Using Swarming Robotics and Advanced Teaming to Address the Tactical Challenges of Urban Reconnaissance

ABSTRACT

Several DoD projects, either emerging or already underway with DARPA, DTRA, and the Army itself, are exploring the military utility of using Swarming Robotic and Autonomous systems to conduct urban reconnaissance in a manned-unmanned Advanced Teaming relationship. The key to advanced capability lies in collaborative autonomy between machines and humans, pushed down to the lowest tactical levels, i.e., Squads and Platoons. However, any useful study and demonstration of a complex task like this must first begin with properly bounding the scope and nature of the tactical challenge we are attempting to solve. Do we understand the basic task and its fundamental sub components? Have we prioritized the underpinning technologies to give us collaborate autonomy? Do we understand how the complexities of urban terrain complicate the nature of the task? Engineers must have insights into the key tactical tasks associated with the specific mission, their nuances, and the expected tactical behaviors of participating unmanned system co-combatants. JHNA proposes insight to this issue from the Users' perspective.

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The U.S. Department of Defense continues to explore the military utility of using Swarming Robotic and Autonomous Systems (RAS) to conduct many critical missions. Among the most challenging is the requirement to conduct reconnaissance of an urban area. The primary center of gravity for the utility of such an advanced capability lies in demonstrating collaborative autonomy between machines and humans, but only if DoD can develop the ability to employ these systems down at the lowest tactical levels, i.e. Squads and Platoons. It is challenging enough for humans to conduct military operations in urban terrain, much less design autonomous systems to operate in the same setting. To properly develop the kinds of small tactical autonomous robotic solutions that will be useful in future urban combat, three distinct actions should take place***. First, engineers must have insights into the key tactical tasks associated with the specific mission, their nuances, and the expected tactical behaviors of participating unmanned system co-combatants. Second, Advanced Teaming with unmanned systems is emerging as relevant. Therefore, the government User, S&T and developer communities must cooperatively work solutions that prioritize the tasks associated with a given mission most suitable for Advanced Teaming, (in this case for urban reconnaissance). This, in turn, supports prioritization of technology development, including that associated with collaborative autonomy. And third, industry needs a new lexicon to better communicate with the User community on the sophistication of their technology's capability, similar to DoD Technology Readiness Levels, and the implications of that technology on the User co-combatant. Current engineering lexicon is Autonomous Levels For Unmanned Systems (ALFUS). JHNA proposes the development of Operational-ALFUS. This paper will focus on the first discussion, and only touch briefly on the second two.***

Scoping the Problem

The first step in any detailed analysis of this challenge must be in acknowledging the enormity of the problem set. Warfare in the 21st century includes a variety of complexities of a world populated by enemies that have adapted to offset U.S. strengths. We can predict this. However, as compound, complex and hybrid threats evolve, the likelihood they will retreat into megacities that look less like the Baghdad of 2007 and more like the dystopian future Los Angeles depicted in *Blade Runner,* means there will be physical engineering and operational

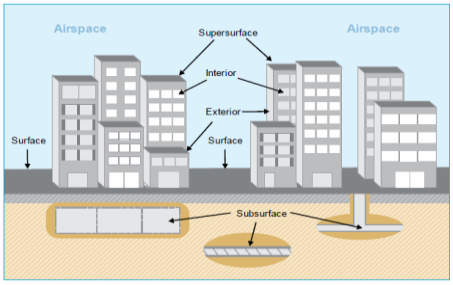

Figure 1. An urban scenario presents complex terrain challenges for control of both man and machine

challenges we have yet to envision. Increasing urban populations are certain, and this will compound problems related to increasingly more complex urban terrain and the requirement to avoid unwanted collateral damage. Nevertheless, the U.S. Army still intends to conduct combined arms maneuver. Using available assets and employing cross-domain capabilities, the Army will engage in close combat on the surface, subsurface, and supersurfaces within these urban settings. Maneuver formations must be able to reliably locate, displace or destroy enemy forces and weapon systems despite the enemy's use of noncombatants and dense urban environment for concealment.

