FUZZY LOGIC IN FIRE CONTROL SYSTEMS FOR AIR DEFENCE

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Abstract: It is the necessity defense combat against modern offensive weapons from the air to apply the best and most efficient defense tactics and technology. The problems of shooting targets in air space are solved by appropriate design of a fire control system, and the latest developments employ computational intelligence models and techniques. In this paper, a fuzzy-logic knowledge-base system in the fire control system for missile based air defense has been investigated. The aim of this paper is to provide a quality guidance process with minimum number of measurements, and to use the results for modification of the existing air defence systems, which are present in our Army (Strela 10). The novelty is in defining fuzzy logic variables for the approaching velocities between target and missile drf and the angle of lead when the missile is still on the launcher ksif. This fuzzy logic based technique reduces the demand for determining of the parameters usually calculated using provisional estimates and employed in missile's homing guidance. It is developed by using Fuzzy Toolbox of Matlab. Simulation model in the vertical plane is developed by using Matlab/ Simulink platform. *Copyright © 2007 IFAC*

Keywords: Air defence systems; angle of lead; fuzzy logic; homing guidance; missile; incoming-leaving regime.

1. INTRODUCTION

Modern combat against air-attacking enemy is most complicated because the modern weapons for offensive from the air have high maneuvering capabilities and move with high velocity. Thus the problem of shooting airborne enemy targets while these are in the air is very complicated too. In missile systems for air defense, this problem is to be solved by fire control (sub)system, and moreover always according to the technology of air-attacking enemy.

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The motivation for this paper arose from the research project 07-1191/4 at the Military Academy "General Mihailo Apostolski" Skopje and the Faculty for Electrical engineering - Skopje titled "Development and implementation of algorithms for guidance, navigation and control of mobile objects". The aim of this paper is to provide a quality guidance process with minimum number of measurements, and to use the results for modification of the existing air defence systems, which are present in our Army (Strela 10).

In this paper the homing guidance system is assumed to be employed as built-in subsystem of the air-defence system. Functional schematic of the homing guidance systems (among which the active, semi-active, and passive are distinct) is shown in Figure 1.

Resolving the problems of fire control involves:
- Detection and identification of the enemy target;
- Calculation of the target's motion parameters;
- Solution for shooting target and directing of the launcher accordingly;
-Launch of the missile and controlling its motion as a function of the applied guidance law.

The missile guidance law has so crucial impact as to impose essential distinction among air defence systems (e.g. system such as Line-of-sight; Homing; Navigational; and Compound guidance).

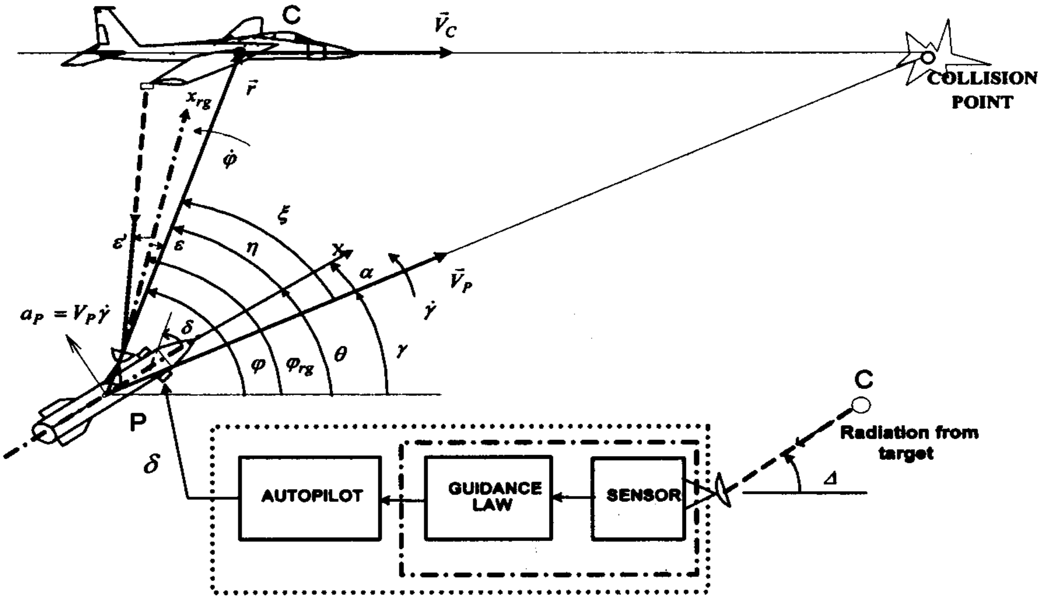

Fig. I. Schematic of homing guidance missile base air defence system.

