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A real-time dynamic optimal guidance scheme using a general regression neural network

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ABSTRACT

This paper presents an investigation into the challenges in implementing a hard real-time optimal non-stationary system using general regression neural network (GRNN). This includes investigation into the dynamics of the problem domain, discretisation of the problem domain to reduce the computational complexity, parameters selection of the optimization algorithm, convergence guarantee for real-time solution and off-line optimization for real-time solution. In order to demonstrate these challenges, this investigation considers a real-time optimal missile guidance algorithm using GRNN to achieve an accurate interception of the maneuvering targets in three-dimension. Evolutionary Genetic Algorithms (GAs) are used to generate optimal guidance training data set for a large missile defense space to train the GRNN. The Navigation Constant of the Proportional Navigation Guidance and the target position at launching are considered for optimization using GAs. This is achieved by minimizing the miss distance and missile flight time. Finally, the merits of the proposed schemes for real-time accurate interception are presented and discussed through a set of experiments.

1. Introduction

Despite high performance computing power, real-time implementation of a complex evolutionary algorithm requires an efficient design, software coding of the algorithm, algorithm manipulation so as to exploit special features of the hardware and avoid associated shortcomings of the architecture. There have been many effort made earlier to demonstrate efficient algorithm design and software coding to achieve real-time performance (Benoit et al., 2010). However, computationally complex real-time applications, for example optimal algorithms to solve nonstationary system design problem in a dynamic environment, are difficult to implement by exploiting the power of high performance computing domain and/or efficient algorithm design technique and/or better software coding. In particular, the requirement of any level of online optimization for large number of data brings hard constraints and uncertainty in implementing the application in real-time. An alternative solution is to exploit algorithm manipulation, for example, performing off-line optimsation and then replacing database of optimal parameters with learning algorithms for online execution. In implementing a computationally complex scenario like this, an artificial neural network algorithm could play a vital role in learning the dynamic features in order to achieve the real-time solution of complex evolutionary problems.

This paper considers a closed loop complex real-time missile guidance scheme to demonstrate the potentiality of the GRNN algorithm to solve an evolutionary nonstationary problem. This requires optimal dynamic inputs to the scheme based on the nonstationary enemy objects which is extremely challenging, particularly due to complex computational demand for real-time optimal guidance. There was much research reported earlier on how a missile tracks a target and what the optimal guidance law should be used (Zarchan, 1999, 2002; Lin, 1991; Becker, 1990; Hur and Song, 1990; Madkour et al., 2006; Wu et al., 2010; Cui et al., 2011; Shin, 2012; Sun and Xia, 2012). Most of these applications have considered different approaches for adapting the proportional navigation law to improve the performance of the guidance algorithms in two-dimensional environments. Moreover, missile guidance and control algorithms are very time critical. The calculation of the parameters with regard to the missile-target interception requires to be done in a specified time in a 3D defense space. Therefore, missiles guidance can be classified as a hard real-time system. In practice, guidance and control algorithms are very complex and challenging to be implemented in real-time applications.

This investigation proposes a real-time neural network based optimal guidance algorithm for a missile pursuing a maneuvering/nonmaneuvering target in a three-dimensional

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(3D) environment. In order to achieve a robust guidance system, it needs to address some practical constraints, for instance uncertainty in object identification, natural disturbances etc. This research focuses particularly on the algorithm design in implementing a framework for a missile guidance system by considering that the target tracking system provides necessary parameters. The proposed guidance system considers not only adapting proportional navigation law but also identifying the appropriate time (hence, the position of the target) for launching the missile. This time is referred here as to 'attention time', which is the time from the target's entry to the defense zone to the missile launch. The proposed approach discretises the missile defense (destruction) zone into a large number of patterns. Each pattern is considered as a trajectory identified by 'nine' parameters. An off-line optimizer generates the optimal navigation constant, and the missile attention time for the given pattern based on the target position and its maneuvering parameters. In other words, these two parameters are the outputs for the corresponding set of target input parameters of the optimizer. These generated optimal data are used as training data for the neural network.

In this paper, genetic algorithms (GAs) is used to estimate an optimal set of the effective navigation constant and the missile attention time. The GA is selected as the optimisation technique as it is a parallel global search algorithm and easy to be implemented. It is reported earlier that the Recessive trait Crossover, which is referred to here as (RCGA), offered better performance as compared other GA based optimization approach for problems with a few numbers of variables (Madkour et al., 2007). The same RCGA approach is used in this application. The structure of the neural network used in this application is general regression neural network (GRNN) (Specht, 1991; Kanmani, et al., 2004; Kanbuaa et al., 2005; Hu et al., 2010; Abas, 2011). Finally, the proposed algorithms are implemented, tested and verified through a set of experiments. Their performances are evaluated using a simulation model for a tactical target. A comparative performance of the proposed algorithms is presented and discussed to demonstrate the merits and capabilities of the approach.

