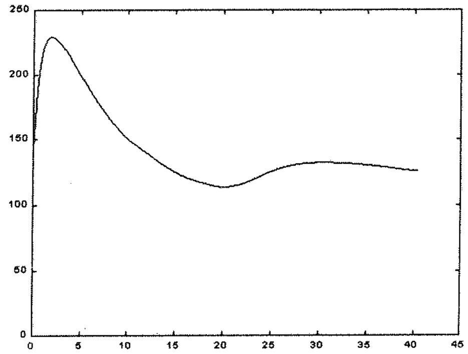

Figure (9) Speed versus time for time-optimal guidance law against maneuvering opponent.

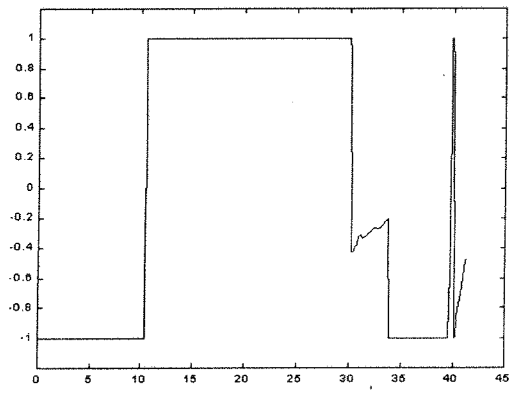

Figure (10) input to the aircraft for non-maneuvering opponent.

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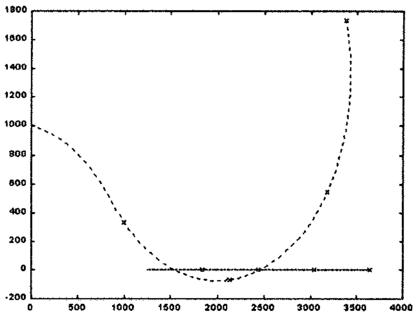
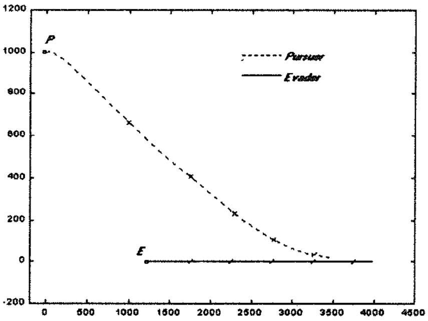


a)



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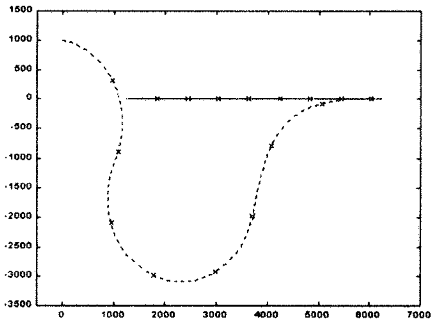


c)

Figure (6) Maneuvering path for
a) classic b) time-optimal and c) proposed
guidance law for non-maneuvering opponent.

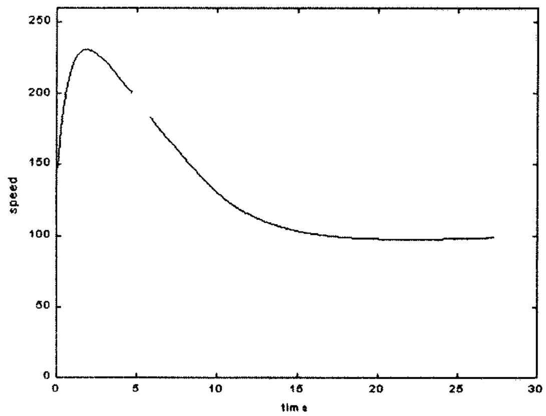
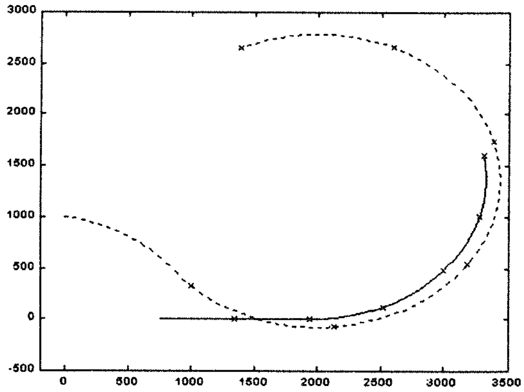
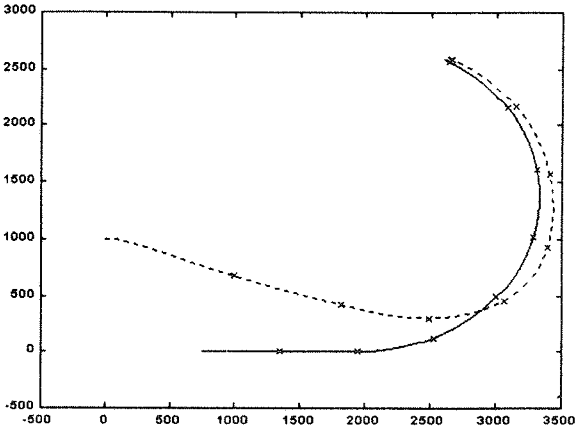


Figure (7) Speed versus time for time-optimal
guidance law against non-maneuvering opponent.



