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Uncertainty in ALUAS Scenarios

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Abstract

This document presents an Air Launched Unmanned Air System (ALUAS) scenario. The emphasis is on defining the scenario to a level suitable for research in stochastic decision and control. Sources of uncertainty in the scenario are discussed.

1 Nomenclature

ALUAS	air launched UAS	IFF	identification friend or foe
AGL	above ground level	IR	infra-red
AoR	area of responsibility	LOS	line of sight
BDA	battle damage assessment	LS	loitering sensor
CAS	close air support	LW	loitering weapon
CEP	circular error probability	MAV	micro air vehicle
ELINT	electronic signals intelligence	MS	mothership
EO	electro-optical	MD	missed detection
FA	false alarm	Pd	probability of detection
FOV	field of view	RF	radio frequency
GCS	ground control station	RPG	rocket propelled grenade
GSD	ground scale distance	SAV	small air vehicle
GT	ground team	UAS	unmanned air system
ID	identification	UAV	unmanned air vehicle
IED	improvised explosive device	UGS	unattended ground sensor

2 Introduction

This document addresses the concept of air launching smaller vehicles from a larger vehicle or mothership (MS). The first of these concepts is where the larger vehicle carries only loitering weapons (LW). An example of this is Low Cost Autonomous Attack System (LOCAAS)[1]. Multiple vehicles are carried in a canister, which upon release, search for and attack targets autonomously with no operator involvement. Later variations of this concept include Dominator and Weapons Web, which can include an operator viewing video to provide target confirmation.

The second concept is where the mothership or Small Air Vehicle (SAV) carries only Loitering Sensors (LS). The higher flying MS also has sensors and an operator to select objects of interest. Multiple Micro Air Vehicles (MAVs) can be released as required to view numerous objects up close to provide additional evidence of whether the objects are targets. An example of this is Cooperative Operations in UrbaN TERrain (COUNTER)[2] which seeks to have the operator identify targets in a cluttered urban environment.

The third concept, and the one discussed in this document, is Close Air Support (CAS). Here, a high flying mothership carries both loitering weapons and loitering sensors. The mothership patrols an Area of

Responsibility (AoR) looking for targets and responding to service requests from Ground Teams (GTs). The operator views video to identify targets, but can also release control to the GTs. An example of this is a Predator carrying a missile and an air launched UAV[3]

Notional CAS scenarios are described and sources of uncertainty are discussed.

3 Components of CAS Scenario

3.1 Vehicles

The MotherShip (MS) is larger than the SAV. Anywhere from considerably smaller than a Predator up to the size of a Predator. The vehicle should be sized for a 12-24 hour mission and cruise at 100 mph with dash to 150 mph and carry 4 SAVs. It has satellite communications for video feeds to a remote operator. The control station can be in theater or remote. Generally, the MS will fly between 10K feet and 15K feet and fly above the weather. Nominally, the mothership has Electro-Optical/Infra-Red (EO/IR) sensors that have a video Ground Scale Distance (GSD) resolution of 1 foot at 15K feet Above Ground Level (AGL) with narrow Field Of View (FOV). The mothership at 15K feet is undetectable and invulnerable. Decreasing the altitude to decrease GSD or get under the weather will increase the chances of detection and vulnerability. The mothership carrys 2 Loitering Weapons (LW) and 2 Loitering Sensors (LS).

Once released, the Loitering Weapon (LW) flys at 100 mph at 700 feet AGL for 1 hour. It has an EO/IR sensor with GSD of 6 inches at 300 feet AGL. The LW video is Line of Sight (LOS) up to 7 miles to any receiver in range or controlled by a mobile Ground Team (GT) with Ground Control Station (GCS). The loitering weapon has a satellite Iridium command link. The loitering weapon is not recoverable. Default operation is to be flown directly into the target using the out the nose video by the operator with GSD resolution of 1 inch just before contact. Lethality is approximately 20 feet suitable for a standard sized vehicle or 2-3 dismounts, and has a Circular Error Probability (CEP) of 20 feet. At 700 feet AGL the loitering weapon is not easily detectable—at 300 feet it is easily detectable.

