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THE UAV STRIKE PACKAGE: HOW DO THEY TEAM?

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Huge strides are being made in bringing autonomous control to UAVs, but what are the next major hurdles to overcome? What attributes are still missing from the UAVs that will keep them from being a ubiquitous battlefield presence? What has to be done to sate the need for future Multi-UAV strike packages? This paper looks at the two areas necessary for single and especially multi-UAV systems: performing situational assessment and dealing with tightly coupled tasks. Although at the surface, the two areas seem completely unrelated, dig deeper and one will find that they are co-dependent to the point that one cannot be worked on without influencing the other. Although it's obvious to the casual observer in the UAV community that these are huge problems, the nuances of the challenges are not obvious. This paper starts shedding light on these challenges. Unfortunately, these areas are so overwhelming that it is our intent only to shed light on the difficulties faced and our way forward, not to provide solutions to the problems – though, understanding is the first step to solving.

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The UAV Strike Package: How do they team?

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Abstract

Huge strides are being made in bringing autonomous control to UAVs, but what are the next major hurdles to overcome? What attributes are still missing from the UAVs that will keep them from being an ubiquitous battlefield presence? What has to be done to sate the need for future Multi-UAV strike packages? This paper looks at the two areas necessary for single and especially multi-UAV systems: performing situational assessment and dealing with tightly coupled tasks. Although at the surface the two areas seem completely unrelated, dig deeper and one will find that they are co-dependent to the point that one cannot be worked on without influencing the other. Although it's obvious to the casual observer in the UAV community that these are huge problems, the nuances of the challenges are not obvious. This paper starts shedding light on these challenges. Unfortunately, these areas are so overwhelming that it is our intent only to shed light on the difficulties faced and our way forward, not to provide solutions to the problems - though, understanding is the first step to solving.

Introduction

Becoming a team leader is a difficult process. As anyone in management knows,

it is very difficult to keep a team working towards the same end goal. As one person

misses a deadline for a piece of the project, the rest of the team falls behind waiting for

the missing piece to be completed. As UAVs become more team oriented, they face the

1

same problem. Often, a successful mission depends on a set of sub-goals to be completed in a specific order. Essentially, we are asking these UAVs to become team members and to work closely together. Initially, the tasks that UAVs are/will be doing are fairly independent of each other, or de-coupled. As UAV prove their worth and become more trusted, they will be asked to execute increasingly coordinated tasks.

Coordination

> n 1: the skillful and effective interaction of movements [ant: incoordination] 2: the regulation of diverse elements into an integrated and harmonious operation 3: the grammatical relation of two constituents having the same grammatical form *Word Net ® 1.6, © 1997 Princeton University*

In my own words, coordinated tasks are tasks that are dependent upon each other for their completion. In the multi-UAV community, a distinction is often drawn between coordinated, cooperative, and collaborative. Unfortunately to make head or tails out of this paper, it necessary to briefly describe each of these terms, knowing a priori that no universally accepted definition exists. I consider that coordination is done in a pre-mission plan. It is making sure at the beginning that all the pieces are aligned and fit together. As the definition above states, it is the integrating of operations. If everything goes as planned, coordination is all that would ever be needed. Because of Murphy, i.e. Murphy's Law, nothing ever seems to go as planned; therefore, we need a way of re-coordinating plans.

Collaboration

n 1: act of working jointly: "they worked either in collaboration or independently" [syn: coaction] 2: act of cooperating traitorously with an enemy [syn: quislingism] *Word Net ® 1.6, © 1997* Princeton *University*

Collaboration is keeping coordinated on loosely dependent or coupled tasks. It is the act of re-coordinating plans that is loosely tied together. I keep mentioning the idea of loosely coupled because a different level of interaction needs to take place if the plans are tightly coupled. Two people planning on attending the same conference would be a loose coupling. Generally, while they have the same end goal, it does not matter how they get there, where they are staying, or even what time they arrive. On the other hand, two people moving a couch through a doorway is a tight coupling. What one does directly effects the actions of the other person. Presenting papers at a conference is also an example of collaboration. While the audience has a general idea of my research, they probably would have a difficult time producing products that are 100% compatible with my work. In the UAV community, having two UAVs flying in deconflicted airspace would be collaborative. Given that if one of the UAVs penetrates the other's airspace, both UAVs notify each other and react appropriately.