(a)



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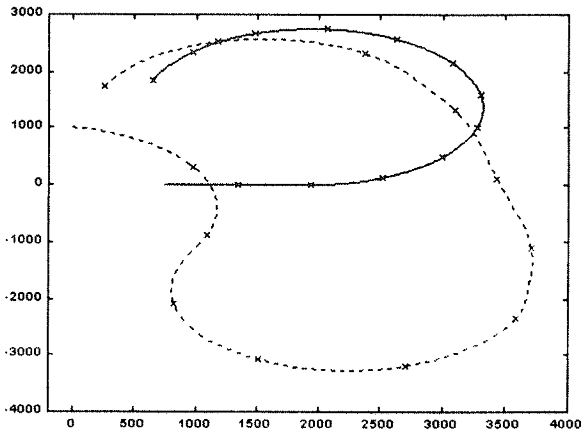
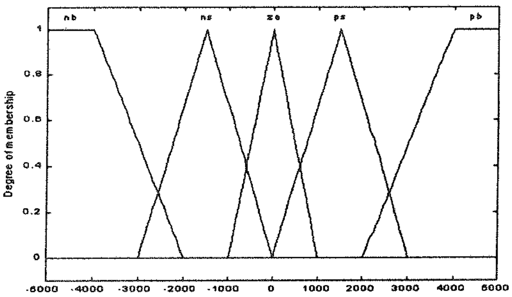
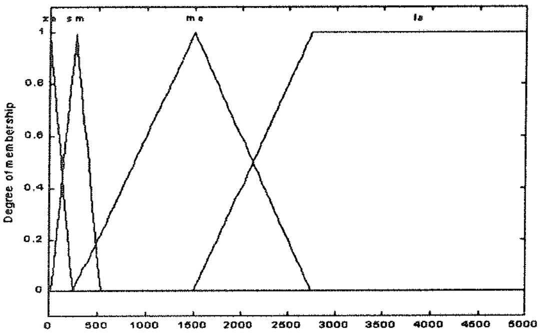


(c)

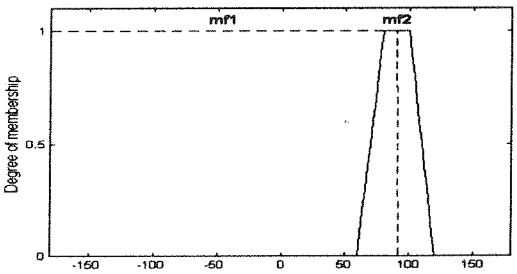
Figure (8) Maneuvering path for
a) classic ,b) time-optimal and c) proposed
guidance law for maneuvering opponent.



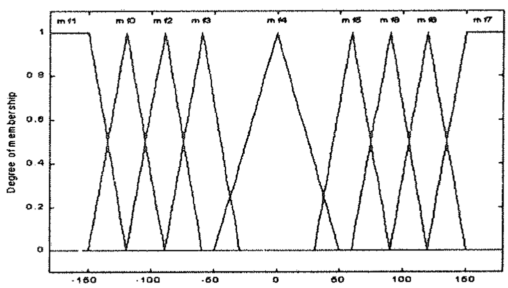
(a)



(b)

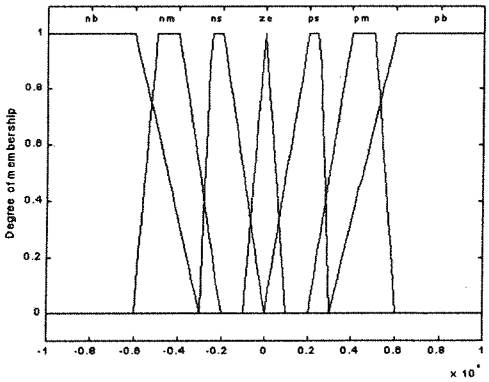


(c)

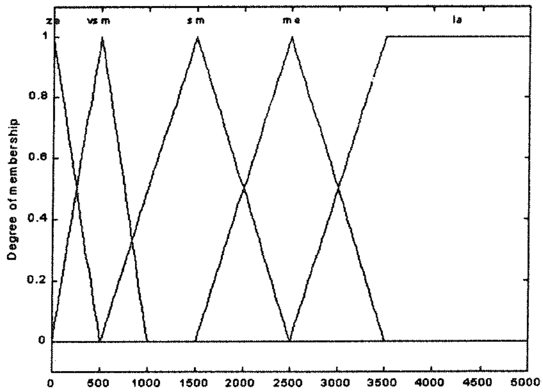


(d)

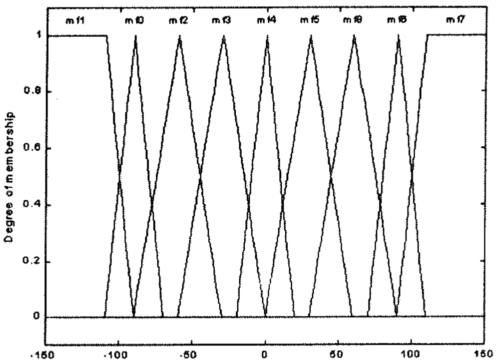
Figure (4) membership function of
a) y-distance b) x-distance c) heading angle and
d) output angle for first rule base.



