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Predicting pilot behavior during midair encounters using recognition primed decision model

Yang Hu*, Renfu Li, Yuanyuan Zhang

Huazhong University of Science and Technology, Wuhan, Hubei 430074, PR China

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ABSTRACT

Next Generation Air Transportation System is designed to deal with the dramatic increase of air traffic. To achieve this goal, new technologies and operation concepts are to be introduced. In this paper, a novel pilot behavior model is developed to support design and analysis of new technologies and operation concepts that are to be used in midair encounter scenarios. In this method, Bayesian network is used to build a probabilistic framework for human and automation components. To model human pilot, different human information processing stages which include perception, decision making and response are formulated. Especially, this paper firstly proposes a recognition primed decision model to describe human pilot's decision making process. In addition, a structural pilot model is introduced to promote the accuracy of existing pilot behavior models. Finally, this paper shows how this method could be used to study midair encounter scenarios. Meanwhile, the validity and feasibility of this method are investigated and discussed.

1. Introduction

In order to provide increased traffic capability and safety performance, Next Generation Air Transportation System (NextGen) is designed with multiple new operation concepts [34]. However, every aspect of these new concepts requires careful investigation to ensure safe transition from current airspace [45]. Especially, the investigation of midair encounter scenarios needs special attention, because of the intricate pilot behavior and safety-critical nature of midair encounter scenarios. Considering the dramatic increase of airspace density, NASA states that the methods of investigation should have high accuracy and fidelity [34]. Therefore, new and advanced pilot behavior models are significant to support design and analysis of midair encounter scenarios in NextGen airspace. The pilot behavior models are expected to have potential applications in the following two aspects: (1) Advanced pilot behavior models could be used to support the development of new collision avoidance system in NextGen. Current collision avoidance system (Traffic Collision Avoidance System, TCAS) will become less effective in NextGen due to some of its weaknesses. Unrealistic pilot behavior model assumed by TCAS is among the most prominent ones. In the training program, human pilots are trained to interpret TCAS command and follow it correctly [4]. However, in reality, the responses of human pilots do not always meet the assumption of TCAS [10]. The research of Boston area [21] revealed that only 13% of pilot responses followed the assumption of TCAS. In 63% of the cases, human pilots maneuvered in the correct direction, but did not maneuver as aggressively or as promptly as TCAS assumed. However, in 24% of the cases, human pilots maneuvered in the opposite direction to that instructed by TCAS. (2) New

* Corresponding author.
E-mail address: huyang4404@hust.edu.cn (Y. Hu).

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Nomenclature

AM_i	action set of memory item MI_i
$Am_{l,\,i}(k)$	lower limit of kth action interval
$Am_{u,\,i}(k)$	upper limit of kth action interval
a_{ch}	action chosen through decision making process
a_i	action of experience e_i
E_i	expectancies set of experience e_i
Em_i	expectancies set of memory item MI_i
F_i	feature set of experience e_i
$f_i(s)$	*sth* feature in feature set F_i
$Fm_{l,\,i}(s)$	lower limit of $f_i(s)$
$Fm_{u,\,i}(s)$	upper limit of $f_i(s)$
G_a	goal set stored human pilot's mind
G_m	goal set assessed from mental simulation results
G_i	goal set of experience e_i
$\hat{G}_s$	the frequency of feature interval $(Fm_{l,\,j}(s), Fm_{u,\,j}(s))$ in all memory items
GM_i	goal set of memory item MI_i
$G(0, \sigma)$	Gaussian noise with mean 0 and standard deviation σ
I_i	index number of experience e_i
IM_i	index number of memory item MI_i
$\hat{q}(j)$	the frequency of feature boundary set $(FM_{l,\,j}, FM_{u,\,j})$ in all memory items
R	human pilot's control input to the aircraft
$\hat{r}$	the reliability of onboard equipment assessed by human pilot
$unfrnd(a, b)$	uniformly random distribution in interval (a, b)
X_A	changes of aircraft states
X_S	aircraft states in the airspace
X_{SP}	information perceived by human pilot
X_O	aircraft states observed by onboard equipment
X_D	information displayed by onboard equipment
X_P	information acquired by human pilot
X_H	new states of aircraft
Δ_t	time step
Δ_f	abstraction metric for features
Δ_a	abstraction metric for actions

Subscript

O	own aircraft
I	intruder aircraft

operational concepts (e.g., reduced separation operation and high density operation) in NextGen require more precision in evaluating system performance. Advanced pilot behavior models with improved accuracy are useful simulation evaluation tools to meet this requirement [34].

In the literature, several pilot behavior models have been developed to study midair aviation. Musavi et al. [24] develop human pilot's behavior model to investigate the interactions between manned and unmanned aircraft. Yildiz et al. [48] model human pilot's behavior in the study of complex interactions in medium scale airspace. Tumer et al. [37] model the aircraft and human pilot as an agent with decision making capability in the study of optimizing air traffic flow. In these three researches [24,37,48], human pilot is modeled as a strategic decision maker, and reinforcement learning algorithms are used to derive human pilot's decision making strategy. By using reinforcement learning algorithms, human pilot is modeled as a decision maker who tends to choose actions to maximize a certain cumulative reward in an environment. In these researches [24,37,48], the reward is usually defined by a reward function which is the combination of mathematical representation of decision maker's goals. Virtanen et al. [38] use influence diagram to model human pilot's decision making in the study of air combat. Influence diagram uses directed acyclic graph to describe the dependence relations among different types of nodes (deterministic node, chance node and decision node). Human pilot is modeled as a decision node in the graph, and this node is associated with a utility function which describes the preference of human pilot. This utility function is designed to represent the goals that human pilot attempts to achieve in air combat. Through influence diagram analysis, probability distributions of the utility function are produced to select human pilot's preferred maneuver. Lee and Wolpert [22] develop a framework called "semi net-form game" to study midair encounters. Similar to influence diagram, directed acyclic graph is used to represent midair encounter scenario in this framework. Semi net-form game contains a decision making model called "level-k relaxed strategy" which is essentially based on multiple-attribute utility theory and