CHARACTERIZATION OF AIR TRAFFIC CONTROLLERS' VISUAL SEARCH PATTERNS AND CONTROL STRATEGIES

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Abstract:

Due to the high cost of training new air traffic controllers, we need less costly ways to effectively train them, particularly in the light of the bubble of new controllers expected to enter the FAA workforce in the near future. If we can better understand how veteran controllers visually search and control multiple aircraft under different situations, then we could improve the training procedures to reduce the time and cost for training new controllers. An experiment was conducted to characterize and classify veteran controllers' visual search patterns and aircraft control strategies using a high-fidelity simulator. Eye tracking data and verbal responses were analyzed together to discover dominant strategies. The results show promise on using veteran controllers' strategies to support training of novices, especially FAA Academy candidates.

Keywords: eye tracking, eye movement, air traffic control, visual search patterns

1. INTRODUCTION

The demand for air traffic control specialists (ATCSs) is going to increase significantly over the coming years, as the air traffic demand is expected to double by 2020 [1] at a rate of 5% per year [2]. The growth in aggregated air traffic is not only creating the need to develop enhanced air traffic control systems [3], but also hire and train more ATCSs to meet the demands. In addition to being an occupation in which high levels of workplace stress are common [4-7], a growth in the number of aircraft they must control means that there can be significant increase in their workload [8-11]. Increase in workload can increase human errors related to attention, judgment, and communication [12-13]. For this purpose, a better understanding of the how experienced ATCSs accomplish their tasks is required. We need to better understand how expert ATCSs keep their situational awareness through effective and efficient visual search strategies and aircraft control strategies so that the results might be used to train next generation of ATCSs who will face increased and unprecedented demands.

Situational Awareness has been defined in multiple ways, such as the "continuous extraction of environmental information, the integration of this information with prior knowledge to form a coherent understanding of the present situation, and the use of that coherent understanding to direct perception and anticipate future events" [14] and as the "perception of elements in an environment, within a volume of space and time, and comprehension of their meaning and projection of their status in the near future" [15]. In air traffic control, this concept is referred as developing a "picture" [16-18]. The skill of building the "picture" is extremely important as tragic consequences are often due to loss of situation awareness [19].

One way that we can better understand how Air Traffic Controllers carry out the task of building the "picture" is through the use of eye tracking data analysis which enables the investigation of visual search strategies [20-21] and even workload [22]. There exist multiple variables that affect the visual search strategy when building the "picture", such as traffic load, geometry and assessing whether or not aircraft are actually in conflict with one another [23-27]. The expert ATCSs have honed this practice through years of experience, and due to the tacit nature of this knowledge, it is difficult to explain to novices.

Eye tracking technology allows us to analyze the eye movements that the experts apply to build the "picture". These series of eye movements, fixations and saccades is called a "scanpath" [28]. They can provide aid in understanding the strategies used in conflict detection [29] and how visual groupings are formed in such a task [30]. There also exist clear differences in the scanpaths used by experts and novices [31-33], and when presented as a method of instruction to the novices, the rate of false alarms was reduced [34] and their accuracy increased [35].

The purpose of this research is to investigate veteran ATCSs' visual search and mitigation strategies when detecting aircraft conflicts (i.e. possible collisions) using realistic scenarios so that the results can be used to effective train the novices.

2. EXPERIMENT

2.1. Participants

Eleven veteran retired Air Traffic Control Specialists (ATCSs) participated in the experiment.

2.2. Apparatus

24-inch by 24-inch monitor was used to display the I-Sim simulated traffic provided by the FAA. The eye movements were captured using a Tobii TX300 eye tracker. The eye fixation threshold was 60 ms and the visual angle accuracy was 0.4 degrees.

2.3. Task

Each ATCS's task was to (1) observe high-fidelity radar displays that contained multiple moving aircraft, (2) detect possible aircraft conflicts, and (3) mitigate those conflicts through verbal communication with the pseudo pilots. Two pseudo pilots controlled all the aircraft on the display based on each ATCS's command. Videos were created using Tobii Studio software that overlays eye movements onto the scenarios provided on the display. After the participant's task was complete, the video was replayed to the participant and a survey was conducted to ask about the participant's visual search and aircraft control strategies. Their verbal answers were recorded.