Additionally, complex urban terrain will still compel maneuver forces to slow down, communications may be spotty, and situational awareness will be less developed. Within the short linear distances common in urban environments, commanders commonly lose line of sight communications with their subordinate, small tactical units. Higher headquarters have a limited capability to provide useful threat information. The fixes for these problems must be done locally.

Because of these common challenges, the utility of RAS systems capable of operating in swarms for urban reconnaissance, occupies a critical place in the desired future capabilities of the U.S. Army. Unfortunately, current simple manned-unmanned teaming (MUM-T) concepts are not elegant enough to properly articulate how future autonomous swarms will operate among themselves and with their human teammates. Consequently, the Army is pursuing the notion of “Advanced Teaming” to further develop a doctrine and dogma that will prove useful.

The Analytical Challenge

If the development of an Advanced Teaming capability with RAS platform technologies is essential to success in future urban warfare, we must begin with a process that will permit effective analysis. We must be able to properly decompose mission-to-task-to-desired autonomous and swarming robotic behaviors. This has not yet happened. Simply put, to date there is a general lack of investigation into specific militarily relevant operational tasks most suitable for Advanced Teaming and its underpinning technologies. Advanced Teaming concepts and their required technologies are complex and not universally understood amongst the government stakeholders. The excuse: it’s too hard, it’s too futuristic, and it means too many varying things to different people. We must first baseline with common terms of reference. Then we must create common understanding of the scope and scale of advanced teaming and its considerations and challenges. We need to develop a repeatable process that investigates and analyzes this problem.

Terminology: Advanced Teaming Requires a Baseline Common Terms of Reference

With Advanced Teaming stakeholders viewing the problem through the different lenses of their Services, DARPA, and industry at large, e.g., we need to start with a common baseline understanding of the terms MUM-T and Advanced Teaming.

While many believe MUM-T and Advanced Teaming are the same, we see them as significantly different. MUM-T is defined in FM 3-04 as "the integrated maneuver of Army Aviation RW and unmanned aircraft systems (UAS) to increase AWT/SWT effects capability capitalizing on UAS sensor, payload, and longevity while increasing survivability to manned systems through standoff and reducing Soldiers required to execute a task." Simply put, it's a manned system paired with an unmanned system. The manned platform gets better standoff, early warning, and increase safety from the threat. The unmanned system can be loaded up with a variety of sensors and effects potentially enabling better reconnaissance and attack.

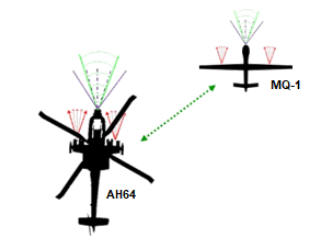

Figure 2. Simple MUM-T is not "Advanced" Teaming

However, there are tradeoffs to gain these advantages. The substitution of an unmanned platform for a manned platform removes a human pilot, which is an asset typically more responsive, intuitive, inquisitive and mentally agile as a system than the unmanned replacement. Plus, in all cases, the addition of a remotely piloted UAV capability adds additional workload on the humans required to operate it, so, this mitigates some of the unmanned systems benefits.

Advanced Teaming (AT) is much more complicated than simple MUM-T, but portends exponentially better benefits. Our view of AT is that it involves a manned system and an entity of multiple unmanned systems with autonomous behaviors, and specific, militarily relevant capabilities. We'll call this entity a swarm. Additionally, we use the word "hive" to indicate from where the unmanned systems in the swarm originate. The hive may not necessarily deploy all its system at one time, but may rotate systems in and out to facilitate endurance, maintain redundancy in capabilities, and facilitate rearming and refueling. The hive has its own comms network, or "Hive Net," with its members and uses software algorithms such as market

Figure 3. Advanced Teaming in an urban setting will be Multi-Domain

based planning to optimally determine which members address a task. A single manned system will have primary command and control responsibility for the swarm, but other interested manned systems may simply have access to the swarm's capabilities. The swarm itself is a team member that is a co-combatant and an integrated package of heterogeneous or homogeneous interoperable, autonomous, and inquisitive systems acting within a single cooperative network to achieve increased awareness, understanding, capability, and military utility. It ultimately should operate and collaborate across domains, environments and Services.

