AN INTELLIGENT CONTROL AIR COMBAT TARGET BASED ON BLACKBOARD FRAMEWORK

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Abstract

In this paper, one-to-one air-to-air combat simulation techniques are summarized briefly. An Intelligent Control Air Combat Target(ICAT) is proposed based on the analysis of pilot's model of air combat decision making and flight control. ICAT is a system based on blackboard framework in which the knowledge of intelligent decision making is partition into Knowledge Source(KS); The air combat process data and problem-solving state data are organized hierarchically in a global database (blackboard); and a blackboard control module is set to monitor the air combat situation and problem-solving state and activate related KS. Through the use of blackboard framework, a flexible, modular approach combining intelligent decision making with flight control function is provided. A simulation example is given to show the effectiveness of ICAT.

I. Introduction

The simulation of Air-to-Air combat is a very important way to evaluate the aircraft performance, explore the air combat tactics and train pilots. A great deal of efforts in the simulation of air-to-air combat have been made in last several decades.

The early studies in air combat simulation were aimed to evaluate aircraft performance and deal with air combat tactics(1)(2). Later, some computer programs for the simulation of air combat were combined with the air combat simulator, that enables human pilots to fly air-to-air combat against the computer controlled opponent in an air combat simulator, and realizes the human & computer interactive air combat studies and training(3)(4).

Techniques employed in simulating air-to-air combat can be roughly grouped into the following three classes:

1. mathematical approaches:

(1) Differential Game Theory(5).

(2) Game Matrix(4).

2. Knowledge Based Approaches:

(1) Tactical Logic Decision(6).

(2) Adaptive Maneuvering Logic(3).

(3) Expert System Techniques(7).

3. Flight Simulator Approach (man-in-loop simulation).

The first two approaches fall in the class of pure digital simulation method. They can be used conveniently and inexpensively, but they are lacking in fidelity, and have no way to enable human pilots to participate in the process of air combat simulation. They can only be used for tactic study and aircraft performance assessment, but can not be used in pilot's training. Flight simulator approach , on the other hand , provides more realistic results, and enables pilots to participate in the simulation process. It could be used for pilot training as well as engineering researches , but two-dome air combat simulator is very expensive and it can not provides with an invariant opponent.

Obviously, if pure digital simulation approaches could be combined with flight simulator, their weaknesses would be counteracted , respectively, by each other's corresponding strong points. Much work has been done in this aspect, the main method used is replacing one dome in two-dome air combat simulator by digital computer program, so as to realize the air combat simulation of human against computer. The AML and Game-Matrix approaches stated above have been used respectively in fighter's simulators and helicopter's simulators(3)(4). In this paper, such computer programs are called Intelligent Air Combat Target(IAT).

This paper summaries main problems existing in today's IAT, in view of these problems, An IAT called Intelligent Control Air Combat Target(ICAT) is proposed and implemented . The system framework of ICAT is blackboard framework. Based on the blackboard framework, the dynamic decision making function of ICAT is realized and air combat intelligent decision making and flight control functions of ICAT are effectively combined.

II. Main Problems And The Train of Thoughts

There are several drawbacks attached to today's IAT:

(1). Over-Simplification of aircraft model

Almost all of them use reduced dynamic

flight equations. The aircraft is assumed to be a point-mass model,no moment equation are utilized.The control inputs are angle of attack(α),slide angle(β),bank angle(ϕ), thrust(P) ,load factor(n_y) [3] [8] rather than elevator,rudder,ailerons or throttle.Because the changes of α,ϕ,n_y...... do not depend on the equations of motion of six degrees of freedom,flight maneuvers of these IATs do not reflect reality to a certain extent.

(2). Constraints of Regular Tactic Decision Making Mode

As viewed from the moments of making tactical decisions, almost all of existing IATs employ the regular tactical decision making mode.These decision making modes can be grouped into three classes:

1). Fixed Time Interval Mode

In AML program,the decision making time interval is determined as 1.5 to 2 seconds,but according to the specific characteristics of air combat and pilot's control on aircraft.The fixed time interval mode is not appropriate.There are two reasons for this.The first one is that the air combat situation changes very fast,if decision making time interval is too large,there would exists a possibility that air combat situation have changed a lot during some time interval,then the IAT may miss the attack opportunities or loose a position advantage against his opponent;If decision making time interval is too short,the flying of aircraft will not reflect reality,because a pilot can not change his flight maneuvers very frequently.