(a)



(b)



c)

Figure (5) membership function of
y-distance b) x-distance and c) output
angle for second rule base.

25. If (y-separation is ze) and (x-separation is vsm) then (desired-heading-angle is mf4)
26. If (y-separation is nm) and (x-separation is ze) then (desired-heading-angle is mf7)
27. If (y-separation is nm) and (x-separation is me) then (desired-heading-angle is mf8)
28. If (y-separation is nm) and (x-separation is la) then (desired-heading-angle is mf8)
29. If (y-separation is nm) and (x-separation is sm) then (desired-heading-angle is mf6)
30. If (y-separation is nm) and (x-separation is vsm) then (desired-heading-angle is mf6)
31. If (y-separation is pm) and (x-separation is ze) then (desired-heading-angle is mf1)
32. If (y-separation is pm) and (x-separation is me) then (desired-heading-angle is mf2)
33. If (y-separation is pm) and (x-separation is la) then (desired-heading-angle is mf2)
34. If (y-separation is pm) and (x-separation is sm) then (desired-heading-angle is mf0)
35. If (y-separation is pm) and (x-separation is vsm) then (desired-heading-angle is mf0)

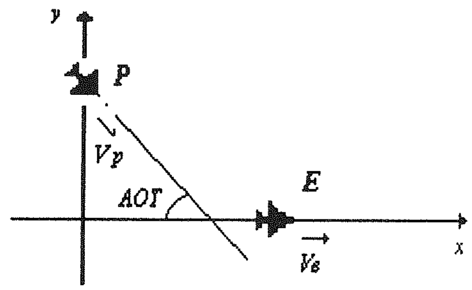


Figure (1) Encounter situation.

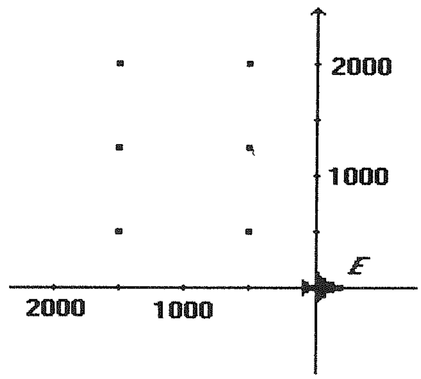


Figure (3) test points.

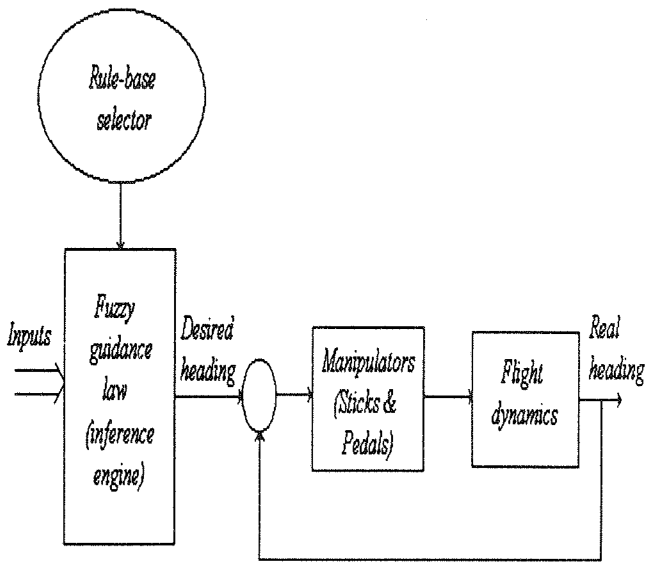


Figure (2) The structure of maneuver generator system.

29. If (y-separation is ps) and (x-separation is me) and (AOT is not mf1) then (desired-heading-angle is mf6)
30. If (y-separation is nb) and (x-separation is ze) and (AOT is not mf1) then (desired-heading-angle is mf6)
31. If (y-separation is pb) and (x-separation is ze) and (AOT is not mf1) then (desired-heading-angle is mf6)
32. If (y-separation is nb) and (x-separation is me) and (AOT is not mf1) then (desired-heading-angle is mf8)
33. If (y-separation is pb) and (x-separation is me) and (AOT is not mf1) then (desired-heading-angle is mf8)
34. If (y-separation is nb) and (x-separation is la) and (AOT is not mf1) then (desired-heading-angle is mf5)
35. If (y-separation is pb) and (x-separation is la) and (AOT is not mf1) then (desired-heading-angle is mf5)
36. If (y-separation is ps) and (x-separation is la) and (AOT is not mf1) then (desired-heading-angle is mf8)
37. If (y-separation is ns) and (x-separation is la) and (AOT is not mf1) then (desired-heading-angle is mf8)
38. If (y-separation is nb) and (x-separation is sm) and (AOT is not mf1) then (desired-heading-angle is mf6)
39. If (y-separation is pb) and (x-separation is sm) and (AOT is not mf1) then (desired-heading-angle is mf6)
40. If (y-separation is ze) and (x-separation is la) and (AOT is not mf1) then (desired-heading-angle is mf6)