The loitering sensor is recoverable. The LS flys at 60 mph at 2000 feet AGL for 3-4 hours. It has an EO/IR sensor with GSD resolution of 6 inches with narrow FOV. It has LOS video up to 20 miles and an Iridium command link. The LS can transmit video to any receiver in LOS range, and also be controlled by a mobile GT with GCS. It is not easily detectable at 3K feet AGL, but is easily detectable at 1K feet AGL. At 1K feet AGL the GSD resolution is 3 inches.

3.2 Ground Team

For this scenario, there can be up to 2 mobile GTs with a Ground Control Station (GCS) in the Area Of Responsibility (AOR). The mobile ground team can be: covertly observing; in a convoy; in contact with the targets; or engaged in hostile operations. The mobile GTs may or may not be coordinating their actions. If not, there may be a conflict in allocation of critical limited resources. For the purposes of this scenario, the resources are fixed. Also, the AOR is 50 miles by 50 miles and the MS initially is somewhere near the perimeter on a search sweep. The mobile ground team will also have weapons and sensors. If they are within 100 meters Line Of Sight (LOS), the GT can provide high confidence discrimination of weapons and individuals with GSD resolution of 1 inch. Note: there may be GTs that can receive video, but do not have a GCS.

3.3 Targets

The class of targets addressed are small teams of 2-6 insurgents. Their weapons include AK-47, Rocket Propelled Grenade (RPG), machine gun, mortar, Improvised Explosive Device (IED), car-bombs, suicide vest, and suicide car. Mobility is by sedan and small trucks. The environment is largely urban where there are significant numbers of people and vehicles. The insurgents and their vehicles are virtually indistinguishable from the indigenous people. There are plenty of places to hide and provide camouflage. Even in less urban areas, concealment is readily accomplished. A GSD resolution of 6 inches is needed for high confidence discrimination of weapons and a GSD resolution of 1 inch is needed for high confidence discrimination of a particular individual.

4 Notional Scenarios

4.1 Setup

Initially the MS is patrolling the AOR. This can be a blind Zamboni search, or a sophisticated probability map that concentrates more effort on certain roads or urban areas. The default mode is the wide FOV sensor with GSD resolution of 2 feet. This should give excellent detection of vehicles and acceptable detection of people, especially if there is motion, good contrast, or a temperature differential. The remote GCS is in command of the MS and video is streamed to the remote sensor operator. There is an automated target cuing system to aid the sensor operator that has an estimated error performance of FA_{c2}, MD_{c2} at GSD resolution of 2 feet. Given an alert, the operator can go to narrow FOV. The sensor operator has an estimated error performance of FA_{o2}, MD_{o2} at GSD resolution of 2 feet, and FA_{o1}, MD_{o1} at GSD of 1 foot.

The operator can take the MS off the search to loiter, but there may be a mission objective to average every t_{hp} hours visiting the higher probability areas and average every t_{lp} hours visiting the lower probability areas. There are only 2 loitering weapons and 2 loitering sensors in scenarios 1-3. When they are launched, no more assets, other than the MS, are available for the duration of the mission. If the loitering weapons are launched early in the 12 hour mission, there will be no assets to attack a high value target if one should appear later in the mission. By the same token, if the loitering sensors were launched early then there will be no assets other than the MS if a later request is made by a mobile ground team. The expected value of the mission should have a penalty for returning to base with the loitering sensors, since more area could have been covered and this would increase the Probability of detection (P_d) of a target. There should also be a penalty for launching weapons that are not used and a high penalty for striking (and killing) non-combatants.