2). The decision making time interval depending on the finish of maneuvers

As shown in reference [7],in the process of air combating,each aircraft cycles through a series of stages that include selection, action and updating. During selection, an air combat maneuver is selected according to current air combat situation, and after a maneuver has been selected, the aircraft performs a series of actions;during updating,data representing the airspace situation at a particular time point are updated,and system goes into the next circle.It is obvious that if great changes in air combat situation occur during the action,this decision making mode could not make a quick response.

(3). Predetermination of Decision Making Time Point in Maneuvers

As shown in reference [8], several decision points are preset in an air combat maneuver.This decision making mode could decrease the response time of IAT to the changes of air combat situation, but it still can not guarantee to make response to the changes of air combat situation in desired speed.

in view of the two problems stated above, ICAT is designed in different research train of thought,main points are as follows:

1). The nonlinear equations of six degrees of freedom are used as the equations of motion of aircraft.Basic maneuvers are implemented by control surface deflection and settings of engine state,flight control systems are designed to control all the control surface(elevator,rudder,ailerons) and engine.

2). Blackboard framework is used to implemented the dynamic decision making mode.In ICAT,a monitoring module is built to determine at all times whether decision conditions are satisfied in case all decision conditions are satisfied,the monitor module would activate the decision making modules to make tactical decision.This implies the moment of tactical decision making of ICAT is not predetermined.It is determined according to air combat situation(such as sudden changes of opponent's maneuvers or the finish of own tactical maneuver).

As to knowledge representation methods, both production rule and frame are adopted to represent respectively pilot's tactic decision knowledge and flight control knowledge.These knowledge are constituted into rule base and maneuver base,and are processed by different knowledge sources in ICAT.

III. System Design and Implementation

1. The pilot's Model of Air Combat Decision making and Flight Control

By analyzing the process of a pilot's tactical decision and flight control during air-to-air combat,we can create the pilot's model of air combat decision and flight control.It is shown in figure 1.

According to figure 1,we can describe the pilot's decision making and flight control process during air combat as follows:

1). Environment information (the flying states of two aircraft) is sensed by pilots with various perceptual systems (instruments, sight),based on these information,the pilot can determine characteristic data which reflect the tactical advantage over his opponent .The characteristic data are called the air combat situation data in this paper.

2). According to the air combat situation data and air combat decision making principles,the pilot makes decision on tactical maneuver,thus comes to a conclusion by reasoning.

3). A tactical maneuver is generally composed of a series of control subtasks.To accomplish a tactical maneuver,the pilot must carry on task planning according to air combat state,determining a course of action among all these subtasks.

4). The pilot accomplishes each control subtask by controlling various actuators (such as elevator,rudder, ailerons and engine).In addition,the pilot also must select and control a weapon system for firing according to the air combat state.

5). Control surface deflections caused by actuator and the change in thrust will cause the change of force and moment applied to the aircraft,that will cause the aircraft to be steered along its desired three dimensional flight path.

Based on the analysis about the whole air combat process stated above,it would be noticed that the pilot's function manifests in two aspects:

a).High level decision and planning: these include drawing characteristic data, tactical maneuver decision,task planning, which are a series of problem solving activities taking the form of judging and reasoning.

b). Flight control: this is accomplished by the pilot with the help of control surface deflection and engine.

2.System Framework Design

Because ICAT is used as pilot's air combat opponent,it must be provided with two functions stated above.here,high level decision and planning involves the knowledge representation and processing; Flight control function is realized by flight control system.

The system framework of ICAT is designed based on the model of air combat decision and control described above.The general structure of ICAT can be represented as shown in figure 2.

It could be seen from figure 2 that the system framework of ICAT is a blackboard framework.It consists of three parts:

(1). Blackboard data base

All data needed in the process of system running are kept in a global data base. which include:

1). Static data: such as stability derivatives, aircraft performance data, geometry and mass data,engine data, control parameters and so on.