Appendix 2

List of rules for the second rule base

1. If (y-separation is nb) and (x-separation is ze) then (desired-heading-angle is mf7)
2. If (y-separation is ps) and (x-separation is ze) then (desired-heading-angle is mf1)
3. If (y-separation is pb) and (x-separation is ze) then (desired-heading-angle is mf1)
4. If (y-separation is nb) and (x-separation is me) then (desired-heading-angle is mf6)
5. If (y-separation is ps) and (x-separation is me) then (desired-heading-angle is mf3)
6. If (y-separation is pb) and (x-separation is me) then (desired-heading-angle is mf0)
7. If (y-separation is nb) and (x-separation is la) then (desired-heading-angle is mf8)
8. If (y-separation is ps) and (x-separation is sm) then (desired-heading-angle is mf2)
9. If (y-separation is pb) and (x-separation is la) then (desired-heading-angle is mf2)
10. If (y-separation is nb) and (x-separation is sm) then (desired-heading-angle is mf6)
11. If (y-separation is pb) and (x-separation is sm) then (desired-heading-angle is mf0)
12. If (y-separation is ns) and (x-separation is me) then (desired-heading-angle is mf5)
13. If (y-separation is ns) and (x-separation is la) then (desired-heading-angle is mf5)
14. If (y-separation is ze) and (x-separation is me) then (desired-heading-angle is mf4)
15. If (y-separation is ze) and (x-separation is la) then (desired-heading-angle is mf4)
16. If (y-separation is ns) and (x-separation is ze) then (desired-heading-angle is mf7)
17. If (y-separation is ze) and (x-separation is ze) then (desired-heading-angle is mf4)
18. If (y-separation is ns) and (x-separation is sm) then (desired-heading-angle is mf8)
19. If (y-separation is ze) and (x-separation is sm) then (desired-heading-angle is mf4)
20. If (y-separation is ps) and (x-separation is la) then (desired-heading-angle is mf3)
21. If (y-separation is nb) and (x-separation is vsm) then (desired-heading-angle is mf7)
22. If (y-separation is pb) and (x-separation is vsm) then (desired-heading-angle is mf1)
23. If (y-separation is ps) and (x-separation is vsm) then (desired-heading-angle is mf0)
24. If (y-separation is ns) and (x-separation is vsm) then (desired-heading-angle is mf6)

problems could be useful. Further research is under investigation to generalize the guidance law to include other encounter situations. The simulations have showed the applicability and effectiveness of the proposed method and its superiority to some other guidance laws. The resulted control input is of bang-bang nature, which is in accordance with the experiences from air combat. We also showed that the linguistic information of fighter pilots could be transformed to quasi-optimal guidance laws.

6-Acknowledgement

The authors wish to thanks General Saeedi, the head of the flight institute of the IRIAF air university, and many instructor pilots in IRIAF for their valuable cooperation.

Appendix 1

List of rules of the first rule base

1. If (y-separation is nb) and (x-separation is ze) and (AOT is mf1) then (desired-heading-angle is mf0)
2. If (y-separation is ps) and (x-separation is ze) and (AOT is mf1) then (desired-heading-angle is mf1)
3. If (y-separation is pb) and (x-separation is ze) and (AOT is mf1) then (desired-heading-angle is mf0)
4. If (y-separation is nb) and (x-separation is me) and (AOT is mf1) then (desired-heading-angle is mf2)
5. If (y-separation is pb) and (x-separation is me) and (AOT is mf1) then (desired-heading-angle is mf2)
6. If (y-separation is nb) and (x-separation is la) and (AOT is mf1) then (desired-heading-angle is mf3)
7. If (y-separation is ps) and (x-separation is la) and (AOT is mf1) then (desired-heading-angle is mf2)
8. If (y-separation is pb) and (x-separation is la) and (AOT is mf1) then (desired-heading-angle is mf3)
9. If (y-separation is ns) and (x-separation is ze) and (AOT is mf1) then (desired-heading-angle is mf1)
10. If (y-separation is nb) and (x-separation is sm) and (AOT is mf1) then (desired-heading-angle is mf0)
11. If (y-separation is ns) and (x-separation is sm) and (AOT is not mf1) then (desired-heading-angle is mf7)
12. If (y-separation is ps) and (x-separation is sm) and (AOT is not mf1) then (desired-heading-angle is mf7)
13. If (y-separation is pb) and (x-separation is sm) and (AOT is mf1) then (desired-heading-angle is mf0)
14. If (y-separation is ns) and (x-separation is la) and (AOT is mf1) then (desired-heading-angle is mf2)
15. If (y-separation is ns) and (x-separation is sm) and (AOT is mf1) then (desired-heading-angle is mf1)
16. If (y-separation is ze) and (x-separation is ze) and (AOT is mf1) then (desired-heading-angle is mf1)
17. If (y-separation is ze) and (x-separation is sm) and (AOT is mf1) then (desired-heading-angle is mf1)
18. If (y-separation is ze) and (x-separation is la) and (AOT is mf1) then (desired-heading-angle is mf0)
19. If (y-separation is ps) and (x-separation is sm) and (AOT is mf1) then (desired-heading-angle is mf1)
20. If (y-separation is ns) and (x-separation is ze) and (AOT is not mf1) then (desired-heading-angle is mf7)
21. If (y-separation is ze) and (x-separation is ze) and (AOT is not mf1) then (desired-heading-angle is mf7)
22. If (y-separation is ze) and (x-separation is sm) and (AOT is not mf1) then (desired-heading-angle is mf7)
23. If (y-separation is ns) and (x-separation is me) and (AOT is mf1) then (desired-heading-angle is mf0)
24. If (y-separation is ns) and (x-separation is me) and (AOT is not mf1) then (desired-heading-angle is mf6)
25. If (y-separation is ze) and (x-separation is me) and (AOT is mf1) then (desired-heading-angle is mf1)
26. If (y-separation is ze) and (x-separation is me) and (AOT is not mf1) then (desired-heading-angle is mf7)
27. If (y-separation is ps) and (x-separation is ze) and (AOT is not mf1) then (desired-heading-angle is mf7)
28. If (y-separation is ps) and (x-separation is me) and (AOT is mf1) then (desired-heading-angle is mf0)