Cooperation

n 1: joint operation or action: "their cooperation with us was essential for the success of our mission" [ant: competition] 2: the practice of cooperating: "economic cooperation"; "they agreed on a policy of cooperation" *Word Net ® 1.6, © 1997* Princeton *University*

Cooperation is maintaining the coordination of tightly coupled tasks, i.e. re-coordinating tightly coupled tasks. A software development team on a highly integrated piece of software requires a great amount cooperation. Each member needs to have a fairly detailed understanding of what other team members are doing. If nothing else, each team member needs to have an understanding of the big picture and how all of the pieces fit together. A multi-ship strike can often be a tightly coupled task that requires cooperation. If one item/member's schedule slips, it can directly affect the rest of the package. The following quote provides an excellent transition into the rest of the paper, "Coordination is managing dependencies between activities. ... Similarly, even though words like 'cooperation,' 'collaboration,' and 'competition' each have their own connotations, an important part of each of them involves managing dependencies between activities." [1]

Management of a Team

Management of closely coupled tasks is often an art. Program management with several team members is a good example of closely coupled tasks. It is often a fine balance between trusting one's subordinates, being skeptical of their ability to complete the tasks, and hedging one's bets against unforeseen events. Often managers go into a program with minimal status reporting; and as time goes on, the manager gives more attention to the team members that need it. Also the tasks that are most critical to the program's success or have the least slack tend to get the most oversight. Furthermore, the team members most able to complete the tasks or that have the best track record get the most important tasks. For new program managers, one of the hardest things to do is to delegate responsibilities and not micro-manage the team members. A major problem

4

with program management is that one has to make decisions without all the information. It requires them to predict what will happen from several key data points. To fall back on my controls background, they have to develop dynamic models of the program and the team members. As new data points are received, the managers have to update their models. As actions become more important or erratic, the manager needs to have better models, and thus, asks for more timely data. Most of these concepts are directly applicable to the multi-vehicle strike problem.

Closely Coupled Tasks

The following is an example of a UAV Strike that involves closely coupled tasks:

Tightly coupled tasks are tasks that have strong dependencies on other tasks; these dependencies can include spatial constraints, temporal constraints, ordered sequences, and multiple vehicles per task. The following section deals with the generic reactive suppression of enemy air defenses (SEAD) scenario to demonstrate tightly coupled tasks. It contains the following tasks: search, decoy, identify, locate, and attack. Assume for this example that four UAVs are available. Tightly coupled tasks require close cooperation. In this example, UAV1 runs a decoy pattern to activate the enemy radars while UAV2 and UAV3 are laying low trying to identify and locate the sources. UAV4 is positioning itself for the kill. The location and identification scheme takes three UAVs in specific spatial relation. This is an example of tight coupling between UAVs 1, 2, and 3. The decoy pattern that UAV1 flies directly affects the flight paths of UAVs 2 and 3. While at the same time, UAVs 2 and 3 are trying to avoid detection and therefore constrain the types of patterns UAV1 can fly. Furthermore, hypothetically, the types of weapons carried require the bombs to hit within several seconds of each other. As we progress down the scenario, let us assume that a site is located and identified. It is a type of target that requires two UAVs to simultaneously attack it. Now, UAV4 and either UAVs 1, 2, or 3 must join in on the attack. UAV2 was chosen. UAV2 and UAV4 now have to coordinate their time of arrivals, spatial position, and attack axes so that the bombs will arrive within several seconds and that neither UAV is in the blast area. This demonstrates a tight coupling not only spatially but also temporally. Furthermore, it requires both UAVs to estimate time of arrivals and flight paths to achieve them. To further complicate matters, one can add pop up threats that cause perturbations of the trajectories,

causing the UAVs to rethink task assignments, times of arrival, and attack axes. [2]

As one can see, the tasks of a UAV strike mission can be highly co-dependent. Though, this co-dependence can be handled and organized through a pre-mission plan. The need for cooperation arises from the occurrence of unplanned events. Such events can include the emergence of pop-up/unknown threats, vehicle failures, loss of vehicles, weather, and changes in location of targets. Each of these events can cause the original plan to change; the timing in the plan and the target assignments might no longer be valid. Furthermore as the tasks get more tightly coupled, the human controller has a more complex re-plan to accomplish in possibly less time. This forces the vehicles to have some of the intelligence aboard the aircraft to be able to re-plan. With the possibility for loss of communications to the ground station, the vehicle needs to have the ability to autonomously react to events. Moving back to closely coupled tasks, the strike package needs to understand the cause-effect relationship between the tasks. For instance, UAV1 might have to take a picture of the target 1 minute before the striker, UAV2, releases weapons to allow the image processing enough time to verify the target. Whatever happens, UAV1 needs to be in picture range of the target 1 minute before UAV2's Time on Target (TOT). If something happens, for instance UAV1 is delayed by navigating around a pop-up threat, it needs to know how it is effecting the mission and possibly swap tasks with another UAV so that the picture can still be taken 1 minute before the strike. In swapping tasks, the UAV1 needs to be able to determine which tasks

are feasible and eligible for swapping. This leads to the next topic of worldview or situational awareness.