2). Dynamic data: including all data needed in tactic decision making,planning and flight control.These data are divided into five different level of abstraction.They are motion parameter level,air combat situation level,tactic maneuver level,task planning level and flight control level.

(2). Knowledge Source(KS)

Knowledge sources are used to accomplish tactic decision making,task planning and flight control.Knowledge sources are represented as procedures and modular inference engine/knowledge base pairs. Different KS deal with data in different level of abstraction.

1). Intelligent decision making knowledge sources

These KSs accomplish tactic decision making,task planning and give out data to instruct the flight control system.They include four KSs as follows:

a). The calculation of air combat situation data(RC)

According to both side's motion parameters, this KS calculates data related to the air combat situation for both side,such as deviation angle, angle off,height differences of both side.

b). Maneuver Decision Making(MD)

According to air combat situation data and pilot's tactical decision making knowledge, MD knowledge source reasons out the appropriate tactical maneuver.

c). Task Planning(TP)

A certain tactical maneuver is only a kind of flight mode. To accomplish a tactical maneuver,first,it must be divided into several different control subtasks, then these subtasks are finished in a certain sequences. To each control subtask there corresponds definite control variable and ending condition. The TP knowledge is used to arrange subtasks in a definite sequence, and produce some data related to the control subtasks, such as the value of control variables and ending conditions, finally,give out the control law to be adopted and coordinating action information of different actuator.

d). Weapon Firing(WF)

According to motion parameters of both side,this KS judges whether some weapon's firing conditions are satisfied so as to decide which weapon(gun or missile) to be selected.

2). Flight Control Knowledge Source

Based on the values of control variables, control law,coordinating action information and the engine state, flight control KS computes control surface deflection and thrust values. These data serve as inputs of aircraft's model, so as to drive aircraft to fly along desired flight path.

(3). Blackboard Control Module

The function of blackboard control module is to monitor the blackboard data base. If some conditions are satisfied,it activates proper KS to make intelligent decision.

In ICAT,RC knowledge source and flight control KS are activated after each fixed time interval; MD knowledge source and TP knowledge source are activated only if their preconditions are satisfied.The blackboard control module compare at all times these KS's preconditions with blackboard database, when some KS's preconditions are satisfied, it is activated by blackboard control module.

Because blackboard control module activates KS according to the state of blackboard database, the decision moments are not predetermined. and thus the dynamic decision making method is realized.

In ICAT, MD knowledge source applies data-driven, forward reasoning method to make tactical decision; TP knowledge source computes data for control subtasks according to tactical maneuver adopted and blackboard state. It is represented as procedure.

IV. Simulation Result

In order to justify and improve the function of ICAT, a program which combine two ICAT is developed. This program is called Two Aircraft Air Combat Simulation System(TAACSS). In TAACSS, after inputting initial data of both aircraft, two aircraft would begin to simulate air-to-air combat, the air combat process is displayed by reduced three dimensions image of aircraft. Flight trajectories and image of weapon firing can be not only displayed during air combating process but also saved in datafiles. Various motion parameters and data of control surface deflections are saved in datafiles, and could be displayed in curves.

A typical engagement between two identical fighters as simulated by the TAACSS is illustrated. One aircraft is called 'attacker', the other 'target'. Data related to these two aircraft are labeled respectively, 'a' and 't'.

Initial conditions are set as follows:

Attacker:

a). Position in the earth axis system:

$$X_a=11000(m);Y_a=2100(m);Z_a=0$$

b). Euler angles in the body-fixed axis system:

$$\psi_a=180(deg.);\phi_a=0$$

c). Pitch angle in the wind axis system:

$$\theta_{wa}=0(deg.)$$

d). speed:

$$V_a=270(m/s)$$

Target:

a). Position in the earth axis system:

$$X_t=10000(m);Y_t=2100(m);Z_t=0$$

b). Euler angles in the body-fixed axis system:

$$\psi_t=184(deg.);\phi_t=0$$

c). Pitch angle in the wind axis system:

$$\theta_{wt}=0(deg.)$$

d). speed:

$$V_t=270(m/s)$$

e). Simulation time length is set to be of 60 seconds.

