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Guided Missile with an Intelligent Agent

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ABSTRACT

Guided missiles involve the use of a conventional deviated pursuit course like proportional navigation algorithm and its variants, which is optimal when the speed advantage of the guided missile is very high and the target maneouvering is minimal. Against the present-day aircraft, which employs fly-by-wire technology for high maneouverability and high speed, missiles need to have a much higher speed advantage or to use a combination of artificial intelligence and modern control algorithms. Results of simulation of pursuit and evasion with an autonomous intelligent agent incorporated in the control loop are presented.

1. INTRODUCTION

Missile evasion by fighter/deep penetration aircraft has been dealt with by many researchers. MacFadzean[1] illustrated that a salvo is necessary to effect kill of an aircraft that has executed an escape maneouver. Ong and Pierson[2] showed that optimal maneouver for an aircraft is to turn towards the missile. The software package available from the Leader, Systems Performance and Effectiveness Section, Weapon Systems Sector, DRA, Farnborough, GU14 6TD, UK, (source: advertisement) helps to simulate missile evasive maneouvers so as to improve the survivability of an aircraft against missile threat. Thus, if N missiles are available on the launchers at any time, no more than $N/3$ or $N/2$ enemy aircraft can be brought down based on the doctrines adopted by different armies. With escalating cost of a missile and the potential damage that an intruding aircraft can cause, there is a need to improve the single shot kill probability of a missile to a certainty. Recent advances in distributed artificial intelligence, such as deploying intelligent agents[3] (IA) hold promise of improving the performance and decreasing the miss-distance (distance between the target and the closest point of approach of the missile) to a small value.

The word agent brings to mind a travel agent, insurance agent, or a bank agent, one who searches among options and makes a suitable offer, negotiates a contract, or offers a needed service matching the price one can pay. Intelligent agents

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are software entities that perform a similar function. They come under the category of distributed artificial intelligence, and are associated with several problem-solving functions. They are characterised by some general attributes like autonomy, social ability, etc. (Table 1), which not surprisingly, reads like the syllabus of a training course for agents. They perform as cooperative problem solvers in a multi-agent environment, or as single autonomous agents. Typically, the functions they perform are negotiation and exchange of information with other agents to solve a problem in a multi-agent context, search through a large collection of data to sift relevant information like a personal assistant, or weigh alternatives and select the best like a manger in a factory. Thus, intelligent agents are considered as software robots.

It makes sense to conceive of multiple agent types in a system. One can have agents for every independent cognitive activity or a reasonably sized domain-specific activity. They may be characterised by their functions, such as interface agents, information agents and task agents[4]. An information agent provides intelligent access to a heterogeneous collection of information sources. An interface agent extracts relevant information and passes it on to the user. A task agent performs the desired task, be it goal-oriented coordination or implementation of an action to achieve the goal. In this paper, the task agent has been referred to as an intelligent agent to distinguish it from other agents by its functions.

Table Some general attributes expected of intelligent agents

Attribute	Function
Autonomy	Ability to operate without direct intervention of humans or others
Social ability	Ability to communicate with humans and other agents
Reactivity	Ability to perceive the environment and respond to changes in it
Pro-activeness	Ability to take initiative and exhibit goal-directed behaviour
Intelligence	Having human-like mentalistic notions of knowledge, beliefs, intentions and obligations
Rationality	Acting to achieve its goals and not preventing its achievement
Selectivity	Ability to focus attention on what it needs and ignoring the rest