2.4. Scenario

A total of twelve scenarios were designed, each testing a particular type of conflict based on multiple aircraft having different types of conflicts such as converging, head-on, tailgating, and streams. The scenarios were presented to each ATCS in random order to prevent any confounding effects such as learning or fatigue. A scenario snapshot example is provided in Fig.1.

Fig.1. Example of how aircraft are displayed on a radar screen. Only a portion of the display is shown to better illustrate the aircraft and their associated data blocks. The full display can be found in Fig. 2 within the results and discussion section.

2.5. Data analysis

Eye movement data was refined to show the eye fixations and saccades that forms sequential visual scanpaths. Then, the visual scanpaths were mapped with the ATCSs' verbal description of their visual search strategies. After representative visual scanpaths were selected based on the agreements of two analysts.

Recorded verbal answers on visual search and aircraft control strategies were transcribed word by word. After, the transcriptions were characterized and classified.

3. RESULTS AND DISCUSSION

3.1. Visual scanning strategies

The majority of veteran ATCSs preferred applying an overall circular-shaped strategy (entirely circular or spiral), either at the beginning or throughout the entire scan of the sector. Fig. 2 represents examples of spiral, circular, linear and quadrants visual scanning strategies, and Table 1 shows a summary of why the experts chose such strategies. The starting location of the scan was not static and varied upon the sector characteristics. The starting locations were among the center of the sector, high-density areas, or low density areas.

Table 1: Visual Scanning Strategies

Reason	Freq.	Participant
Continuous scan rather than disjointed	2	P1, P11
Focus on time-sensitive areas	2	P9, P5
Faster scan	1	P2
Focus on high-density areas	1	P10
Aid in recognizing wrong altitudes for direction of flight	1	P7
Preference based on training and experience	4	P3, P4, P8,P6

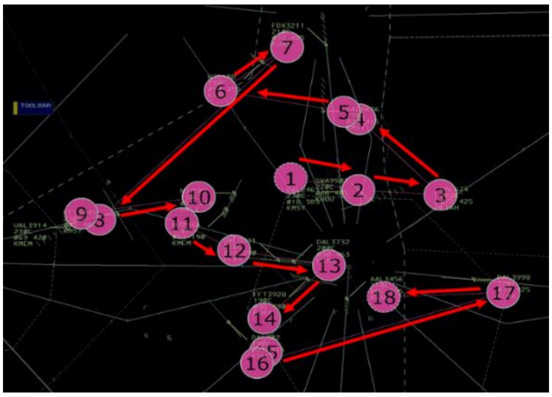
The survey results showed that the altitude is the highest priority when searching for possible conflicts. After reading the altitude, most experts considered the direction and then the speed of the aircraft. In addition, more than half of the participants prefer to start their visual scanning from the area at where the most aircraft were located.

3.2 Detection of conflicts

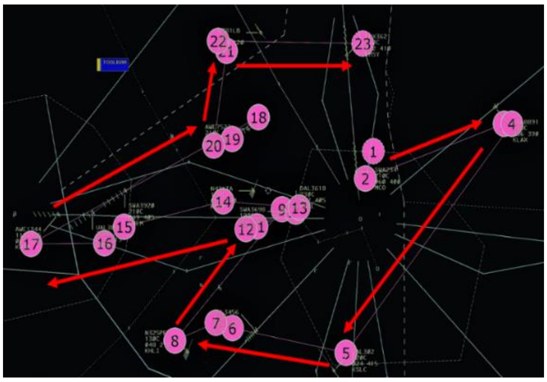
In regards to the information hierarchy, the ATCSs showed clear preferences of observing the altitude first, followed by direction, and lastly speed (Table 2). Speed was used by the experts to finally confirm whether it is highly likely that a conflict will occur. In other words, even if the altitudes are the same and two aircraft are converging, a faster airplane will pass the converging point first than a slower aircraft, and therefore, a conflict would not occur.

