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Time Delay Neural Network For Target-Intercept Problem Solving

Artur Korgul
Institute of Automation of Command Systems
Military University of Technology, Warsaw, Poland
01-489 Warszawa ul. S. Kaliskiego 2
e-mail: akorg@granit.ias.wat.waw.pl

Abstract. The target-intercept problem is formulated mathematically. The step by step strategy of proportional navigation for efficient fighter guiding to the manoeuvring air target is presented. The practical application of Time Delay Neural Network (TDNN) to realize this strategy is suggested and simulated numerically.

1. Introduction

Recently, neural networks have received much attention from the point of view of their possible application for the control of complex systems and processes [1], [2], [3]. The guiding of fighters to the manoeuvring air targets by ground based air defence system represents the special case of such a large and territorially distributed process. The most essential points of the problem are:
- noisy-dense environment,
- high degree of uncerntainty,
- high order of nonlinearity ,
- necessity of intensive and massive data processing in real-time.

The fundamental problem which should be solved in such a command guidance system consists of targets trajectory tracking and working out the fighters navigation strategy to capture the moving and manoeuvring air objects [4], [5]. To realize the target-interception, the vector fields of velocities of flying objects in three dimensional space must be correctly estimated from the noisy radar plots of these objects. It means that both: filtering radar signals and proper guiding of a fighter are most essential in solving this problem. This paper presents the main thesis for efficient realization of a fighter's guidance by three dimensional, proportional navigation strategy which is supplied on-line with the data from ground radar tracking system. The special kind of TDNN (Time Delay Neural Network) to recognize the continuous and smooth trajectories of flying objects is suggested. It offers the excellent properties for filtering the noisy and rather sparse radar plots. This kind of TDNN is also used for deriving the turning rate of LOS (line of sight) and closing rate of air objects in pursuit scenario , which permits realization of the long-range proportional navigation strategy with the use of the ground radar plots only.

2. The verbal statement of target-interception

Having the ground radar plots of air objects (both the targets and fighters) being detected on-line in discrete time instants (i.e. adequate time series of data) and shifted to the three dimensional sliding window, estimate the continuous and smooth trajectories of these objects to predict their further positions and to derive their vector

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fields of velocities which ensure proper navigation of the fighters to intercept the air targets [4], [5], [6]. The following questions have to be answered:

- how to guarantee the continuous proximity and similarity of estimated trajectories of flying objects with those already identified in order to detect correctly their common orientation of LOS in space and their relative motion,
- how to define practical and numerically effective procedure to aid the target interception ?

When seeking the answers to these questions one should consider the possibility of using the differential equations for describing and analysing this process. The results of phenomenological analysis of the dynamics of the motion of a plane registered by a ground observer (i.e. radar system) prove the accuracy of the above suggestion. It indicates that the possible trajectory of a flying object is smooth and can consist of the following elements, spliced together:

- the segment of directed straight line,
- the segment of left-handed or right-handed circle,
- the segment of left-handed or right-handed screw line.

In general these trajectories can be arbitrarily oriented in three dimensional space provided that the additional constraints of real man-machine system (i.e. pilot-aircraft) is not considered.

3. Mathematical formulation of target-interception

In order to simplify mathematical description, the plane is treated as a single particle, its motion is scaled in finite period of time [0, T] and examined in aerodynamical environment in right-handed spatial frame of reference 0xyz (i.e. Cartesian coordinate system). Thus, the vector field of velocity of manoeuvring air target can be described by means of the following set of nonlinear and nonstationary partial differential equations (1):

$$\begin{cases} \dfrac{\partial v_{xc}}{\partial t} = \dfrac{F_{xc}}{m_c} + v_{yc} \cdot rot_z \vec{v}_c - v_{zc} \cdot rot_y \vec{v}_c \\ \dfrac{\partial v_{yc}}{\partial t} = \dfrac{F_{yc}}{m_c} - v_{xc} \cdot rot_z \vec{v}_c + v_{zc} \cdot rot_x \vec{v}_c \\ \dfrac{\partial v_{zc}}{\partial t} = \dfrac{F_{zc}}{m_c} - g + v_{xc} \cdot rot_y \vec{v}_c - v_{yc} \cdot rot_x \vec{v}_c \end{cases} \quad (1)$$

Analogically, the equations of the vector field of velocity of pursuing fighter can be presented by the means of the same formula if (c) index (target) is changed into (m) index (fighter).