2 TRADITIONAL MISSILE GUIDANCE

Constant line of sight (CLOS) or augmented proportional navigation (APN) are the two most popular guidance laws employed in missiles to pursue a target, either in an all-the-way command-guidance-missile or in a missile fitted with terminal homing. In this paper, missiles guided by PN guidance law are considered. The scheme of interconnection of components of the missile is shown in Fig. 1. From the launch to the time when terminal homing takes over, signals from a ground-based radar are received and processed by the receiver unit onboard the missile. The signal environment can be hostile, if jammers are present. The signals include identification code and command signals, commanding the missile to steer towards the target. The receiver unit contains signal processing software. Processed commands are communicated to the onboard computer (OBC). In close range, when the missile's homing unit receives echo from the target, it processes the echo and communicates the commands to the OBC. In the extreme proximity of the target, the radio proximity fuze amplifier communicates signal to the OBC besides triggering the explosive chain in the warhead. The OBC, in addition, constantly monitors the state of sensors like accelerometers, angle-sensors of the control surfaces, dynamic and static pressures, etc, and fusing this information, generates steering control commands and communicates them to the control unit that controls the missile motion. Under most circumstances, the guidance law is adequate to effect a kill. PN algorithm is expressed in the generalised form[5]:

$$\vec{\alpha} = \lambda \vec{L} \times \vec{\omega}$$

where L is normal direction of the command acceleration (latax); $\vec{\omega}$, angular velocity of the line of sight (LOS); and λ is the navigation constant. To account for the maneouvering target, the PN

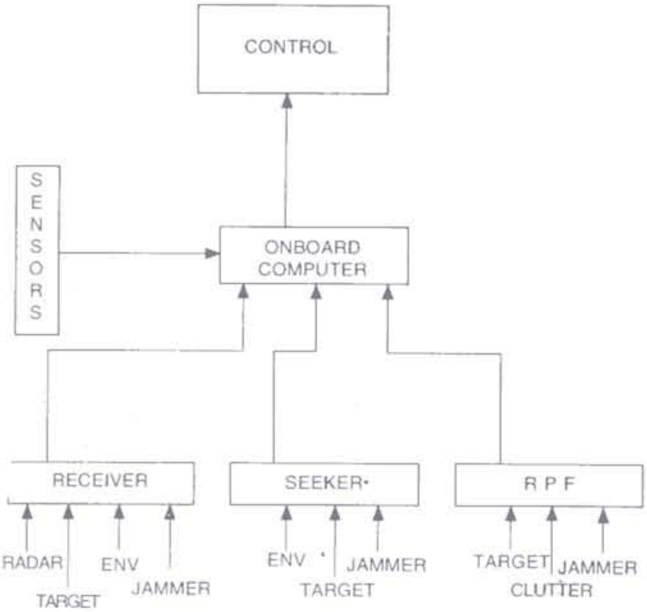

Figure 1. Conventional interconnection of sub-systems in a missile.

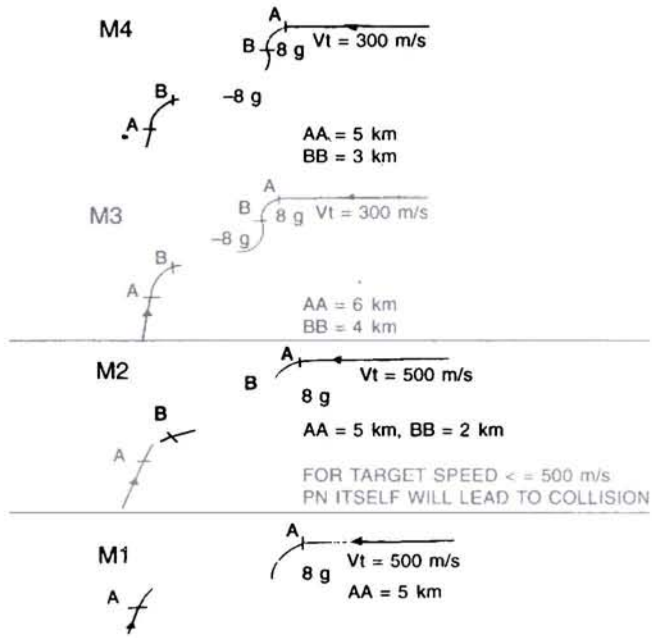

Figure 2. Typical missile-target maneouvers

algorithm is augmented by $\alpha\tau$, the measured acceleration, as given below:

$$\vec{\alpha} = \lambda \vec{L} \times \vec{\omega} + \overline{\alpha\tau}$$

Since APN makes use of extra information, namely, knowledge of target maneouver, the missile is expected to be more efficient with lower demand on acceleration. However, unfavourable conditions exist, which include target maneouvers, saturated axial accelerations, intermittent loss of guidance commands, measurement errors, tracking noise, etc. Serious limitation in performance is noticed when the target makes maneouvers[6]. Typical maneouvers are shown in Fig. 2 and column 2 of Fig 3. For example, in maneouver M3, the target aircraft senses the approaching missile either through its own sensors or through intelligence and makes a maneouver. The maneouver is to turn towards the missile for some period followed by a turn in the opposite direction. With the relative distance between the missile and the target as variable, the missile motion under APN guidance law is simulated; the results are shown in Fig. 2. The maneouver and the miss-distance are shown in columns 2 and 3, respectively.

The results show that in a simulation where complete information (state variables–position coordinates and velocity vectors) is available to both the pursuer and the evader, APN algorithm is not always adequate.

In this paper, emphasis is not on deriving a new guidance law. It is aimed to demonstrate the efficacy of incorporating AI in the form of an autonomous intelligent agent in a missile. The two subjects are dealt with extensively in the references cited.

3. INTELLIGENT AGENT-BASED ARCHITECTURE

To deal with the situation described above, an IA-based architecture is proposed, as shown in Fig. 4. This is a multi-agent system in which each block is equipped with an agent with limited but pertinent information. The IA interacts with the information agents.

The IA continuously interrogates these information agents. Under normal circumstances, the IA allows the OBC to control the missile. When the IA senses a situation (a maneouver) which is known to be beyond the capability of the OBC of the missile, it invokes an expert system, disables the OBC and enables the expert system to take over the control of the missile. In Fig. 4, the library of countermoves consists of several expert systems, relevant to different phases and kinds of missile – aircraft encounters. In the present paper, only one expert system is considered. The time-optimal control of a system is usually of the bang-bang type[7]. In other words, in the state space, trajectory from any initial point to a given terminal point can