4.2 Scenario 1

There are no mobile ground teams in the AOR to request assets or services. This may or may not be known a priori at the beginning of the mission. In general, there can be up to 2 mobile GTs requesting services over the life of the mission. Little may be known about the expected number of events, and their distribution over the mission time. However, if the mission is repeated periodically in the same AOR, the historical data can be used. This doesn't rule out a high event day. How long do you hold assets in reserve? If 2 medium value targets appear early in the mission, do you attack them? What if a high value target appears later? If a valid target is identified and it is not attacked at that time, there is a rapidly reducing probability as a function of time that the target can be returned to later in the mission. If the vehicles cross the previously discussed detection threshold, then there is virtually no probability of the target being returned to later. Possible target sites to be viewed can be transmitted to the operator from Unmanned Ground Sensors (UGS), which will appear as alerts. The UGS have an historically estimated False Alarm (FA) rate with possible low, medium, and high value targets. The UGS have a historically determined Poisson alert distribution. Also, the loitering sensors can be launched to cover the area quicker or to reduce the revisit time.

4.3 Scenario 2

There is one mobile GT in the scenario requesting services that has a receiver, but not a GCS. The mothership has all assets initially. Two insurgent teams detonate bombs at Police Head Quarters. The two insurgent teams flee in 2 different directions in small pickup trucks as a diversion. Meanwhile a covert mobile GT has observed this activity and requests assets to follow and destroy, if possible. The mobile Ground Team recognizes the fleeing trucks as a diversion, and there is likely a 3rd insurgent team currently hiding that is waiting to attack the 1st responders with RPGs and machine guns. The mobile GT will strike the 3rd

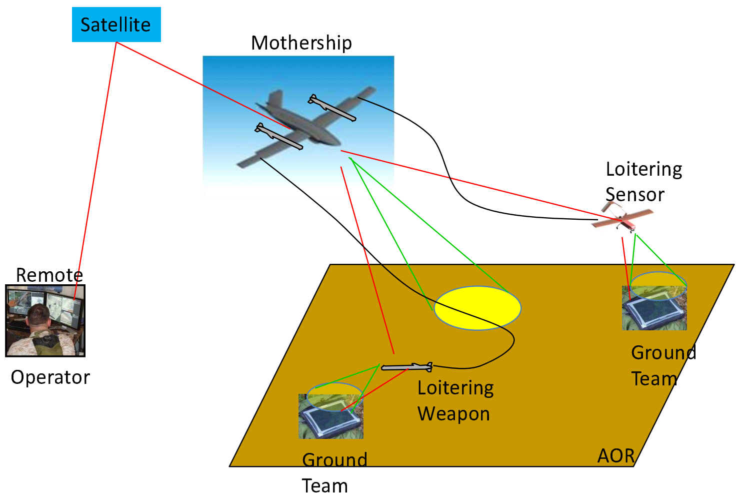

Figure 1: ALUAS Scenario

insurgent team when it shows and requests overwatch to aid detection. Luckily the MS is within sensor range and the operator detects the fleeing vehicles with aid of the mobile GTs organic sensors. Launch the 2 loitering sensors? Launch the 2 loitering weapons? Launch sensors then weapons? Move MS over mobile GT position? Keep 1-2 loitering weapons in reserve for potential aid to mobile GT?

4.4 Scenario 3

Two mobile Ground Teams with GCS are in the AoR, see Figure1. The mothership has all assets initially. The 1st mobile GT is taking fire from insurgents in a dense urban environment. The GT requests the service of a loitering sensor to search for sources of fire. A short time later, the GT requests a service to track, and strike if possible, an attacking vehicle that is now fleeing the area. Sometime later the 2nd mobile GT convoy, which is 30 miles away, has hit an IED and is pinned down. They request control of a loitering weapon to take out a machine gun that is well protected. Sometime later, they request control of a loitering sensor to provide overwatch for the remainder of the convoy trip to it's destination. Should the MS be moved? Should the loitering weapon be sent after the fleeing vehicle? Should the LW be held in reserve? Should control be relinquished to the 2nd mobile GCS team? Should the MS be moved as a relay? Will the 1st mobile GT request more services?

