eye Scan visualization Tool) to replay navigation tasks and corresponding gaze data was developed. Qualitative analysis from FEST revealed visual scan patterns of expert pilots, not only looking ahead on the map but also revisiting areas on the map they just flew over to retain confidence in their orientation.

Observations from the first experiment suggest that pilots (especially with less experience) tend to perceive these OTW cues in a biased way, favoring their prior beliefs. Instead of making a fair estimate, some pilots seemed to choose the location they need to navigate rather than considering other possible locations. Some believed what they expected instead of what they saw. Some only sampled visual cues in view which were compatible with their current belief and disregarded cues that did not fit with their current belief.

Suppose a navigating pilot updates his belief and/or confidence on his position whenever he sees salient terrain features, i.e., visual cues. The terrain features in the pilot's sights are information (*d*) provided to the pilot, who infers his/her current position (*H*) based on the data. Thus, the probability of a pilot's current position being at a planned waypoint after seeing a valley (i.e., hills on the left and right) can be obtained by applying Bayes' rule.

$$p(H|d) = \frac{p(d|H) \cdot p(H)}{p(d|H) \cdot p(H) + p(d|\neg H) \cdot p(\neg H)} \qquad (1)$$

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where *p(H)* is the pilot's belief probability before seeing the scene *d*, (i.e., hills on the left and right), *p(d|H)* is the conditional probability that the pilot sees the scene when pilot is at a planned waypoint , and *p(d|~H)* is the conditional probability that the pilot sees the same scene when the pilot is in the other valley. For simplicity, we only consider two possible hypotheses: locations *H* and *~H* respectively, as described in the previous paragraph. Then, we have *p(~H) = 1– p(H)*. Both valleys have hills on the left and right, and the pilot is equally likely to see the terrain features when the pilot is at the planned waypoint (*H*) or in the other valley (*~H*). Then,

$$p(d|H) \blacksquare p(d|\sim H) \tag{2}$$

If a pilot realizes this fact, his posterior belief *p(H|d)* should be unchanged from his prior belief *p(H)*. An elementary calculation yields *p(H|d) = p(H)* from Bayes' rule. However, our experiments showed that the initial bias not only carried on, but also *amplified* favoring the initial bias.

This bias was especially obvious for less experienced pilots; they seemed to believe what they expected to see instead of what they actually saw. This misperception can be explained by three human errors. First, pilots experienced confusion between inference *p(H|d)* and evidence *p(d|H)* especially when *p(d|H)* is high. Because pilots already believed that they were on-track and the scene was a very likely cue, i.e., *p(d|H) ≈ 1*, they approximated *p(H|d) ≈ p(d|H) ≈ 1*, which is not a correct estimation. These pilots chose an easy, inaccurate approximation instead of inferring in a non-biased manner. This confusion pushed the initial bias the wrong way.

Second, pilots could incorrectly assume mutually exclusive events from the evidence, i.e., *p(d|~H) =1 – p(d|H)* as opposed to the correct assumption shown in Eq. (2) *p(d|H) = p(d|~H) ≈ 1*. The terrain feature they see is neither a unique nor an exclusive visual cue, rather it has multiple solutions. However, pilots sometimes overweighed the visual cue favoring their initial bias: they did not consider the possibility of the visual cue being from another valley *(~H*).

Third, pilots sampled data in a biased manner as in inattentional blindness [4]. They disregarded cues which were not compatible with their current belief. They did not update their belief when the OTW view included visual cues incompatible with their current hypothesis. However, when they were given a compatible cue, they used the cue to solidify their possibly wrong hypothesis as shown in the two previous misperception types. These visual perception patterns were observed through the whole navigation experiment, and Table I summarizes visual misperception modeling of these errors.

TABLE I. VISUAL MISPERCEPTION MODELING [1]

Misperception Type	**Posterior probability**	
Type 1	$p(H\|d) = p(d\|H)$	when $p(d\|H) \approx 1$
Type 2	$p(H\|d) = \frac{p(d\|H)\cdot p(H)}{p(d\|H)\cdot p(H)+(1-p(d\|H))\cdot p(\sim H)}$	when $p(d\|H) \approx 1$
Type 3	$p(H\|d) = p(H)$	when $p(d\|H) \approx 0$

III. NAVIGATION PERFORMANCE AND CONFIDENCE

In the second experiment where fifteen pilots participated, subjects were "On-track" and had a corresponding high confidence 58.4% of the time, but the second most frequent state was the dangerous quadrant, "Off-track" yet still confident that they are "On-track". When pilots were "Off-track", their perception was wrong 77.9% of the time. This observation was more explicit in auto-navigation scenarios. The results confirm pilots' biased perception toward the intended route. Error 1 and Error2 are defined as a Great Circle distance between 1) perceived and actual location and 2) perceived and intended location respectively. No significant correlation between pilots' confidence and Error1 was found whereas negative significant correlation (ρ=-0.65, Spearman's Rank Correlation Coefficient) was found between pilots' confidence and Error2 as shown in Fig. 1. Our exploratory analysis also showed that experts pilots with more total-flight-hours were actually in the "dangerous" quadrant more than novice pilots, yet both were fairly close.

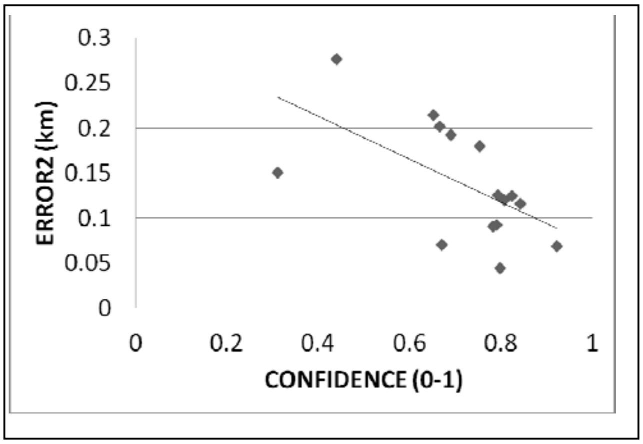

Figure 1. Pilots' confidence vs. Error2 (Great Circle distance between perceived and intended location).

If aviation personnel can proactively identify the circumstances in which usual misperception occur in navigation, they may reduce mission failure and mishap rate. Fleet squadrons and instructional commands can benefit from this study, especially for use in search and rescue, anti-surface warfare, combat search and rescue, and naval special warfare operations because of the low-level navigation flight profiles required. This study can also improve crew resource management inside the helicopter cockpit. Helicopter crews are heavily reliant on each member of the crew, and additional complacency can occur when one of the members is confident that they are on course.

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