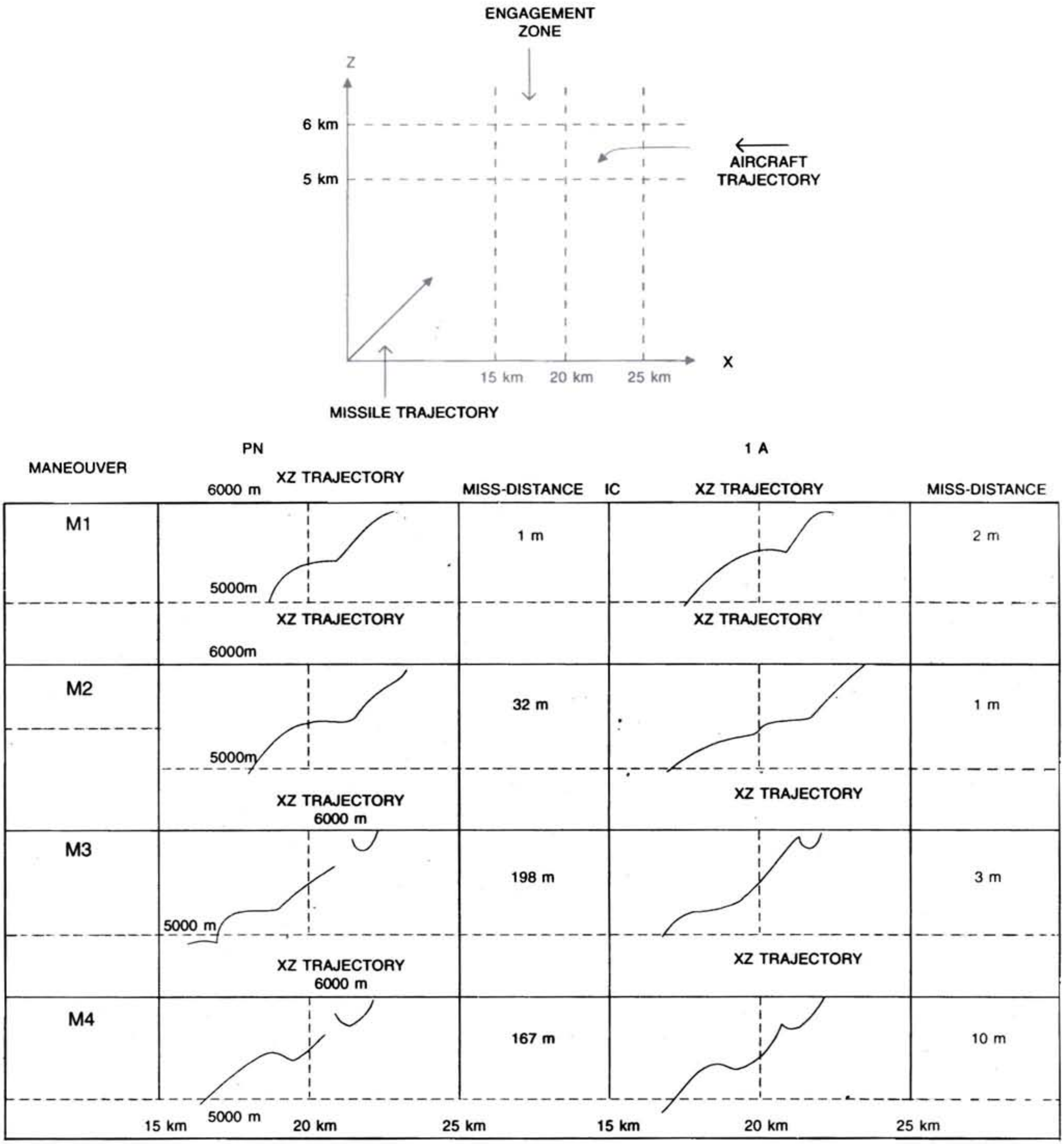

Figure 3. Target and missile trajectories with and without intelligent agent control for different maneouvers in the terminal phase in engagement zone.

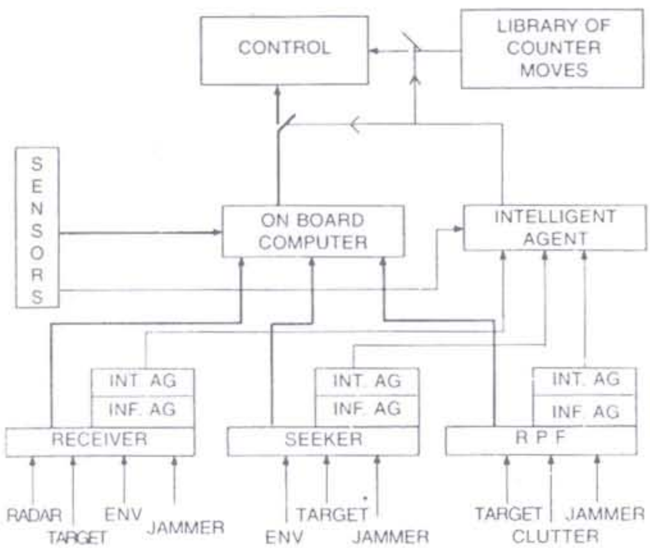

Figure 4. Interconnection of sub-systems in a missile with multiple intelligent agents.

be achieved in the shortest possible time by employing maximum lateral acceleration (Latax) followed by maximum deceleration with the switching time as the determining factor. This principle is invoked to form the rules of the expert system in the present case. The rules are as follows:

Rule

IF The relative range (Rr) between the missile and the target aircraft is less than 2.5 km

THEN No change in the guidance law, i.e., continue APN.

Rule 2

IF 2.5 km < (Rr) < 6 km, and

IF Latax is saturated at one side for more than 1.4 s

THEN Force latax to saturation in opposite direction for 1.6 s, and accept OBC command, and fire Rule 2.

Figure 5 shows the latax demanded on a missile under the APN law, and Fig. 6 shows the latax executed by IA.