Having the vector field velocities of flying objects we can obtain their trajectories (both the air target and fighter). For this purpose we must integrate velocity fields according to the formulas (2):

$$\begin{cases} x(t) = x_0 + \int_{t_0}^{t} v_x(x,y,z,t)dt \\ y(t) = y_0 + \int_{t_0}^{t} v_y(x,y,z,t)dt \quad \text{for } t \geq t_0 \\ z(t) = z_0 + \int_{t_0}^{t} v_z(x,y,z,t)dt \end{cases} \tag{2}$$

In the course of analysis of the target-interception we have to define the initial and terminal conditions for the set of above equations (1), (2). Therefore we should consider the geometrical interpretation of pursuit-evasion scenario, as presented on fig.1.

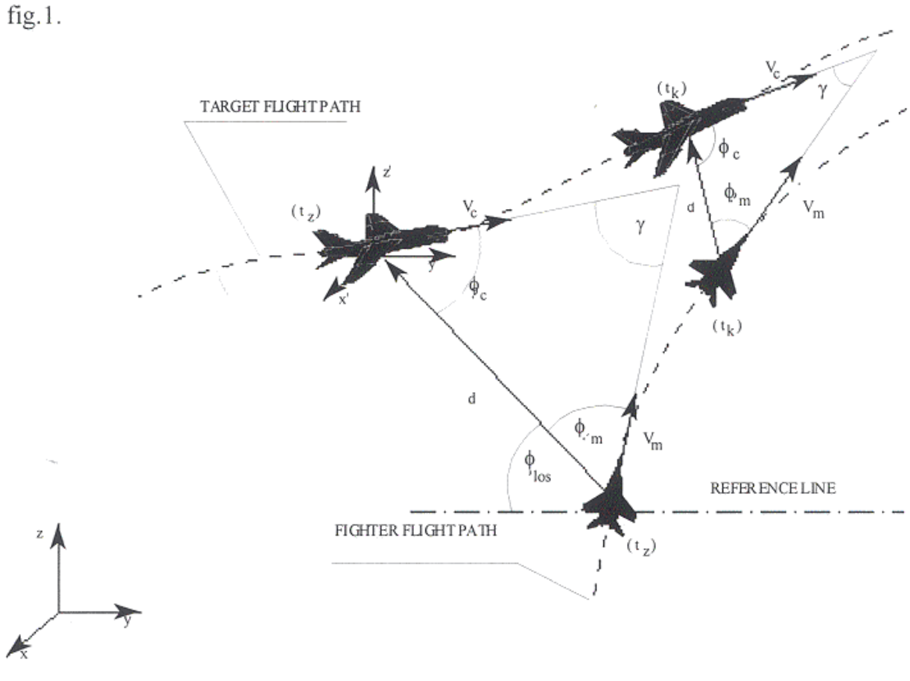

Fig. 1. Pursuit geometry for proposed guidance law

To intercept the manoeuvring air target, the pursuing fighter must reach and slide the „collision course" configuration with this target. Then the initial conditions are as follows:

- the distance between target and fighter is given according to the formula (3),

$$d_o = \sqrt{(x_{mo} - x_{co})^2 + (y_{mo} - y_{co})^2 + (z_{mo} - z_{co})^2} \tag{3}$$

- the heading angle of target velocity vector to LOS (line of sight) is given according to the formula (4),

$$\phi_{co} = \arccos\left[\frac{(x_{mo} - x_{co})v_{xco} + (y_{mo} - y_{co})v_{yco} + (z_{mo} - z_{co})v_{zco}}{\sqrt{(x_{mo} - x_{co})^2 + (y_{mo} - y_{co})^2 + (z_{mo} - z_{co})^2} \cdot \sqrt{v_{xco}^2 + v_{yco}^2 + v_{zco}^2}}\right] \tag{4}$$

- the heading angle of fighter velocity vector to LOS is given according to the formula (5),

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$$\phi_{mo} = \arccos\left[\frac{(x_{mo}-x_{co})v_{xmo} + (y_{mo}-y_{co})v_{ymo} + (z_{mo}-z_{co})v_{zmo}}{\sqrt{(x_{mo}-x_{co})^2 + (y_{mo}-y_{co})^2 + (z_{mo}-z_{co})^2}\cdot\sqrt{v_{xmo}^2+v_{ymo}^2+v_{zmo}^2}}\right] \qquad (5)$$

The terminal conditions for interception take the form:

- up to go time to randezvous is given according to the formula (6),

$$(T_k - t_z) = \frac{d(t_z)}{v_m(t_z)\cdot\cos\phi_m(t_z) + v_c(t_z)\cdot\cos\phi_c(t_z)} \qquad (6)$$

- the heading angle of fighter velocity vector to LOS needed to slide the „collision course" configuration is given according to the formula (7),

$$\phi_m(t_z) = \arcsin\left[\frac{v_c(t_z)}{v_m(t_z)}\cdot\sin\phi_c(t_z)\right] \qquad (7)$$

- the angle of interception is given according to the formula (8),

$$\gamma(t_z) = 180^\circ - \varphi_c(t_z) - \varphi_m(t_z) \qquad (8)$$

4. Solution

Since the angle of interception (γ) depends only on the type of fighter and its weapon, not on target manoeuvres, the optimal on line pursuing strategy is defined by the following condition (9):

$$\left.\frac{d\gamma(t)}{dt}\right|_{t=t_z^*} = 0 \;\Rightarrow\; \Delta\phi_m(t_z^*+\Delta t) = -\Delta\phi_c(t_z^*+\Delta t) \qquad (9)$$

As a result the whole step by step strategy of fighter guiding can be easily derived and presented in the following formulas (10), (11):

$$\begin{cases} v_m(t_z^*+\Delta t) = v_m(t_z^*) + \Delta v_m(t_z^*) \\ \phi_m(t_z^*+\Delta t) = \phi_m(t_z^*) - \Delta\phi_c(t_z^*) \end{cases} \qquad (10)$$

Where:

$$\Delta v_m(t_z^*) = \frac{\Delta v_c(t_z^*)\sin\phi_c(t_z^*)}{\sin\phi_m(t_z^*)} - \frac{1}{\sin\phi_m(t_z^*)}\left[2\omega_{LOS}(t_z^*)\cdot\Delta d(t_z^*) + \omega_c\cdot\Delta d + d(t_z^*)\cdot\Delta\omega_{LOS}(t_z^*)\right]$$

$$\Delta\phi_c(t_z^*+\Delta t) = \Delta\phi_{LOS}(t_z^*+\Delta t) + \omega_c\cdot\Delta t \quad \text{and}$$
$$\Delta d(t_z^*+\Delta t) = -[V_m(t_z^*)\cos\phi_m(t_z^*) + V_c(t_z^*)\cdot\cos\phi_c(t_z^*)]\Delta t \qquad (11)$$

5. Practical application

Having the formulas (10) and (11) the following question can be raised:

- how to realize this strategy numerically on-line if the radar plots of flying objects are disposed in discrete and rather sparse time moments only ?

The following vector fields should be identified in this case:

- the flying objects velocities (v_c, v_m),
- the turning rate of target (ω_c),
- the turning rate of LOS (ω_{los}),
- the closing rate of objects ($\dot{d}$).

All these must be considered in three dimensional continuous space, having the real-time series of discrete radar plots of the sequential positions of these objects only. This nontrivial identification problem has been solved practically by using the time

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delay neural network (TDNN) to differentiate the time series of discrete and sparse radar plots [7], [8]. The original structure of this network is presented on fig.2, whereas the pursuit scenario simulated numerically is shown on fig.3.