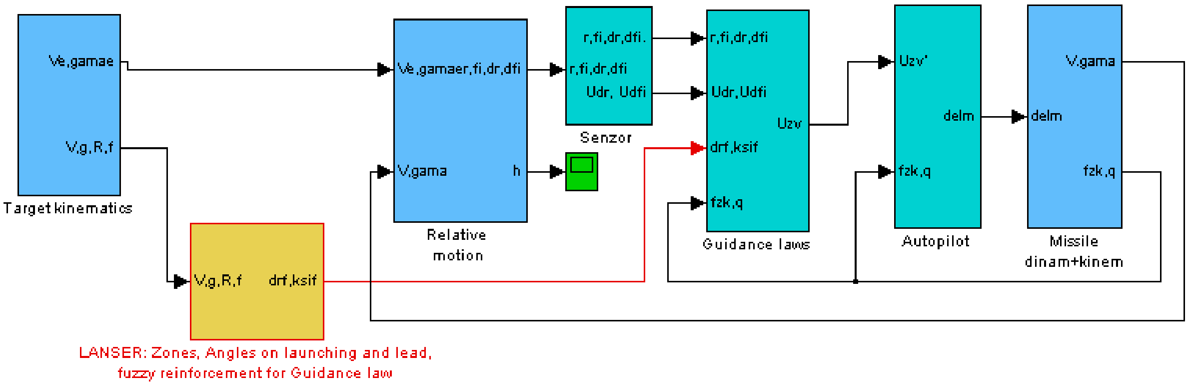

Fig. II. A Matlab/ Simulink implementation model of the air defence system in Figure I.

2. HOMING-GUIDANCE SYSTEM IN THE VERTICAL PLANE

For the purpose of realization of the investigation reported in this paper the simulation model of homing-guidance missile systems for air defense in vertical plane (Davis et al. 1958; Deskovski, Deskovski et al., 2003; Dimirovski, et al. 2004; Siouris, 2004). Simulation model in the vertical plane is implemented in the Matlab/ Simulink computing environment.

The motion of the target in the vertical plane is described by equations:

$$\begin{aligned}
\dot{V}_e &= a_{ex} \\
\dot{\gamma}_e &= -\frac{a_{ez}}{V_e} \\
\dot{x}_{eg} &= V_e \cdot \cos\gamma_e \\
\dot{z}_{eg} &= -V_e \cdot \sin\gamma_e
\end{aligned} \qquad (1)$$

where $a_{ex}(t)$ and $a_{ez}(t)$ are the accelerations of target's center of the mass, (they represent the dynamics and maneuvering properties of the target), V_e and γ_e are velocity of target and pitch of target's trajectory, (they are part of the equation for relative motion), x_{eg} and z_{eg} are the coordinates of target's center of the mass. In homing-guidance model, we have defined the block "Target kinematics".

The motion of missile in the vertical plane is described by the equation:

$$\begin{aligned}\dot{V} &= a_{x_k}\\ \dot{\gamma} &= -\frac{a_{z_k}}{V}\\ \dot{x}_g &= V \cdot \cos\gamma\\ \dot{z}_g &= -V \cdot \sin\gamma\end{aligned} \tag{2}$$

In the homing-guidance model, we have defined the block "Missile dinamic+kinem".

The kinematics equations of homing-guidance in the vertical plane are:

$$\begin{aligned}\dot{r} &= V_e \cdot \cos(\varphi - \gamma_e) - V \cdot \cos(\varphi - \gamma)\\ r\dot{\varphi} &= -V_e \cdot \sin(\varphi - \gamma_e) + V \cdot \sin(\varphi - \gamma)\end{aligned} \tag{3}$$

In this simulation model of homing guidance, the method for proportional navigation has been applied (Neupokoev, 1970, Peresada, 1973, Deskovski, 2004).