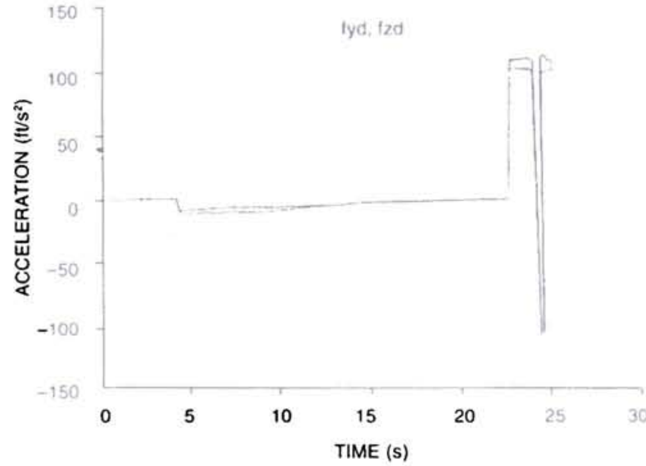

Figure 5. Latax demanded under APN law

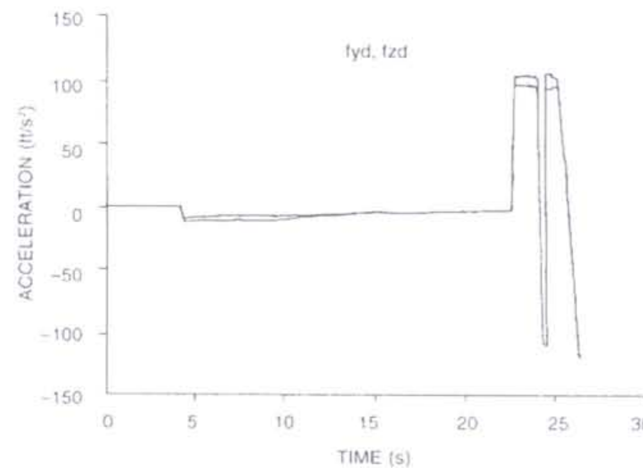

Figure 6. Latax executed by the expert system

4. SIMULATION

Four maneouvers are considered, as shown in Figs 2 and 3. M1 is a maneouver in which the target aircraft turns towards the missile with 8g (maximum limit before the pilot passes out). M2 is a turn towards the missile at 8g, and then goes on in straight flight. M3 is a turn towards missile at 8g and then reverse 8g (pitch down and pitch up maneouver), and M4 is a turn similar to M3 with a different velocity, as shown.

Figure 3 shows the intercept trajectories under APN guidance law and under IA, with the resulting miss-distances in each case.

5. RESULTS & DISCUSSION

The results indicate that in all cases, the IA has successfully handed over control of the missile to counter the evasive maneouver of the target. It has demonstrated the attributes of an IA, such as autonomy, social ability, etc., given in Table 1. In each case, a missile that would have been wasted is given a new life, and a kill is achieved. While evidence weighs in favour of an intelligent agent, software reliability should be ensured in system design. There shall not be any hitch or uncertainty in handing over of control from OBC to an expert system. Fail-safe and/or handshake mechanism must be built-in for smooth and guaranteed transition of control between the OBC and the expert. The simulations are carried out under noise-free conditions. Neither maneouvers nor the expert systems are exhaustive. Further simulations need to be carried out to establish the limits of performance of IA.

Currently, the authors are exploring the possibility of introducing corrections in the PN law using several neural network architectures to be incorporated in the library of countermoves for deciding the appropriate action by the IA.

6. CONCLUSION

Maneouvers and countermoves, like electronic countermeasure (ECM) and electronic counter-countermeasure (ECCM) are perpetual and progress with technology. For example, MacFadzean[1] demonstrated that initiation of a move 2s before intercept avoids collision. However, it is almost impossible to initiate the maneouver at the exact time. Hence, the aircraft commences maneouvers while entering the threat zone both to confuse the fire control and outmaneouver the missile. Based on the limited simulations carried out, it is possible to state that incorporating an IA system onboard a missile will enhance the kill probability to near certainty. One may safely conjecture that if the IA system is incorporated onboard a fighter aircraft, it can also enhance its survivability, and automate release of decoys to confound both missiles and ground radar.

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