primary part of the maneuver that produces necessary vertical and horizontal separations. The distance in x-direction is supposed to be somewhat less than its real value to produce better results.

4-Simulation Results

Massive simulations were made to illustrate the satisfactory performance of the model. Without losing the generality, we supposed that the evader is initially on the (0,0) and its velocity vector is in the positive x-direction. For the pursuer's initial position, six points in the second quarter is selected as shown in figure 3. The points in the third quarter are not considered because of the symmetry. For each of these points, the initial heading of the pursuer was set to the values $k18/\pi$ k=0,35. So a total of 216 initial configurations were considered. The ratio of pursuer's to evader's speed was set to its maximum acceptable value for a planar maneuver. For ratios less than this value the results are better while for the greater ratios require an out-of-plane maneuver and the in-plane maneuver is not appropriate.

The simulations showed that this fuzzy guidance law was capable of producing appropriate maneuver in more than 90 percent of tested initial conditions. The failure of the guidance law in reaching the appropriate end-of-maneuver conditions mostly happened in the points very near to the evader. In fact, the pilots prefer to perform an out-of-plane maneuver in these situations too. The decision between in-plane and out-of-plane maneuver depends on many other factors and not considered here. The outline of a supervisory system necessary for generating higher level decisions is introduced by Akbari and Menhaj [14].

Also two simulations have been performed for comparison of the proposed fuzzy guidance law to other guidance laws. Furthermore, these two simulations show the applicability of this guidance law to maneuvering targets as well. In the first simulation a situation as fig. 1 is modeled in which the target E is non-maneuvering, i.e. it doesn't change its direction during simulation. The figure 6 shows the simulation results. The maneuver produced by proposed guidance law (c) is sketched along ones produced by proportional navigation (a) and optimal guidance law (b) proposed in [9]. While the PNG fails to satisfy the firing requirements at the end of maneuver, two others produce appropriate end-of-maneuver parameters. Though the optimal guidance law has resulted in a great loss of speed that is undesirable (see figure 7).

In the second simulation target E can maneuver with limited turn radius. To simulate this situation, in each time step we simply suppose that E is non-maneuvering and apply the above fuzzy rule bases to it. Then in the next time step E has a new moving direction that determines the new x-axis and so new coordinates and the computations will be done in these new coordinates. Again the produced maneuver has been compared to PNG and optimal guidance law against maneuvering opponent (figure 8). Like the non-maneuvering case, the optimal method results in an undesirable loss of speed (figure 9). The results of this simulation show that although the rule bases are designed primarily for a non-maneuvering target, it could work for a maneuvering target as well. Also simulations show the ability of proposed guidance law to generate satisfactory results while other guidance laws fail to fulfill firing conditions or even place the attacker in a defensive position (fig. 8).

An interesting feature of the proposed guidance law is its near-optimal performance. Figure 10 shows the input u_p of the pursuer. It is in accordance with the bang-bang control scheme that is expected from optimal control theory and of experiences with air combat.

The proposed guidance law could be fit into the framework for a decision-support system recently proposed by the authors [14].

5-Conclusion

We showed that fuzzy guidance laws with the form of fuzzy rule bases could be successfully used for modelling very complicated air combat maneuvers. In this regard, the breaking of main problem to a series of some simpler and solvable one else the heading would be changed as much as possible in the direction that pilot wants. This is in accordance with what a real pilot does during the air combat. The output of decision process of the pilot is the desired moving direction and then this mental command translates to stick and pedal movements that in turn will be converted into real position and direction changes. The pilots have a vague and qualitative sense of their fighter's dynamics that let them determine the best maneuver concerning dynamical limitations.