5 Uncertainty

These notional scenarios are rife with uncertainty and unknowns, plus there is limited ability to estimate the probability distribution of events. At base, this is a stochastic dynamic resource allocation problem. The tasks are not overly coupled and do not have tight timing constraints. However, there are limited assets that, once used, cannot be reused. Also, this problem, because of the finite resources, is dominated by expected future value. If assets are expended now to service an event, what if there is a future event? If an asset is used to service a medium value event, what if there is a later much higher valued event (such as a CAS attack request)?

These scenarios are set up with a low degree of coupling with the adversaries. The behavioral assumptions are also very simplistic. This means there is only modest ability to plan for what may happen in the future. Events are responded to as they occur, of course. Myopic approaches may be acceptable because of the lack of statistical information about future events. However, some hedging for the future is advisable. If not, critical events in the future may not be serviced.

One behavioral assumptions is that if a UAV crosses the AGL threshold, it will be detected. One could use a probability as the detection threshold, if there were some data to support it. Also, there is an implied behavior change by the targets if a UAV is detected. This could be: a suppression of target activities; an increase in camouflage to break track lock or hinder high confidence discrimination; or commence decoy activities. The complete list of possible actions is not known. There may be a vulnerability AGL where the UAVs may not be physically attacked, but there may be some RF/IR jamming that could reduce the effectiveness of the UAV sensors, communication, and navigation. There is also the possibility that the ALUAS may be able to track or jam target radio transmissions.

Of particular concern is high confidence discrimination of objects as targets. In general, to discriminate and track a specific vehicle with 95% confidence will require a GSD resolution of 1 foot viewed over 360 degree aspect angles and operator FA$\leq$ .15. To discriminate that an individual is carrying weapons with 95% confidence requires GSD resolution of 6 inches viewed over 360 degree aspect angles and operator FA$\leq$ .1. To discriminate a particular individual with 95% confidence will require a GSD resolution of 1 inch viewed over 360 degree aspect angles and operator FA$\leq$ .07. An operational rule may be that a loitering weapon cannot be used to strike a target until a 95% confidence is obtained, even if this is only obtained at terminal conditions where an emergency abort could still be made. The 95% confidence may be obtained by fusing multiple sensor observations. Another operational rule could be that there must be a 99% confidence that there are no friendlys in the blast zone and a 95% confidence that there are no non-combatants in the blast zone. Also, ELINT, by itself is insufficient evidence to strike an object as a target.

5.1 Sources of uncertainty during a mission:

- There are an unknown number of events. Expected values are estimated from available historical data.
- Target density is unknown. Expected value is estimated from available historical data.
- The number of mobile GTs in AOR may be known, but not which will request services, or when.
- Which specific services that will be requested by the GT is not known, but the suite of possible services that can be requested is known.
- The weather conditions are known, but the conditions can change significantly over the mission (ceiling, rain, sand, wind).
- The detectability of air vehicles as a function of AGL can have significant variance.
- The vulnerability of air vehicles as a function of AGL has a smaller variance.
- The ability of the sensors and the operator to accurately detect and classify targets is a complex function of state, sensor, target, operator, telemetry, noise, and environment.
- A single observation by a sensor/operator generally is not sufficient to achieve a $P(O = T) > .8$.
- It is difficult to estimate the sensor/operator error rate (FA/MD).
- The lethality of a loitering weapon can have appreciable variance.
- A kill cannot be registered until a BDA is done (95% at GSD of 1 inch, 90% at GSD of 3 inches, 85% at GSD of 6 inches, 80% at GSD of 1 foot).
- Once control of an asset is transferred, it is not known if it will be returned.
- Generally, the ground component provides the highest confirmation of correct kill.