2. A proposed guidance framework

The real-time implementation of any optimal guidance algorithm is not easy since a nonlinear two-point boundary value problem needs to be solved to obtain the optimal trajectory. Theoretically, this missile-target dynamic is highly nonlinear due to the fact that the equations of motion are best described in Cartesian coordinate system, whereas aerodynamic forces and moments are conveniently represented in the missile and target body axis system (George and Siouris, 2004). Direct numerical solutions to this problem introduce a heavy in-flight computational burden. The convergence characteristics also may not be guaranteed. Thus solving the problem in real time is often not feasible (Song and Tahk, 2002; Vaidyanathan et al., 2006).

The basic idea of the proposed guidance is to train neural network to learn the functional form of the optimal guidance command in terms of the current states and terminal conditions, and use them for real-time guidance. Fig. 1 shows the block representation of the proposed guidance technique which can be divided into two strides. These include (i) an off-line optimal guidance algorithm to generate training data for the GRNN using the RCGA, and (ii) on-line application of this trained GRNN in real-time missile guidance under the PNG laws.

The off-line optimal algorithm minimizes a performance index which is defined by a combination of the missile flight time f_t, and the miss distance M_d as denoted by

$$j = \min\left(\sqrt{(W_t f_t)^2 + (W_d M_d)^2}\right. \tag{1}$$

where W_t and W_d are weighting coefficients.

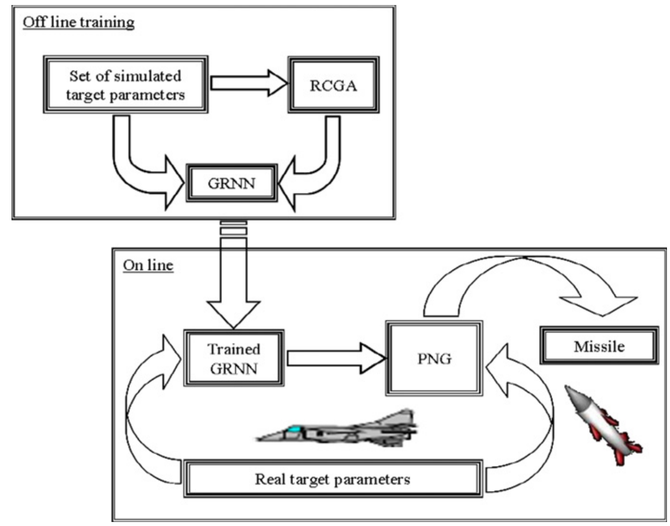

Fig. 1. Neural network guidance technique.

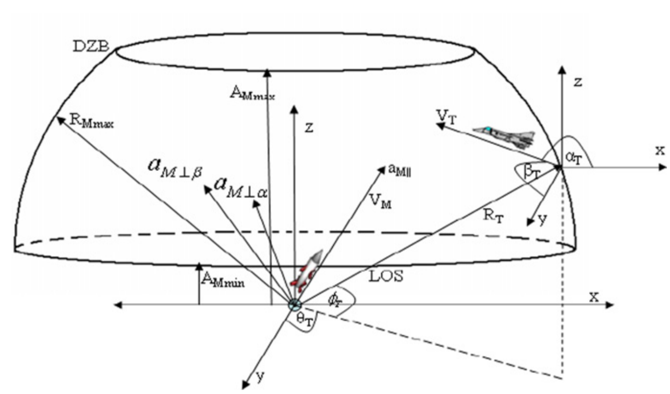

Fig. 2. 3D missile-target engagement geometry and destruction zone boundary (DZB).

This combination gives a trade-off between the two values. In the case of a large variation of these two values, minimizing the sum of squares of the values can be an effective approach (Dahal and Chakpitak, 2007). In fact, there are two parameters which play a key role to minimize this performance index. They are listed below:

i. The effective navigation constant.
ii. The target position at launching time.

It has been reported in the literature that the missile 'flight time' can be greatly reduced by adjusting the effective navigation constant (Lin, 1991; Zarchan, 2002; George and Siouris, 2004; Jackson, 2010). In this application, we consider not only adjusting the navigation constant, but also "optimizing" attention time (hence, the position of the target) for launching the missile.

2.1. Dynamic modelling of the missile and the target

The 3D pursuit geometry of the missile and the target is given in Fig. 2. It is described in a Cartesian coordinate system with origin at the launching point of the missile. The target course can be defined by its velocity vector V_T, and its angles with the vertical and horizontal planes denoted as β_T and α_T, respectively. The target measurements are assumed to be obtained from a typical monostatic radar station with origin at the launching