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MULTI-AGENT RISK-AWARE TEAMING UNDER UNCERTAINTY (MARTY)

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14. ABSTRACT

Mission operations include a myriad of priorities that are subject to change in the field, of which four are com-monly used by pilots: Signature Management (SM), Optimize Killing (OK), Weapon Engagement Zone Denial (WEZD), and Mutual Support (MS). The scope of this project includes three of these priorities, namely OK, WEZD, and MS in an effort to mature autonomy in these areas for unmanned platforms. Furthermore, the inclusion of uncertainty of sensor reliability, asset location, target location/ strategy, and other factors are a focus of this effort.

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Multi-Agent Risk-aware Teaming under UncertaintY (MARTY)

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1. Background and Motivation

Mission operations include a myriad of priorities that are subject to change in the field, of which four are commonly used by pilots: Signature Management (SM), Optimize Killing (OK), Weapon Engagement Zone Denial (WEZD), and Mutual Support (MS). The scope of this project includes three of these priorities, namely OK, WEZD, and MS in an effort to mature autonomy in these areas for unmanned platforms. Furthermore, the inclusion of uncertainty of sensor reliability, asset location, target location/strategy, and other factors are a focus of this effort.

Air and missile threats in contested airspace represent a challenge for a number of Air Force missions [1]. In concert, some of the tasks include Defensive Counterair (DCA), Offensive Counterair (OCA), Intelligence, Surveillance, and Reconnaissance (ISR), Air Mobility Operations (AMO), Strike, and Interdiction. Although not comprehensive, these tasks are required for achieving air superiority to support and defend enemy or friendly airspace. As defined in JP 3-01 [2], in OCA, enemy Integrated Air Defense Systems (IADS) attempt to destroy, disrupt, or neutralize penetrations of their airspace. This is an attempt to degrade OCA operations. One way to address enemy IADS is through Suppression of Enemy Air Defense (SEAD). SEAD missions neutralize, destroy, or temporarily degrade surface-based enemy Air Defenses (ADs) by destructive or disruptive means.

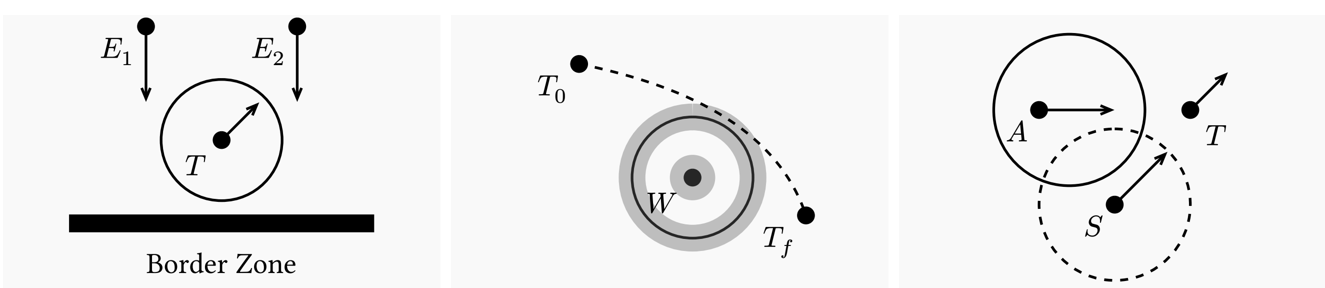
2. Objectives

The objectives of this effort are:

1. Define measures for risk and performance for missions such as the WEZD scenario depicted in Fig. 1(b)
2. Devise robust control strategies for OK, WEZD, and MS scenarios such as the examples in Fig. 1
3. Explore novel team-based strategies which enable mission completion or enhanced performance in adversarial scenarios

3. Description

Previous work has focused strictly on WEZD, i.e., planning paths for vehicle around a known threat so as to keep the vehicle outside of the instantaneous WEZ of the threat throughout its entire trajectory. For example, in [3] a constant speed, constant altitude vehicle sought to reach a target location in minimum time while avoiding the WEZ of a ground-based threat. The WEZ model was based on a cardioid shape which was always oriented



(a) (b) (c)

Fig. 1: Three scenarios that consider mutual support and planning under uncertainty are presented. (a): E_1 and E_2 strive to reach the Border Zone so as to evade capture by the turret T. (b): A target vehicle T starts at a location T_0 and navigates to a final position T_f while avoiding a weapon W whose effective range and location may be uncertain. (c): An Attacker A aims to get his weapon onto the target T, but can only do so when the sensor platform S contains T within its sensor envelope.

towards the vehicle and whose size was a function of the aspect angle of the vehicle in relation to the threat (i.e., its size was largest when the vehicle is heading straight for the threat). A similar problem setup was considered in [4] however the WEZ model was derived from the underlying physics of the engagement. An extension to the case of a vehicle navigating around two WEZs simultaneously was analyzed in [5].

While these works pave the way for a rigorous approach to addressing WEZD in the full information case, they do not directly account for uncertainty. There is a significant need to address real-world implementation issues such as handling environmental factors like wind. For example, in flight tests of the algorithms described in [3] it was observed that, while following the prescribed path plan, it was possible for wind to push the vehicle inside of the WEZ of the threat. The likelihood of such an event occurring is a measure of interest. Beyond that, a more robust path plan or control strategy is desired which directly incorporates some (possibly limited) information on the wind field. Another important category of uncertainty is that of state uncertainty, perhaps in terms of uncertain initial conditions of the ground-based threat. A possible instance to investigate is the threat location having some known distribution, or an unknown distribution with bounds on its first and second central moments, for example. Finally, parametric uncertainty, for example, in terms of adversary capabilities (e.g., maximum range, speed, turn rate, etc.) is an important extension to consider. In any of these cases, it will be necessary to develop and define measures which distill the risk of the proposed trajectory along with the likelihood of success. It is also beneficial to be able to specify thresholds for success associated with these measures and, possibly, to incorporate these thresholds as a constraint.

In addition to WEZD, there is a desire to more rigorously define, quantify, and optimize MS. While WEZD can generally be interpreted as keeping a vehicle outside an adversary's WEZ, the specific meaning of MS is context-dependent and is not nearly as well understood. For example, for a team comprised of an attack vehicle and a sensorcraft, MS may refer to the sensorcraft's ability to provide accurate targeting information to the vehicle when the opportunity to deploy weapons on a target arises. In a more homogenous team setup, MS may be a function of the time required to maneuver to a wingman who is in need of assistance. In the case of a team of vehicles where one of the vehicles is highly valuable and the others are decoys, MS may refer to the team's ability to conceal the identity of the highly valuable vehicle. In a similar scenario where some vehicles are attritable, MS may even refer to having one or more attritable vehicles neutralize a threat in order to improve performance or reduce risk for a wingman.

4. Approach

The method of solution may vary depending on the specific problem formulations and may include (but is not limited to): optimal control, game theory, stochastic optimal control, chance-constrained control, search, Markov decision process, other artificial intelligence methods, and other reinforcement learning methods.

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