Air combat trajectories of two aircraft as seen from a selected point in space and their ground trace are shown in figures 3 and 4. In these figures, each aircraft is plotted at 12 second intervals, and is labeled with time tags:0,1,......,5.'0' is the position of initial time,'5' is the position of ending time.

At position '0', attacker is in a tactically advantageous position, target is in a defensive position. Attacker selects pure pursuit maneuver to hold the aircraft's nose directly on the target; Target selects hard turn maneuver to prevent his opponent from achieving a firing position. In initial time, attacker determines the roll angle of pure pursuit maneuver only according to the target's flight state before selecting hard turn, that angle of rolling control subtask is small(about 30 deg.); Soon later, the attacker's blackboard control module detects the target's motion information resulting from the hard turn maneuver, and then activates attacker's MD and TP knowledge source to make second decision(the time is at about 2.5 second). The second tactical decision generates new pure pursuit maneuver. In this new maneuver, roll angle of rolling control subtask is about 76 deg. The first and second decision results are shown in the roll angle curve as depicted in figure 5. From the results stated above, we can come to the conclusion that through the use of blackboard framework, ICAT can respond to the changes of air combat situation quickly. The flexibility of tactical decision is thus increased.

As for the target, its first maneuver(hard turn) ends at 6.5 second. This maneuver results in the increase of attacker's deviation angle(about 20 deg.), but the target is still in a disadvantageous position; In the second maneuver decision, hard turn is again determined by target's MD knowledge source. The target's TP knowledge source determines that the turning direction is opposite according to the attacker's speed direction. This maneuver continue to increase attacker's deviation angle......., after finishing three evasive maneuvers, both aircraft approach the position '2', this position is about neutral for both side, from then on, both aircraft select pursuit maneuvers to get a tactical advantage position......the whole air combat process results in a flight trajectory like 'scissors'.

V. Conclusion

Main techniques and problems in one-to-one air-to-air combat simulation are summarized in this paper. According to analyzing pilot's model of air combat decision making and control, an Intelligent Control Air Combat Target called ICAT is proposed which is based on blackboard framework, in this system, intelligent control techniques are combined with air combat simulation.Through the use of precise aircraft model,integration of various knowledge representation methods and dynamic decision making method, ICAT could contribute to the increase in fidelity and the level of intelligence of air combat simulation.

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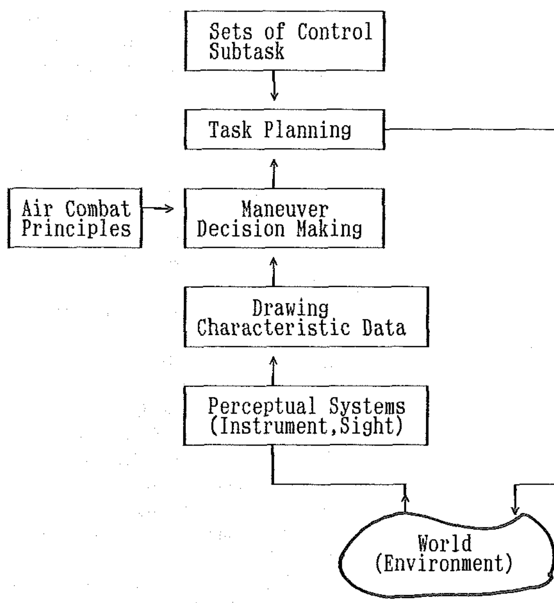