A. Phase I

The first phase of the maneuver is to produce enough vertical and horizontal (y and x -directions) separation between two fighters. This separation is needed because the limited turn radius of ***P*** doesn't let it to simply maneuver to the back of ***E*** with a single turn movement. While producing this separation, it should be cared that ***E*** does not get a chance to turn around and to be in threatening position. This is in fact the hard turn away from the bogey done by pilots as described in section 3.

The inputs to this rule base include vertical (y-direction) and horizontal (x-direction) separation of two fighters as well as heading of the offensive fighter ***P*** with respect to the moving path of fighter ***E*** or "off angle".

The output of the rule base is desired heading of the fighter ***P*** in the next time step. It should be noted that this angle is not the one that the fighter ***P*** really gets in the next time step but it is the desired heading angle and the dynamics of the fighter will determines the heading angle in the next time step. So the output of the rule base is the command (see fig. 2).

The ration or reason behind the rules of this phase is that the fighter ***P*** must swing right and left in the back of fighter ***E*** while minimizing the backward movement which enables fighter ***E*** to turn around toward ***P*** and claims a threatening position.

The fuzzy sets for inputs and outputs have been shown in figure 4. The shape of fuzzy sets has been chosen arbitrarily as triangular and trapezoidal. The boundaries have been found by the information gathered from pilots of IRIAF.

The rule base consists of 40 rules and are shown in appendix 1. The first input is distance in Y-direction ($y_p - y_e$) and the second is distance in X-direction ($x_e - x_p$). Inputs 3 and 4 both are heading angle.

The max-min (Mamdani) inference method is used. This type of inference is computationally easy and effective; thus, it is appropriate for real-time applications. To aggregate the fuzzy output of the rules into one crisp value necessary for determining desired heading, the COA (center of area) defuzzification method is used.

B. Phase II

During the phase II of the combat, fighter ***P*** has now enough vertical and horizontal separation and should maneuver to the back of fighter ***E*** with one simple turn movement. This rule base lets the fighter ***P*** to move toward the back of fighter ***E*** and adjust its heading for a killing shot while keeping the LOS rate as low as possible.

The inputs to this fuzzy rule base are vertical and horizontal (y and x-direction) distances between two aircrafts as the first rule base. During this phase the heading angle is not an important factor in computing the next step path direction because at the end of phase I the aircrafts' relative position is such that the heading will have the desired value during and at the end of the phase II. Figure 5 shows the membership function for the inputs and output of this fuzzy rule base.

C. Switching between two phases

The only remaining problem is to decide which one of the above phases applies to the combat situation in each time step. Unfortunately it is the most difficult problem. In this paper, a (non-fuzzy) criterion is used to determine which rule base should be used. This criterion simply supposes that fighter ***P*** moves from its initial position in an optimal bang-bang path, i.e. with minimum turn radius. It means that in figure 1 fighter ***P*** decreases its heading angle with maximum possible rate till a point midway (from back of fighter ***E***) and then increases his heading through remaining part such that when the fighter ***P*** reaches the x-axis, it's heading would be in the positive x-direction. If this movement will place ***P*** in the back of ***E*** then the second rule base will be used. Otherwise first rule base is used to generate the actually guides a fighter to a point in space that is advantageous to its opponent position. Classic guidance laws mostly are used for missile guidance. Although the pursuit evasion game between two aircraft and between a missile and an aircraft seems to be similar but from some viewpoints they are completely different. In contrast to missile guidance laws, a guidance law that could be used for an attacking fighter engaging in a dogfight combat should fulfill some severe requirements in approach angle. In fact, for a missile the only end part goal of a maneuver is the interception or more generally "entering the explosion zone". But a fighter in a dogfight must perform maneuvers so that at the end it will be placed in the rear quarter of the target with suitable distance and with the heading toward the target and with the low LOS rate. Classic guidance laws cannot be used in such situations especially when the turn rate or radius limitations are taken into account. Here we propose a simple two-phase fuzzy guidance law that could successfully generate a complex dogfight maneuver.

2-Expert's solution to the problem

In this paper, we tried to imitate the performance of an experienced pilot while he/she is subjected to such an encounter situation. To obtain the pilot's reaction in the same circumstance, two main sources are used: 1) Written texts on the air combat and fighter pilot training manuals and 2) The interview with IRIAF pilots. The first source includes of the Shaw's book [6] and some web pages related to the subject [7].

As it is gathered from the above sources, when a fighter pilot is in such situation described above, he/she could react in three ways:

1- Reduce his/her speed greatly.
2- Perform an in-plane maneuver away and toward the back of the bogey.
3- Perform an out-of-plane maneuver.

A speed reduction may not be desirable since a speed advantage (that means energy advantage) is crucial in air combat.

A hard turn away from the target may cause the attacker to lose sight. But if the duration of this will not be long and the turn would not be so hard that bleeds speed, then this maneuver could be used.

The out-of-plane maneuver is the best alternative and when the ratio of pursuer's to evader's speed is greater than some specified value, it is the only possible solution. But as we consider the planar motion, this kind of reaction does not included in our model.