. In this method, the angle velocity of target's trajectory must be proportional with the angle velocity of target's line of sight, that is:

$$\dot{\gamma} = K \cdot \dot{\varphi} \tag{4}$$

The ideal relation in this case is given with:

$$\varepsilon = \dot{\gamma} - K\dot{\varphi} = 0 \tag{5}$$

In the given, implemented model, these guidance laws are used as follows:

- Classical proportional navigation: in this case - only velocity on line of sight of the tagget dfi/dt is measured;

- Classical proportional navigation: in this case - velocity on line of sight on target dfi/dt and velocity of approach between target and missile dr/dt, are measured.

- Improved proportional navigation; in this case - velocity on line of sight of target dfi/dt, velocity of approach between target and missile dr/dt, and acceleration normal to the target's line of sight aen, are measured.

- Optimal proportional navigation: in this case - these parameters are measured: velocity of line of sight of the target, velocity of approach between target and missile, acceleration of target normal to the line of sight and initial angle of lead.

- Classic proportional navigation with fuzzy determined angle of lead ksif and velocity of approach between target and missile drf: in this case, we don't need the measurement of velocity of approaching between target and missile dr/dt, and the angle velocity of target's line of sight dfi/dt.

3. APPLICATION OF FUZZY LOGIC IN FIRE CONTROL SYSTEMS

Engineering a fuzzy control system uses many ideas from the so-called conventional and modern control engineering methodologies, except that in fuzzy control it is often said that a formal mathematical model is assumed unavailable so that a thorough mathematical analysis is impossible (Dimirovski, 1995, Dimirovski, 2002). While it is often the case that it is difficult, impossible, or cost-prohibitive to develop an accurate mathematical model for many processes, it is almost always possible for the control engineer to specify some type of approximate model of the process (after all, we do know what physical object we are trying to control). Indeed, it has been our experience that most often the control engineer developing a fuzzy control system does have a mathematical model available.

In this paper, fuzzy logic is applied for guidance law of a homing missile(Deskovski, 2004). For this purpose, the following variables are fuzzified: the approaching velocity of the target and missile drf, and the initial angle of lead on the launcher ksif. For determining of these fuzzy variables, there have been defined and constructed 4 fuzzy logic controller inference systems (FLC): two FLC are used for determining of drf, and two for determining ksif. Input parameters of the FLC, which are used for determining of drf, are: velocity of target Ve, angle of orientation (2 regimes: target leaving or target arriving) gamae, and angle of elevation of the target - fie.

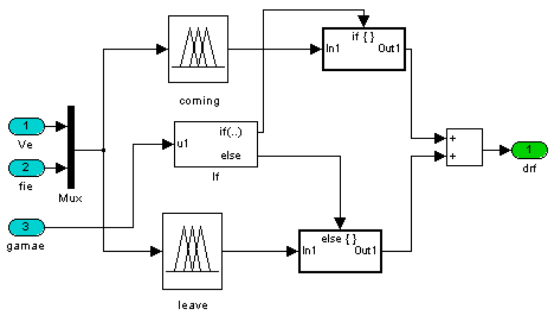

Fig. III. FLC for determining the drf.

When the target is in arrival regime, it is the following fuzzy-rule knowledge-base inference that determines the drf as a function of the input parameters established:

IF Ve is 'mf1' and fie0 is 'low' THEN
output1 is 'mf6'

IF Ve is 'mf1' and fie0 is 'medium' THEN
output1 is 'mf6'

IF Ve is 'mf1' and fie0 is 'high' THEN
output1 is 'mf7'

IF Ve is 'mf1' and fie0 is 'very high' THEN output1 is 'mf8'

IF Ve is 'mf2' and fie0 is 'low' THEN output1 is 'mf5'

IF Ve is 'mf2' and fie0 is 'medium' THEN output1 is 'mf6'

IF Ve is 'mf2' and fie0 is 'high' THEN output1 is 'mf7'

IF Ve is 'mf2' and fie0 is 'very high' THEN output1 is 'mf8'

IF Ve is 'mf3' and fie0 is 'low' THEN output1 is 'mf4'

IF Ve is 'mf3' and fie0 is 'medium' THEN output1 is 'mf5'

IF Ve is 'mf3' and fie0 is 'high' THEN output1 is 'mf7'

IF Ve is 'mf3' and fie0 is 'very high' THEN output1 is 'mf9'

IF Ve is 'mf4' and fie0 is 'low' THEN output1 is 'mf3'

IF Ve is 'mf4' and fie0 is 'medium' THEN output1 is 'mf4'

IF Ve is 'mf4' and fie0 is 'high' THEN output1 is 'mf6'