Our last terminology deals with how the engineering community communicates technology readiness of autonomous systems to Users. In Dec 2007 Autonomous Levels for Unmanned Systems (ALFUS) were published in a pseudo-definition manner by engineer working groups from ARL, DHS and the National Institute of Standards and Technology (NIST). This was an important first crack at defining the increasing sophistication of the autonomy in a system. It is quality work, however; it does not easily translate to relevance to military operational language and technology readiness. Industry needs a better system by which to inform Users on the militarily utility of their system and its implications on the unit. Engineers currently use a standards system known as Autonomous Levels for Unmanned Systems (ALFUS), which does not accomplish that need. JHNA is addressing the refinement of ALFUS into a more militarily useful set of terms, or Operational ALFUS, in another effort.

When a user asks what a RAS will do, the above lexicon will help the engineer to communicate with the user. Industry should frame their system's development around not what their system can do, but, rather, what their system can do for the warfighter. Like the common expression, "Our quad-copters can swarm!" We always ask, "Swarm to do what? Help movement? Help shoot the enemy?"

Create a Process to Analyze and Break Down to Identify and Prioritize Advanced Teaming Missions Tasks

The task analysis process is substantial, as is its discussion. In short, we believe it is critically important to establish warfighter task prioritization. And just as important, if we know which tasks are priority, then we can focus on the underpinning technologies. We especially are interested in autonomous behaviors related to accomplishing those tasks. Without task prioritization, how else do we know where to focus investments? Even better, if we effectively catalog tasks and technologies, we can gain an understanding of where a given technology might have multiple applications. The reason this process is important is because, without it, technology development and resource allocation will be less focused and inefficient – a waste of industry IR&D and DoD R&D dollars.

In this section we are presenting a snapshot of a methodology that facilitates task identification. It's an aviation reconnaissance Advanced Teaming task. To begin the analysis,

we identified three foundational and universal vectors. We use these vectors as the axes for a cube, as shown in the figure below. Each cell in the cube, then, becomes a task for analysis.

The first vector consists of established operational tasks. Keeping the tasks at a higher, operational level, ensures that our efforts would be focused on those that are enduring. In this example, we chose aviation operational tasks. The tasks from FM 3-04 and ATP 3-04.1 and are included and listed in Figure 4.

The second vector consists of the Army Warfighting Functions from ADP 3-0 and the Army Universal Task List (AUTL). We substituted the word "Protection" for "Survivability". The other Army Warfighting Functions remained the same.

The final vector consists of teaming arrangements. While recognizing that all physical domains including air, ground, subsurface, super surface, etc. will play a role in joint teaming operations, our example was service specific, focusing on the most common teaming arrangements in Army operations: Ground to Ground (G-G), Air to Air (A-A), Air to Ground (A-G), and Ground to Air (G-A). There's no reason why subsurface, e.g., could not be added.

The vector based decomposition is illustrative of the interrelationship of the components and helps to put the problem into a larger, overarching, context. This nicely frames our process by which one can attack the challenge bite by bite and prioritize efforts, e.g., look at reconnaissance first.

In the FIRST STEP of our process, we've filled out our vectors and placed them in a cube (Figure 4). This looks rather daunting because each individual cell represents a legitimate potential AT task or tasks decomposition for aviation. As we add more tasks, or more potential teaming arrangements, this becomes even more daunting. But, though substantial, this gives us a good representation of the aviation problem.

