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Cooperative allocation and guidance for air defence application

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ABSTRACT

This project proposes a centralised algorithm to design cooperative allocation strategies and guidance laws for air defence applications. Scenarios in naval and ground context have been defined for performance analysis by comparison to a benchmark target allocation policy. The cooperative target allocation algorithm is based on the following features: No Escape Zones (differential game NEZ) computation to characterise the defending missile capturability characteristics; In Flight (re) Allocation (IFA algorithm, late committal guidance) capability to deal with target priority management and pop up threats; capability to generate and counter alternative target assumptions based on concurrent beliefs of future target behaviours, i.e. Salvo Enhanced No Escape Zone (SENEZ) algorithm. The target trajectory generation has been performed using goal oriented trajectory extrapolation techniques. The target allocation procedure is based on minimax strategy computation in matrix games.

1. Introduction

This research programme has focused on the problem of naval-based air defence systems which must defend against attacks from multiple targets. Technology developments in the field of modular data links may allow the creation of a multi-link communication network to be established between anti-air missiles and the launch platform. The future prospect of such ad hoc networks makes it possible to consider cooperative strategies for missile guidance. Many existing guidance schemes are developed on the basis of one-on-one engagements which are then optimised for many-on-many scenarios (Ge, Tang, Reimann, & Vachtsevanos, 2006; Jang & Tomlin, 2005). A priori allocation rules and natural missile dispersion can allow a salvo of missiles to engage a swarm of targets; however, this does not always avoid some targets leaking through the salvo, whilst other targets may experience overkill.

Cooperative guidance combines a number of guidance technology strands such as:

- Prediction of the target behaviour.
- A mid-course guidance to place the missile in position to acquire and engage the target.
- Allocation/re-allocation processes based on estimated target behaviour and no escape zones.
- Terminal homing guidance to achieve an intercept.

These strands have been and these have been studied as part of the research programme. In the terminal phase, guidance has been achieved by handover to the linear differential game (LDG) guidance law (Shinar & Shima, 2002). Two approaches to missile allocation have been considered (Shin, et al., 2010a). This paper focus on the second one exploiting the no escape zones (NEZ, Isaacs, 1967) defined by a LDG guidance law which either acts to define an allocation before launch (ABL) plan or refine an earlier plan to produce an in-flight allocation (IFA) plan.

One of main challenges in the air defence is unpredictability on future manoeuvres of the oncoming threats. Often, oncoming threats deceive air defence systems by pretending to head to a different direction at the initial stage and changing their course at the late stage. Most of existing guidance algorithms repulsively react to the oncoming threats based on their current motion information. This approach cannot effectively cope with the unpredictability of the oncoming threat manoeuvres. Therefore, this paper aims to address this problem and develop an effective solution.

Despite it is difficult to accurately predict future manoeuvres of the oncoming threat, what is certain is that the threat will either

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fly straight, or turn. Based on this certainty, the potential future trajectories of the threat can be partitioned into a several geometric hypotheses. Under assumption that several missiles can be launched together, this paper develops cooperative allocation and guidance scheme which can intercept the oncoming threats against all these trajectory hypotheses. This approach will allow the proposed scheme to effectively intercept oncoming threats whose manoeuvres are unpredictable.

In Section 2, a statement of the problem is given and the proposed SENEZ concept is described. Then, the proposed target allocation algorithm is detailed in Section 6 after introducing essential concepts used in the target allocation from Sections 3 to 5. Missile guidance, both mid-course and terminal, is discussed in Section 7. The simulation conditions and benchmark allocation policy are addressed at the beginning of Section 8. The simulation results of the SENEZ algorithm from a Simulink 6DOF model are also discussed in Section 9. Finally, Sections 9 and 10 conclude this study and remark on consideration for the exploitation of these cooperative guidance technologies.

2. SENEZ concept

There are occasions when the weapon system policy for defending against oncoming threats involves firing two or more missiles at the same target. Fig. 1 shows an example of such engagements where three missiles are launched against two possible oncoming threats.