IF Ve is 'mf4' and fie0 is 'very high' THEN output1 is 'mf9'

IF Ve is 'mf5' and fie0 is 'low' THEN output1 is 'mf2'

IF Ve is 'mf5' and fie0 is 'medium' THEN output1 is 'mf4'

IF Ve is 'mf5' and fie0 is 'high' THEN output1 is 'mf6'

IF Ve is 'mf5' and fie0 is 'very high' THEN output1 is 'mf9'

IF Ve is 'mf6' and fie0 is 'low' THEN output1 is 'mf1'

IF Ve is 'mf6' and fie0 is 'medium' THEN output1 is 'mf3'

IF Ve is 'mf6' and fie0 is 'high' THEN output1 is 'mf6'

IF Ve is 'mf6' and fie0 is 'very high' THEN output1 is 'mf10'

When the target is leaving, the rule base is very small (16 rules), because in the leaving regime targets with velocity larger than 300 m/s cannot be shoot.

The appropriate choice of 6 membership function degrees for variable have been defined. Similarly, For variable fie0, there are defined 4 membership function degrees, and for the angle it is low, medium, high, and very high. Membership function degrees of the variables Ve and fie0 are triangle contours with linguistic values as follows:

$$V_e = \{mf1, mf2, mf3, mf4, mf5, mf6\}$$

$$fie0 = \{low, medium, high, very\ high\},$$

The fixed sets of theirs values are within in the next presented intervals:

$$V_e = [100, 400 m/s],\ fie0 = [0, 1.507 rad]$$

We have shown in our case study the application of fuzzy system based designs for control, guidance and supervision of missiles and combat scenarios that use fuzzy inference decision and control and which is hybrid combined with math-analytical plus fuzzy soft-computing techniques(Yen et. al. 1998). Of course, this has to be done in a mode ensuring their consistent compatibility. Secondly, we have shown in our application that there is a limited benefit on performance of these system engineering designs according to the real-world facts that to some tasks fuzzy system techniques are better suited while to others math-analytical techniques are more fruitful. And thirdly, it is rather important to note that indeed employing some soft-computing formalism and technique, such as fuzzy systems in here, leads to crating technological systems with higher quotient of machine intelligence and simultaneously improving or simplifying engineering structure of the designed system.

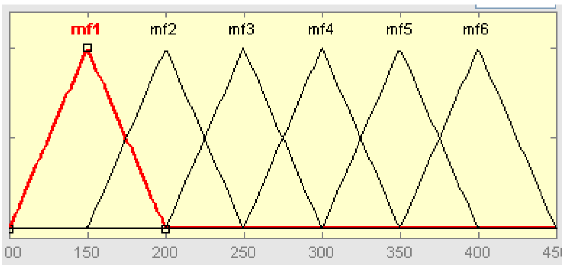

Fig. IV. Fuzzy variable for the velocity Vc.

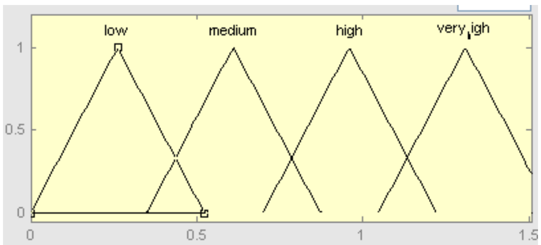

Fig. V. Fuzzy variable for the velocity fie0

4. SIMULATION RESULTS

With computational simulation of the system sown in Figure 2 for several initial conditions, we can execute different simulation experiments for various anti-air combat scenarios. In particular, in here our interest is focused on the results obtained by simulation when fuzzy logical law for guidance is applied for the scenario of approaching interception and of leaving interception.

In Figures VI and VII, the motion of the target and the missile along with the instantaneous miss are represented for the first scenario; the initial conditions are: altitude of target He=1500m, velocity of target Ve=250m/s, and the target is coming, gamae=180. For the second scenario, Figures VIII and IX the motion of the target and missile along with the instantaneous miss are represented; the initial conditions are: altitude of target He=1000m, velocity of target Ve=250m/s, and the target is outgoing, gamae=0.

It is seen from the trajectories in these simulations, for two different scenarios, that the system functions properly and the contact missile-target is obtained in both cases. During the evolution of the instantaneous miss at the contact time and considerably before the contact, the miss reaches rabidly value zero.