Since we consider planar combat, we are restricted to use second alternative as the basis for our guidance law.

3-Proposed guidance law

Here, we propose a two-phase fuzzy guidance law capable of producing an appropriate maneuver, which eventually makes the offensive fighter be placed at a very good firing position.

This two-phase guidance law is in accordance with the decision process that fighter pilots use when they are engaged in an air-to-air combat encounter as described in the previous sections. In general, the pilot breaks down the big problem of "destroying the enemy fighter" to some simpler and easier to solve sub-problems. These sub-problems have more clear and tractable goals that enables pilot to do them by simple maneuvers. So instead of designing or planing a very complicated maneuver that accomplishes the main task, a series of sub-maneuvers will be planned.

Another reason for employing a two-phase guidance law is that obtaining a unique rule base that produce the appropriate maneuver that fulfills all firing requirements is very difficult.

Unlike other guidance laws, ours doesn't generate the control variables (here u_p) directly. The output of the proposed guidance law is the desired or ideal heading angle or by another words the pilot's intent (fig. 2). This is because we just modeled the decision making process of the pilots and not the dynamical response from command to sticks and pedals movements. To complete the model, it is assumed that the control variable u_p will get the value that it satisfies the pilot's intent as much as possible. This means that in fig. 2, if the dynamical limitation of the airplane admits, the next heading angle would be the desired parameter (angle of attack) to LOS and LOS rate measurements.

Menon and Iragavarapu also used fuzzy logic in missile guidance [13]. They presented two approaches for designing a guidance law for the missile to handle large uncertainties in the missile model. In their first approach, a fuzzy if... then ... rule base proposed that approximates the classic proportional navigation guidance. In their second method, the three classic guidance laws were blended using fuzzy logic methods to obtain a composite guidance law.

Here, we used the expert system approach to solve the problem. To do this we tried to imitate what a real pilot does in the same situation. The expert's knowledge is used as the basis for guidance law because the observations have shown that humans are very efficient in performing complex tasks [18] such as one we face here. It seems experiences that one gains for performing an specific task in addition to creativity, adaptability, approximate reasoning and the ability of human operator to handle uncertain, incomplete and vague data and information causes the human performance outdoes the mathematical and optimization models in such applications. In fact, the human operator performance in such systems may be of optimal nature. Although, it is very difficult to obtain the performance criteria that the operator has in his/her mind [18], no systematic solution to it was found yet. The best is to guess some cost functions from intuition.

1-Problem Statement

Here we consider the situation shown in figure 1. Two fighters (P and E) are engaged in a planar air-to-air dogfight combat. The initial position of the fighters is such that places one of them (P) in offensive and the other (E) in defensive position. We suppose that the fighters don't change their roles during the combat. This means that pursuer and evader fighters remain unchanged during the combat.

We suppose that both fighters have known and constant speeds (Vp and Ve respectively). Also we suppose that E moves along the positive direction of x-axis and keeps its direction during the combat. Both fighters have turn radius limitations. So the heading angle of the fighters cannot be arbitrarily changed to any value at each time step. All other dynamics of aircrafts are ignored. The motion equations for Pursuer (P) and Evader (E) are:

$$\dot{x}_p = v_p.\cos(\theta_p)$$
$$\dot{y}_p = v_p.\sin(\theta_p)$$
$$\dot{\theta}_p = k_p u_p, \quad -1 \le u_p \le 1$$
$$\dot{x}_e = v_e.\cos(\theta_e)$$
$$\dot{y}_e = v_e.\sin(\theta_e)$$
$$\dot{\theta}_e = k_e u_e, \quad -1 \le u_e \le 1$$

θ_p and θ_e are the heading angles (measured with respect to the x-axis) and u_p and u_e are the control variables of pursuer and evader respectively.

Now, the problem is to find a maneuver for fighter P to suitably place it in the back of fighter E in order to enable P to perform a lethal shot against E. For an effective shot on the enemy fighter, some severe restrictions on heading angle, distance, LOS rate and etc. shall be fulfilled. The distance between the two fighters for an effective shot shall lie between two maximum and minimum values. The maximum value is related to gun or missile range and minimum value the avoidance of collision with the target or target debris. Heading of the offensive aircraft should be toward the target or a little bit in front of it. Furthermore the LOS rate should be as low as possible [6, 7].

In addition to reach a suitable position, the maneuver should be kept out of offensive fighter accessie. ' bad position'. A "bad position" means a position that lets the defensive fighter (E) gain enough advantage to turn to an offensive or threatening position.

It also should be added that the ratio of two velocities and positions of two fighters as well as the initial heading of the fighter ***P***-as it will be shown in examples- make it impossible for classic guidance laws such as proportional navigation to fulfill the requirements for a successful dogfight maneuver.

We refer to the solution of the above problem as a "guidance law" because it

Furthermore, the advancements in information and military technology has been constantly improved the missile and fighters' capabilities. These improved weapons require new training tools that make it necessary for the opponents in a simulator to be more careful and utilizes more sophisticated guidance laws and tactical decision generators.