Table 2: Order of Information Observed

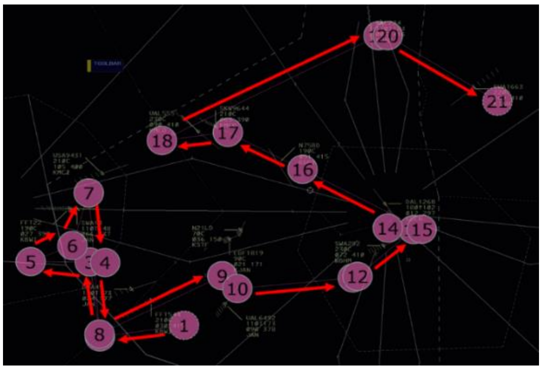
Order of information observed			Freq.	Participant
Altitude	Direction	Speed	10	P1, P3, P4, P5, P6, P7, P8, P9, P10, P11
Altitude	Speed	Direction	1	P2



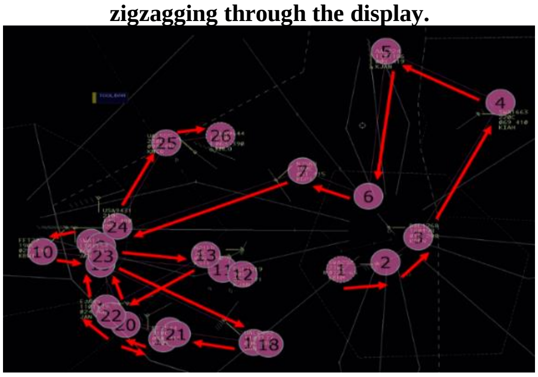
(a) Spiral: Eye fixation starts at the center, then spirals outward in a counter-clockwise manner.



(b) Circular: Eye fixations create a circular motion in a clockwise manner.



(c) Linear: Eye fixation starts at the lower left corner, zigzagging through the display.



(d) Quadrant: Eye fixations first occur mostly on the right-side quadrant followed by those on the left-side quadrant.

Fig.2. (a, b, c, d) Representative visual search pattern examples that were mapped with ATCS's verbally explained visual search strategies.

3.4. Mitigation strategies

In general, ATCSs preferred either altitude change or vector (i.e. direction) change over speed change unless there was a possibility of overtake among streamlined aircraft. In addition, some controllers explained that they do not have a hierarchy of strategies explain above and they apply strategies based on the current situation at the sector such as wind and weather conditions, location of the airport, and high or low altitudes.

In addition, ATCSs provided insights on how mitigation strategies can differ based on the geometry of the aircraft. For example, when two aircraft are converging, it would be much easier to change the altitude of one aircraft rather than having to figure out paths for safe vectoring. However, if it is difficult to increase or decrease altitudes since other nearby multiple aircraft are already occupying those altitudes, then they would choose either to change the direction or speed of an aircraft. If strong winds are present, then vectoring an aircraft towards the strong winds would slow it down (without having to reduce the speed intentionally) so that the other aircraft can pass through first.

Furthermore, the ATCSs explained that they are able to increase customer service by providing shortcuts through changing vectors when allowed and possible. Vector changes at the right time not only prevent possible conflicts but also sometimes guide the aircraft faster, resulting in saving travel time and fuel consumption.

CONCLUSIONS

The visual scanning, conflict detection and control strategies were studied from eleven expert air traffic controllers. Details of the results are provided in the technical report submitted to the FAA. Some conclusions are as follows:

1. There are diverse visual search and aircraft control methods used by experts to build the mental picture of the situation. However, some dominant strategies were identified.
2. Dominant visual search strategies were spiral or circular and dominant mitigation strategy was altitude control.
3. We were able to create a hierarchy of preferred strategies; however, those strategies were affected by multiple factors such as wind/weather conditions or customer service.

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