Package Situational Awareness

Whether the package has a central UAV controller or the leader function is distributed[3,4], the UAVs need to know information about each other, the package goals, and the battlefield environment. This information is the magic ether that helps keep them coordinated. It allows the UAVs to know when things are not going according to plan. In controls terminology, it is the state information of each of the UAVs and the environment. Compared to the amount of data that is required to maintain this information or worldview, the commands to coordinate vehicles require a relatively small amount of data. In fact, if each vehicle perfectly knows all the information about the other vehicles and the environment, direct coordination would not be needed because the actions of the other UAVs could be implied. This type of implicit coordination is the by-product of running the same algorithms on each vehicle. If one has the same algorithms and the same data, they would get the same answer. Thus each UAV is able to predict what the other UAVs are going to do. Unfortunately, this omnipotence is impossible to maintain. Due to communication failures and high bandwidth requirements, this kind of shared knowledge is unrealistic. A core sub-set of this information, though, will have to be shared to keep all the UAVs on the same page. The size and type of this core knowledge is task dependent[5]. For example, two vehicles flying in formation only require knowledge of each other's position, velocities, and next waypoint; whereas, two vehicles coordinating an attack need to know each other's time of arrival, approach angle,

7

and departure angle. In the previous example, while the two vehicles in the attack needed to know this information, the other vehicles could have cared less about these details. Also pulling from the example of the program manager in the team management section, as the UAV falls further behind in his task, the package has to require more state details on the UAV. This could include health, current position, fuel, and time of task completion. If one of the parameters is out of line, the package will have to reassign the tasks.

Linking Closely Coupled Tasks and Situational Awareness

To continue the previous discussion, increased dependence between the tasks can cause an increase in the amount of information shared. In loosely coupled tasks, the tolerances between the tasks are larger. This gives the UAVs more flexibility in the coordination, and thus, the worldview or state information does not need to be as accurate. For example, if someone is driving down an empty four-lane highway, they do not have to be as careful about staying in their lane. In fact, they do not have to know exactly where their lane is. But when the highway becomes very congested, the person now has to pay careful attention to staying in his or her lane while watching what the other cars are doing. The same is true with UAVs. If each UAV is given a 10-mile wide "highway" or corridor to itself, it does need to know where the other UAVs are except if they enter its corridor. As we move from corridor or unrelated flight into formation, the amount of information greatly increases. Formation flight is often considered a tightly coupled task. As stated above, formation flight requires sharing position, velocities, and the next waypoint or accelerations. The closer the formation the faster update rates need to be in order to prevent collision. The same holds with multiple UAVs attacking targets.

8

Overcoming the Bandwidth Problem

As the tasks become more tightly coupled and the number of UAVs per package increases, bandwidth becomes more and more of a concern. Though, if we look at the issues of cooperative strike, we notice that it is made up of a bunch of small tasks that lead to successful execution of the overall goal. Again, this is very similar to program management. While a program manager often has to request status reports from the subordinates, UAVs do not have this same problem. If the UAVs have a relative good idea of the overall plan and how their task affects it, they can update the manager or package when appropriate. Moving from what is called a pull, manager asking, system to a push, subordinate reports, system can greatly save bandwidth[6]. It is very important that UAVs only push relevant data to the appropriate UAVs; otherwise, it is very easy to saturate the datalinks with garbage. Now the challenge becomes determining what is relevant to other UAVs. Hopefully, the importance of the group situational awareness is becoming clear. Also, analyzing the coupling between tightly coupled tasks helps in answering the questions of who needs to know what and when. The following example demonstrates the advantages of the push communications system. Assuming all UAVs know the mission plan and task relationships, the UAVs can send updates only when things deviate from the plan instead of sending updates on regular time intervals. For instance, if UAV1 is supposed to arrive at (X,Y,Z) at time T and a pop-up threat is detected at (X,Y,Z), UAV1 can determine the impact to the mission of not being at (X,Y,Z) and also who else the threat might effect. Then, UAV1 can communicate this information to the proper other UAVs. This also reduces the requirements upon each UAV to look at all the information and determine what is relevant to his mission, which

reduces data processing requirements. Again, the key to making this work is to determine relevancy. Unfortunately, determining relevancy is not as simple as presented above. Even storing task dependencies is not all that simple. Finally, getting a computer to understand the big picture and how it fits in is an artificial intelligence problem that has yet to be solved. Though, great strides are being made in this area.

Conclusion

As one can see, tightly coupled tasks and package situational awareness are tightly woven together. When one adds in the bandwidth limitations and new message protocols, the two become even more interdependent. As a community, it is important to start agreeing on a set of definitions. This paper did not even scratch the surface in that direction. The definitions in this paper were to lend understanding of the terminology used in this paper. As the UAVs become more trustworthy and capable, they will have to start tackling some of the challenges stated here. Even though the research has not been applied to robotics yet, lots of operational research has been devoted to humans executing tightly coupled tasks as program managers and as product teams. It is my position that items such as communications skills and progress monitoring can be applied to the UAV environment.

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