Figure 1

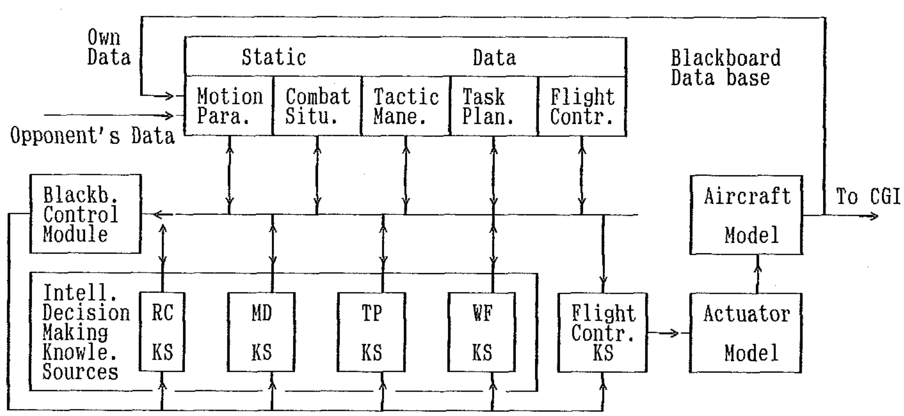

Figure 2

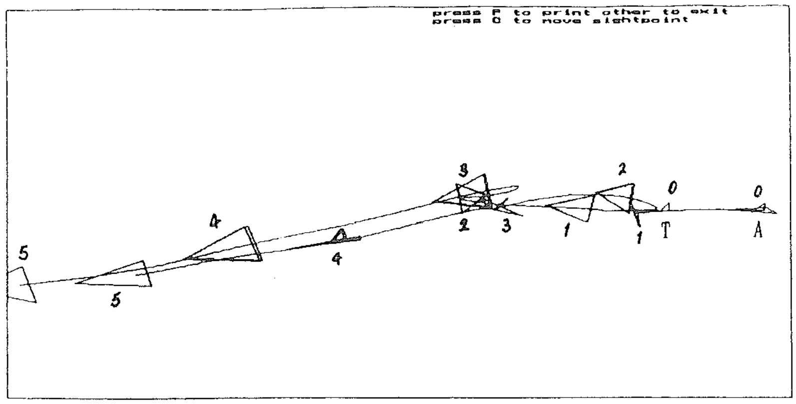

Figure 3

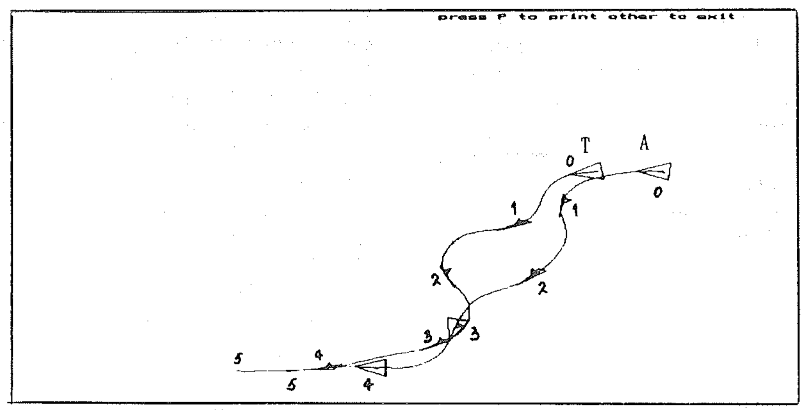

Figure 4

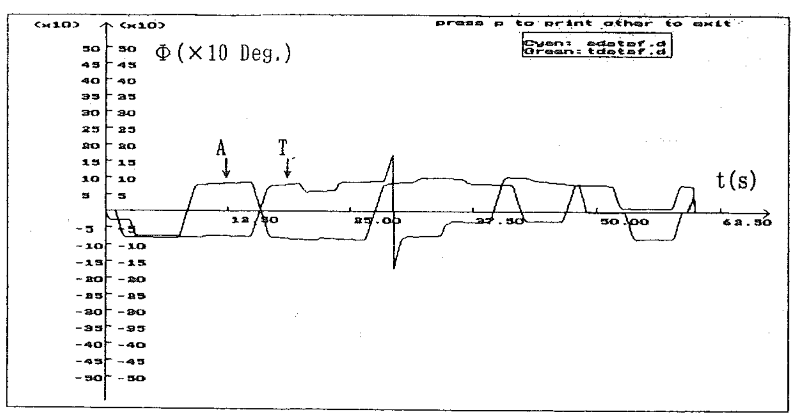

Figure 5