The literature on this subject is not so vast. Two approaches to the problem could obviously be recognized. The first approach, relies heavily on optimization theory especially optimal control theory and differential game theory. The research on this line was triggered mainly by works of R. Kalman [3] and R. Issacs [4] on optimal control theory and differential game theory respectively. The differential game theory-since its main purpose is conflict modeling-has been widely used for combat modeling. The theory provides optimal strategies for both pursuer and evader in air combat scenarios. On the other hand, optimal control theory considers the problem of air combat as a one-sided optimization problem (e. g. it supposes that the moving direction of evader is known during the combat) and provides the optimal maneuver for one of the combatants. Each of these methods received some interest. For example, [8, 10, 17] used differential game while [9] used optimal control theory for solving the problem.

The second approach is based on AI and computational intelligence methods. This approach mostly leads to expert system structures for the decision-making model which in turn would be a part of a very large and complex system. The method usually formalizes the expert's knowledge and experiences in some ways and then builds the model from the formalization. The structures and formalization methods are varying[5, 14, 16].

While each of the above approaches has their limitations, the optimization approach to the problem suffers from some severe drawbacks. The main drawback is that it is very difficult to include realistic combat situations in the formulation. To keep the problem mathematically tractable and solvable, some simplifications are necessary to make the solution far from what is done in real combat situations by experienced pilots. Also, this approach seldom pays attention to the structure of the performance criterion which models the preferences of human decision maker.

As it has been stated before, the number of papers regarding combat of two aircraft is not so many. However, more papers can be found regarding the pursuit-evasion game of a missile and a fighter but they are not considered here. In [16], AI techniques were used in the development of a tactical decision generator (TDG) for within-visual-range (WVR) air combat engagements. Their system uses a series of trial maneuvers and a maneuver-scoring module to select best maneuver in each time step.

Virtanen et. al. used a multistage influence diagram to model and analyze the successive maneuvering decisions in a one versus one air combat [15]. Two myopic and optimal solutions to the problem were found. Their model involves components describing uncertainty, the decision dynamics and the preferences of the pilot. The utility function introduced there measures the overall preferences in different combat states. Preference optimal trajectories that maximize the cumulative expected utility over several decision stages are obtained by solving the influence diagram with nonlinear programming. Their approach is a combination of the two referred methods.

In [10], Using a feedback linearization method, an optimal nonlinear solution to the aircraft pursuit evasion problem formulated as a differential game in three-dimentional space was found by Menon and Duke. The payoff function used by them is a combination of capture time and energy used. The point mass model has been used as the dynamic equations of motion for both pursuer and evader. The most striking feature of their work is the consideration of a realistic weapon envelope for pursuer aircraft.

In some papers, the subject of fuzzy guidance law has been considered [11, 12, 13], but in all of them the proposed guidance law is suitable for missile guidance. In [11], a fuzzy if ... then ... rule base is introduced that generates the control commands of a missile to intercept an incoming high-speed target in the plane. The rule base relates the missile's control

A Two-Phase Fuzzy Guidance Law for Planar Offensive Air-to-Air Combat Maneuver

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Abstract

In this paper we propose a new guidance law based on fuzzy logic that can be successfully used for modelling and generating complicated offensive maneuver in a planar air-to-air combat encounter between two aircrafts. Based on fighter's pilot decision-making process, a two-phase pursuit law represented as fuzzy "if ... then ..." rules is introduced. The rules are obtained from expert's knowledge. Each rule relates the desired moving direction of the pursuer to combat parameters such as distances and heading angles. Massive simulations are used to ensure the satisfactory performance of the model.

Keyword

Fuzzy, Guidance law, air-to-air combat, Expert system

Introduction

The modelling and automation of the pilot's actions and decision-making process during an air-to-air combat may have three main purposes:

1-The automation of air combat for future unmanned wars.
2-The design of decision-support systems for aiding the pilot and decreasing his/her stress and workload.
3-The design of electronic opponent in training simulators.

The motivation for all of these is the improvements in military technology. Technology improvements have changed the figure of the air combats so much and will influence them more in the future[1]. In the early fighters, pilots had to obtain all necessary data and information only through their senses. They had to decide how to maneuver and then how to keep the enemy in front of the gun. There were no help for them. But now, target and enemy information are mostly received by optical and electronic sensors. The fire locking systems keep the target in hand and many other electronic and mechanical systems help the pilot to accomplish his/her tasks. So gradually -as it could be seen- there has been a major shift from human operator to more complex automatic systems in control and information processing tasks. This shift of roles in the cockpit has been made possible by new methods in knowledge representation, AI techniques and control theory. Thus it would be no surprise if the recent and future advances in computer technology, artificial intelligence and computational intelligence methods will eventually lead to complete automation of pilot's tasks and unmanned wars.

On the other hand, in modern fighters, being fast and correct in making decisions are of great importance. Death-and-life decisions not only must be made in fractions of a second but also depend on the information that are time varying, imprecise and even contradicting [2]. Thus, the need to decision-aid systems that help fighter pilots to reach reasonable decisions promptly or evaluate correctness of their decisions is an emerging need.