Without any action taken, the missiles will naturally disperse en-route to the target, each arriving at the point of homing with a slightly different geometry. In such a case, there will be a significant overlap of the NEZ. In this study, a salvo enhanced no escape zone (SENEZ) concept was introduced to efficiently manage this type of engagement, with the cooperating missiles increasing their chances of at least one missile intercepting the target. Mathematical analysis of engagements involving only two defending missiles and one threat have been also performed (Ganebny, Kumkov, Le Ménec, & Patsko, 2012). SENEZ is an attempt to deal with still more realistic scenarios and more players.

In the naval or ground application, it is often the case that a number of assets may be situated in close vicinity to each other. In this situation, it may be difficult to predict which asset an inbound threat is targeting. In the case of air-to-air engagements, there are various break manoeuvres, which an oncoming threat such as an aircraft or attacking missile could execute to avoid an interceptor. Although it is difficult to predict which guidance algorithm the oncoming threat uses or for which defended asset it heads, it is apparent that the threat will either fly straight or turn. Based on this obvious fact, it is possible to partition possible future trajectory of the threat into a small number of bundles. For example, if the oncoming threat is predicted mostly to fly straight, its predicted future trajectory can partitioned into a front sector; if mostly to turn left, into a left sector; and if mostly to turn right, then into a right sector. In this study, the number of the trajectory bundles is determined by the number of missiles in the salvo. Fig. 2 illustrates the partition of possible future paths of the threats for an engagement scenario where the number of missiles in salvos is up to three.

Most of existing guidance algorithms repulsively generate guidance commands based on the current motion information of the oncoming target. However, when there exist a number of defending missiles launched together, a possible effective strategy

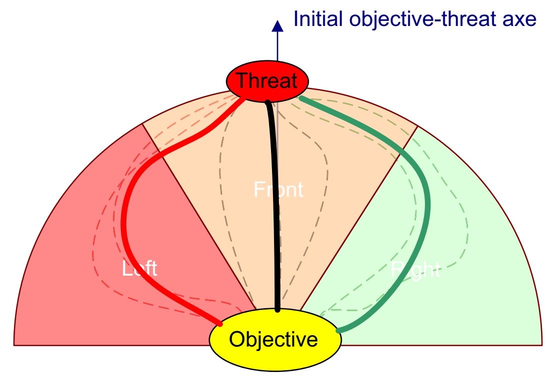

Fig. 2. Trajectory partition into three sectors: the number of missiles in the salvo is three.

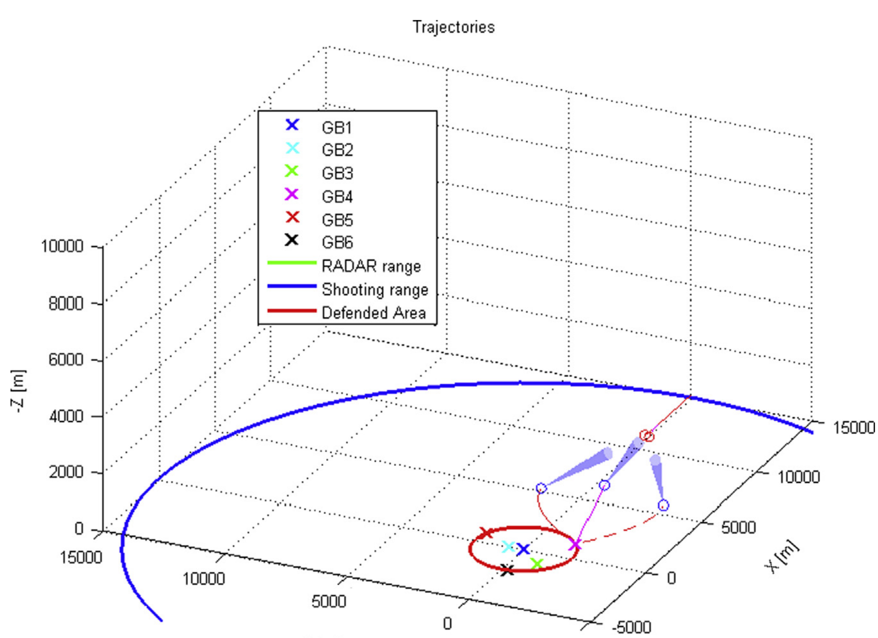

Fig. 1. Multi shoot example in SENEZ firing policy.