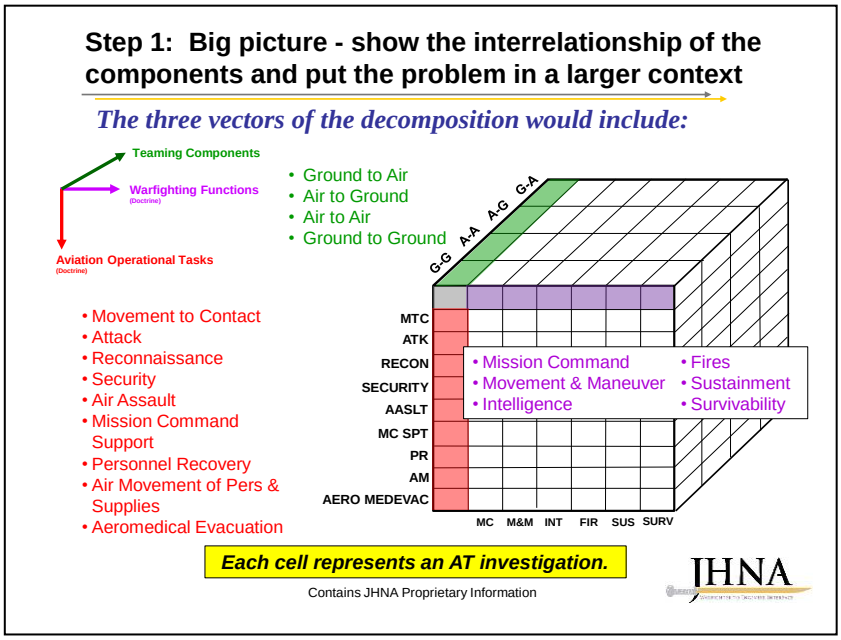

Figure 4

In the SECOND STEP (Figure 5), we now have the obligation to zero in on what we really want to do.

Our recent experience suggests that conducting an area reconnaissance in support of movement and maneuver is important and a priority. Clearly, there are other areas the User community will establish as similarly important.

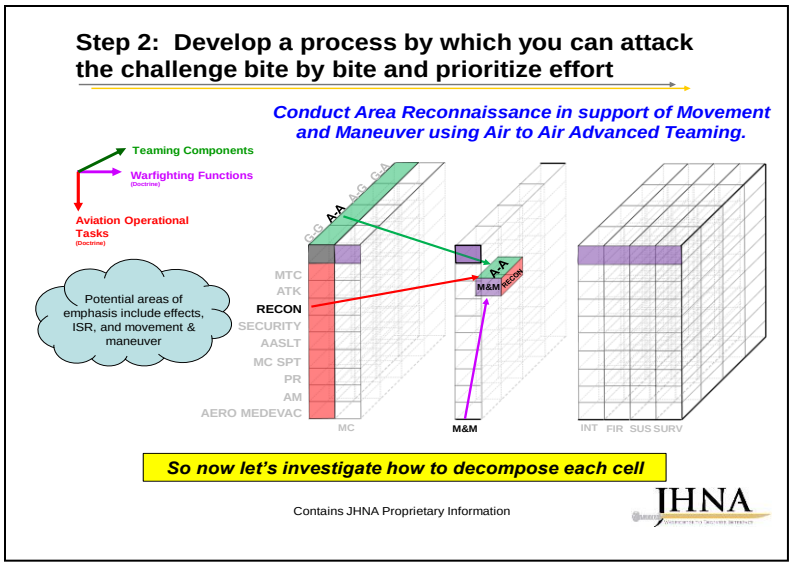

Figure 5

There's a complex third step to the process. It includes identifying and prioritizing the key tasks, and then assessing the key technologies, including those that lead to collaborative autonomy, that enable the tasks. Our experience is that certain technologies will underpin a number of tasks, and therefore investment in those technologies will also get prioritized.