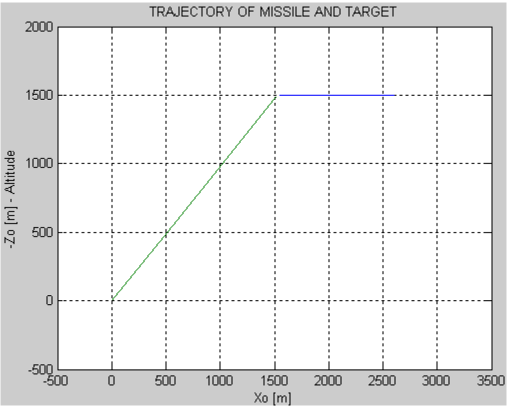

Fig. VI. Trajectories of the missile and the target.

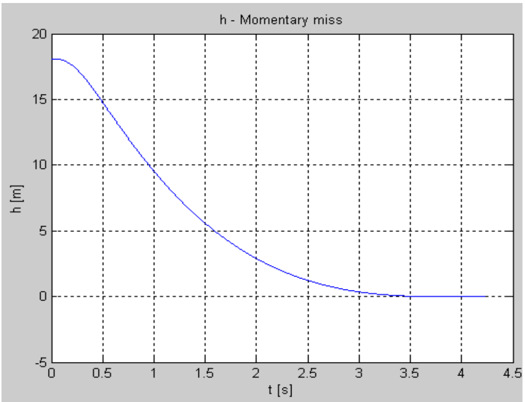

Fig. VII. Evolution of the instantaneous miss.

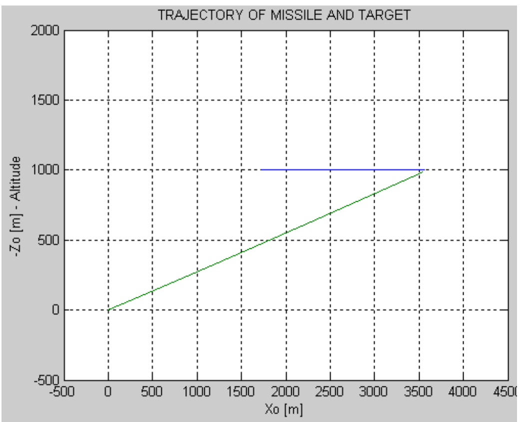

Fig. VIII. Trajectories of the missile and the target.

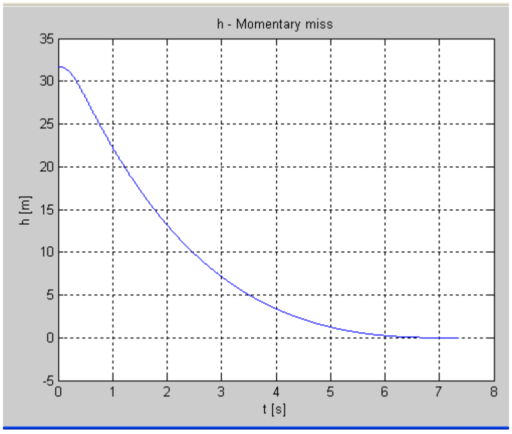

Fig. IX. Evolution of the instantaneous miss.

5. CONCLUSION

In this paper, the application of a fuzzy-logic rule knowledge base to the fire control system (homing missile guidance) for air defence systems has been derived. It is developed by using Fuzzy Toolbox of Matlab. We have used the fuzzy logic for determining the approaching velocity between the missile and the target as well as the leading angle, which will be taken on the launching station settings. These two parameters are used in the law for homing guidance of the missile. With this method, the necessity for calculation of these parameters, which are normally obtained by using some previous estimation, has been ameliorated. The simulation model in the vertical plane was developed in Matlab/ Simulink programming platform.

The aim of this paper is to provide a quality guidance process with minimum number of measurements, and to use the results for modification of the existing air defence systems, which are present in our Army (Strela 10).

The contributions of this paper are the decreased number of sensors which are used in the conventional design. We have obtained the improved manoeuvring missile potential. The third advantage is that we have decreased the necessary hardware mounted on the missile and the destroying missile capability is increased.

The developed simulation programs and obtained simulation results gave us an opportunity to pursue the implementation of the fuzzy logic in the fire control system when the whole 3D space is taken into consideration. This is the topic for the future research.

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