- Generally, an IFF beacon is the best measure to prevent friendly fire.
- The desired AGL and trajectories may not be available due to other constraints.
- Some tracking tasks may require 2 simultaneous sensors on target.
- CAS interdiction may have override priority.
- Targets may or may not be emitting detectable and classifiable signals.
- The expected mission value of launching a vehicle has a large variance.
- There may be unexpected behaviors by targets if UAVs are detected.

6 Adversary Issues

- The definition of possible actions is needed to define a game.
- The probability of taking actions is needed to define a behavioral model.
- If a UAV is detected, what actions will the adversary take: cease activities, flee, hide, camouflage, decoy?
- Will the adversary use RF/IR interference to reduce the effectiveness of sensor discrimination, communication, or navigation?
- Will the adversary spoof signals used for RF tracking & discrimination?
- A behavioral model will have modelling error, the effects of which are not known.

7 Notional Mission Parameters

- There are no additional assets available in the AoR during the mission.
- There can be no friendlys in the blast area.
- There can be no non-combatants in the blast area.
- Target discrimination quality is primarily a function of GSD resolution.
- The video transmission has a restricted range where the LW range is less than the LS range.
- The LW attack must be aborted if the attack criteria is not met.
- A Ground Team that is under attack has priority.

8 Possible Actions

- MS (search, move to xyz, change FOV, launch LW/LS, loiter, observe target, relay LM/LS/GT video, cue, track)
- LW (search, move to xyz, observe target, loiter, attack, cue, track)
- LS (search, move to xyz, observe target, loiter, BDA, cue, track)
- GT (ID target, observe target, track target, attack/defend, request overwatch, request attack target, request observe target, request track target, perform BDA, request BDA, request control LW/LS)

- Remote Operator (initiate search, loiter, move to xyz, change FOV, steer camera, set track, set point, ID in cued MS/LW/LS wide FOV, ID in MS/LW/LS narrow FOV, release LS to expand search, change default altitude, release LW to attack target, authorize release LW/LS, authorize attack target, deny request from GT, respond to requests that assets not available or available at t_1, initiate BDA, override BDA, confirm kill, observe and ID from GT video, receive ID from GT, move to track, move to relay, release control of LW/LS to GT, receive control back of LW/LS from GT, observe 1-7 video streams, request video from GT, send video from MS/LW/LS to GT, abort attack)

9 Observations

- The key performance capability is the operator detection of targets from video.
- An important consideration is deciding when to hold assets in reserve to enable servicing future requests.
- Adversary models are used to increase expected mission value, but the inevitable modelling error could result in significantly degraded realized mission value.
- A rigorous treatment of uncertainty will likely result in a computationally intractable model.
- There are an infinite number of heuristics, whose optimality is unknown, to address intractability.

10 Investment Areas

- Improvements in the man-machine interface, video quality, and cuing are needed to enhance operator detection performance.
- Development of operator/sensor error models are needed to address uncertainty in stochastic decision and control.
- Highly automated team decision making is essential to achieve a significant increase in the vehicle/operator ratio.
- Simulation, testing, and accumulation of historical data is needed to generate essential probability distributions for stochastic decision and control.

11 Summary

A close air support scenario has been presented as a benchmark problem to support the development of stochastic decision and control algorithms. This is a high level definition that would need to be refined further to completely specify the problem.

The specific numbers that are given as a function of GSC or AGL are notional, used strictly for the purposes of illustration, and are not to be construed as representing actual performance metrics. The scenario definition is generic, intended to define a benchmark problem suitable for stochastic decision and control research.

References

[1] Low Cost Autonomous Attack System, http://en.wikipedia.org/wiki/LOCAAS

[2] Gross D, Rasmussen S, Chandler PR, Feitshans G. "Cooperative Operations in UrbaN TERrain (COUNTER)," *2006 SPIE Defense & Security Symposium*, Orlando, FL, 17-21 April 2006.

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