Reconnaissance in an Urban Environment

In the urban fight, much of the discussion comes down to information, and information is gathered through reconnaissance. Reconnaissance is a military mission to develop information about the current status of the elements that can affect a military operation or objective. There are three primary types of reconnaissance: area (including point), route, or zone. Reconnaissance is active; it is an investigation that involves physical movement over, in, or on the terrain for developing and reporting information. Information gathering categories pertain to friendly, enemy, neutral, unknown forces, are wide-ranging, and include, but are not limited to: Personnel; Systems; Equipment; Infrastructure. The partner of reconnaissance is surveillance, which is passive and involves change detection generally looking for a specific area, item, person or activity.

Reconnaissance also develops information on the environment and includes both weather and terrain. The area of responsibility for reconnaissance includes subsurface; surface (street level); supersurface (building level exterior and interior); above supersurface (air).

There are general phases and tasks associated with reconnaissance: Plan & Prepare; Conduct Tactical Movement to Reconnaissance Objective; Conduct Reconnaissance; Report Reconnaissance Information; Conduct Reconnaissance Handover/Change of Mission.

What makes urban reconnaissance tricky for engineers to understand are the nuances in the verbiage, and the tactical behaviors users expect in unmanned systems. In the military

doctrine, words like observe, locate, detect, determine, identify, classify, evaluate, confirm, deny, report, mark, and pinpoint, e.g., all mean something different and specific. Operators want systems that will be inquisitive. These words and their meanings drive specific behaviors in RASs.

Additionally, in orchestrating the events associated with conducting reconnaissance in an urban environment, warfighter use what's known as a battlespace functional area template to help them think through an operation. They bin information and plan a time sequencing of an operation in categories. These categories include: Battle Management or Command and Control; Movement and Maneuver; Fires/Effects/Lethality; Intelligence gathering Processing, Exploitation and Dissemination; Survivability and Force Protection; Sustainment. Each of these major categories have components, e.g., Sustainment includes medical, logistics and personnel considerations. Furthermore, each of them has a relationship to underpinning communications expectations. And often, reconnaissance directly informs and influences these functions.

Example Urban Activities

Advanced teams, and their swarm entities, have innumerable uses. Offensive forces maneuvering in urban terrain face unique challenges that may not be intuitive to industry partners. There are many other key areas where swarms can make a difference. One can therefore envision collaborative swarming assets replacing human tasks, permitting humans to then be re-missioned to focus on those tasks done only, or optimally, by soldiers. Or, swarms can provide general underpinning information or services. We'll list a few here.

In an urban environment, there's a predictable loss of reliable communications. Even within short linear distances, commanders commonly lose line of sight communications with their subordinate, small tactical units. One would expect swarms to support the organization's communication self-healing and retransmission needs.

Higher headquarters typically have a limited capability to accurately depict enemy locations and actions in real time. In urban terrain, loss of situational awareness (SA) occurs quickly. Therefore, swarms could support a localized SA Common Operating Picture. This suggests a need to establish role, rights, privileges and protocols for who can interact with the swarm Net.

Urban operations present greater constraints that further limit freedom of maneuver. Structured streets funnel mechanized forces into channelized axis and blind corners. These paths and locations are usually well-mapped and predictable and thus lend themselves to easy ambush. The concrete canyons formed in the center of most developed metropolitan business districts present three-dimensional engagement areas. In this nightmare environment, mounted forces face top-down attacks and 360-degree threats they cannot detect before the enemy can engage.

A manned maneuver formation, equipped with intelligent and robust swarming capabilities, can commit these collaborative assets to help facilitate the movement of manned maneuver units. Like a cell phone navigation application, swarms can help show less congested movement routes. By congestion, we mean both traffic, trafficability, and the condensed presence of threat forces.

Capitalizing on lower movement signatures, swarms can quietly penetrate enemy defensive zones to perch, dwell, and investigate. Like a dismounted human scout sneaking into position, swarms of numerous small RAS systems can be just as intrusive and inquisitive but present less tactical risk than commitment of a human asset. Note the nature of the tactical behaviors expected of the swarm, including reduced sound decibels, micro-movements to optimally position, and robust sensors.