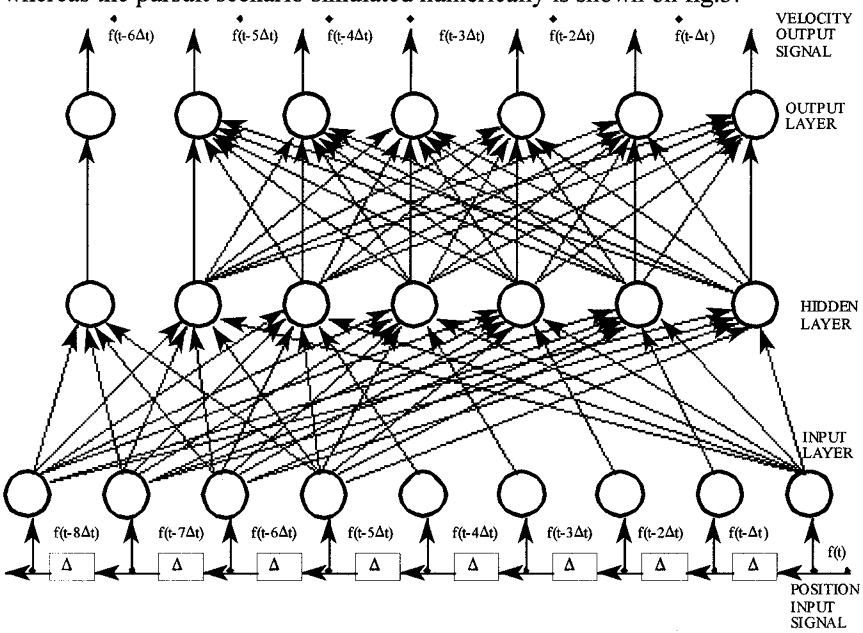

Fig.2. Time delay neural network for differentiating radar plots

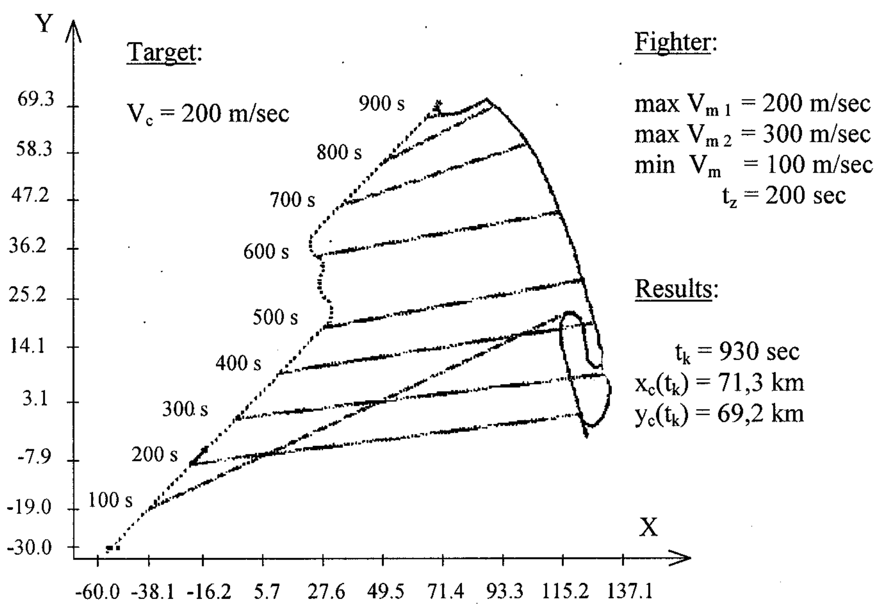

Fig.3. Target - interception simulated numerically

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6. Conclusions

The efficient solution of the target-interception requires the usage of TDNN to differentiate the time series of radar plots of manoeuvring air objects.
If the long-range proportional navigation strategy is to be realized in efficient guidance of fighters, the ground radar tracking system can be used successfully as a source of data.

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References

1. P. Morasso, V. Sanguineti, T. Tsuji: Neural architecture for robot planning. In S. Gielen and B. Kappen, editors, Proc. of ICANN, Amsterdam, Sept. 1993, pp. 256-261, Springer Verlag, London 1993.
2. L.Chin:Application of Neural Networks in Target Tracking Data Fusion. IEEE Trans. on AES.Vol.30, No.1 (1994), 281-287.
3. J. E. Steck, S. N. Balakrishnan: Use of Hopfield Neural Networks in Optimal Guidance. IEEE Trans. on AES.Vol.30, No.1 (1994), 287-293.
4. A. Korgul: The method of fighter guiding to the air targets. Military University of Technology. Warsaw 1991 (in Polish).
5. A. Korgul: Developing of the detailed algorithms for fighter guiding to the air targets. Military University of Technology. Warsaw 1992 (in Polish).
6. A. Korgul: Networks for learning and differentiating an input-output mapping. Proc. Int.Conf. on „Image Processing and Neural Networks '93", Liptovsky Mikulas (Slovakia) May 19. - 20. 1993, 40-46, and extended abstract in S. Gielen, B. Kappen, editors, Proc. of ICANN, Amsterdam, Sept. 1993, p 475, Springer Verlag, London 1993.
7. A. Korgul: Numerical symulation of fighter guiding to the manoeuvring air target. Proc. of III Scientific Conference on Automatization of Command Systems. Jelenia Góra (Poland) May 17. -20. 1995, Vol. 2, 163-172 (in Polish).
8. A. Korgul: Mathematical modelling of fighter guiding to the manoeuvring air target. Postępy Cybernetyki,Vol. 18, No.3-4 (1995), 79-97 (in Polish).