Swarms can refine their designated search areas to perform more intimate urban reconnaissance in ways that large, manned platforms cannot. Small RAS working as a team, as depicted by the robotic spiders in the movie "Minority Report," can execute micro movements on their own to seek confirmation of more detailed intelligence. For a UAS, the equivalent movement is a window-by-window maneuver of look, assess, report when needed, and move to the next window. Using such techniques, swarms could rapidly cover a multi-story, multi-window facility using methods and efficiencies humans cannot deliver.

Swarms can conduct the reconnaissance to refine planned targets in an urban engagement to restrict collateral damage. Often, threats in an urban defense will locate themselves next to civilians or critical civil infrastructure to complicate friendly targeting and elevate risk of unintended damage to non-military resources. Swarms can assist in the critical steps of target detection, identification, classification, laser designation and terminal guidance. This can assist human fire direction centers in clearing targets for engagement and confirming battle damage assessment after munitions are delivered to the target. All of this can be done without risk to human forward observers who would otherwise have to expose themselves to capture, sniper fire or worse, to gather the same intelligence.

One of the unique challenges to fighting in urban environment is the complex, unobservable terrain that forces commanders to assign combat power to cover. A single city block can consume the strength of an infantry brigade, as it struggles to both clear the terrain of the enemy as well as leave enough forces behind to prevent the enemy from reoccupying the buildings already taken. To mitigate this problem, Advanced Teaming RAS swarms can be used to screen in front of advancing forces, linger to the flanks, or to trail behind their human counterparts to conduct more detailed reconnaissance of complex terrain, previously cleared structures and associated dead space.

Cordon and search operations, essential to ensuring a city is truly clear of the enemy, is another manpower intensive mission. Routes into and out of target areas must be reconnoitered and secured to support troop movement prior to launching the mission. Persistent observation of

these routes, as well as the objectives themselves, then must be sustained. Once on the objective, maneuver formations are dedicated to both inner and outer cordons, while the assault force(s) maneuver on the target(s). These cordons must restrict and otherwise preclude movement into and out of the area being cordoned. This traditionally uses human assets in all tasks to surveil, secure, maneuver, and, finally, to execute the detailed actions on the objective. This is both troop-strength consuming and tedious. Note the two components: cordoning is different that searching. This suggests a swarm with capabilities very advanced that include human movement control, or participation in room clearing operations.

Swarms working cooperatively for sustainment missions can also prove useful. RAS platforms securing main supply routes for medical evacuation can prevent causalities from moving through areas that are still contested. Small tactical units, like Squads and Platoons, who occasionally find themselves cut off and isolated in the urban reconnaissance effort, need no longer fear running out of ammunition or critical medical supplies. Logistics swarms can deliver emergency resupply until the small unit's larger parent organization can affect rescue.

Ultimately, swarms and advanced teaming could play a critical role in urban operations.

Summary

This paper has given a top-level view of Using Swarming Robotics and Advanced Teaming to Address the Tactical Challenges of Urban Reconnaissance. To do that, we had to introduce some lexicon, and it included what we think are definitions of a swarm and Advanced Teaming. The underpinning of Advanced Teaming is autonomy, and the problem of where best to invest research dollars to deliver that supporting technology is very complex. However, it can be broken down into three components. First, we need a process to identify the key tasks associated with reconnaissance in an urban area, and then determine which tasks are appropriate for advanced teaming. Second, we need to understand the technologies associated with the autonomy needed to enable Advanced Teaming. Last, we need a method to prioritize which technologies to pursue that get us the right capabilities earliest and most economically. All three of these topics were covered briefly. However, the focus of this paper was to discuss swarm-enabled reconnaissance in urban operations. Advanced Teaming, with a swarm-capable set of robotic and autonomous systems, promises to positively contribute to this mission.