Civilian Research Project

SMALL ROBOTS WITH STRATEGIC EFFECTS

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Abstract

Emerging technologies in the commercial sector offer an opportunity for an immediate battlefield advantage. Three commercial technology and development segments with the greatest potential for creating strategic outcomes are: unmanned air and ground surveillance systems, augmented reality devices for human-machine teaming, and early education programs in robotics. U.S. dominance as a land power in the next century will be challenged by the ubiquity and low cost of robotic systems, as state, non-state, and hybrid actors leverage these technologies. Our ability to lead the development of human-robot teams, the doctrine and techniques for employment, and the technology skills of the future force, will be critical to maintaining strategic overmatch on the battlefields of the future.

Small Robots with Strategic Effects

Emerging technologies in the commercial sector offer an opportunity to maintain a competitive battlefield advantage, while simultaneously increasing the skill and capability of the soldier for future combat scenarios. Three technology and development segments offering the greatest potential for creating strategic outcomes in the future operating environment are: unmanned air and ground surveillance systems, augmented reality devices for human-machine teaming, and early education programs in robotics.

The growing commercial market for unmanned surveillance systems, such as small quad-copter drones, creates incentives for the rapid increase in the capability of these platforms while the size of the market is also driving down individual unit cost. Augmented reality devices, such as the Microsoft HoloLens, are late arrivals to the commercial sector, but the potential for soldier enhancement and human-machine teaming is exceptionally high. Finally, civilian early education programs, like the FIRST Lego League robotics competition, offer an investment opportunity in the future force through program sponsorship targeted specifically at high-density Army recruiting locations.

The combination of focus on these three technology areas is a chance to leverage the commercial market to increase effectiveness and lethality while continuing to focus Army RDT&E (Research, Development, Test and Evaluation) efforts on long term, more robust, technology platforms. These three focus areas could be immediately employed to provide increased surveillance, mobility, and precision to Army elements in almost any environment.

Are we behind?

A 2013 RAND Study commissioned by the Army G8 to help shape Army modernization efforts, compared select foreign military capabilities to those maintained by the United States. The ultimate result indicated that our overmatch in firepower, protection, and lethality was unlikely to be challenged in the foreseeable future and we should continue to invest in our current block of technologies. However, in the category of unmanned systems, certain foreign militaries had operationally employed capabilities, albeit for niche missions, and advanced beyond US development.

> "The U.S. military has been investing in UASs and unmanned ground vehicles (UGVs) for the last few decades. The fighting in Iraq and Afghanistan dramatically accelerated that trend. While the United States and Israel have been at the forefront of tactical-level UASs, there is a relatively low cost of entry into the unmanned systems market, making it ripe for additional foreign competition. South Korea, for example, has developed an automated sentry that is employed along the Demilitarized Zone (DMZ) with North Korea. Iran and China are also rapidly moving into the UAS market."[1]

The study indicates the constantly assumed US advantage in technology is at risk in relation to unmanned systems that enable a land force. It specifically pinpoints the precarious state of US development in unmanned systems due to the rapid proliferation and development of technology.[2] As noted below, the ubiquity of commercial systems permits numerous state and non-state actors to enter the robotic space with relatively few obstacles. "Generally, basic robotics technology is available, and if modest resources are devoted, it is possible to build competency relatively quickly. The Google Cars experience is a case in point."[3]

The most striking conclusion by RAND on unmanned systems is the observation that other nations and militaries have advantages in the unmanned ground vehicle (UGV) space. This particular area is one that US Army should strive to lead, and directly leverage the operational experience of those nations already employing UGVs. South Korea and Israel are highlighted as nations that enjoy a current advantage because they have operationally employed UGVs, and Japan is specifically mentioned as the world's best in development of human-like bipedal robot systems.[4]

The strategic need

Four significant trends create the conditions that influence the strategic need for these robotic capabilities. First, the upward trend of consumer robotics across the globe, and the general trend of military robot investment by state actors. Second, the leadership of the Department of Defense envisions robotics and human-robot teams as a tool to provide overmatch and offset vulnerabilities against future threats. Third, we are likely to face asymmetric or hybrid threats for the foreseeable future based on an enemy that targets our vulnerabilities versus attempting to match our strengths in firepower and protection. Finally, the environment where these trends will all come together is likely to be densely urban, as the world's population continues to consolidate into cities and megacities.

The External factors – Consumer robots and state actors

Robotics are proliferating in our society. The number of commercial robotic platforms, projected robotic investment, and the corresponding expansion of the robot commercial market are only trending up. The International Federation of Robotics lists 2014 as the largest year for global industrial robotics with more than 200,000 units sold.[5] This represents a 136% increase from total industrial robotics sales just a decade earlier.[6] Private drones, small unmanned aerial vehicles mostly costing less than $300, have sales expectations of $84 million dollars and 250,000 units in 2014.[7] Google is testing driverless cars in Texas and California on public roads, and recently hired a CEO to prepare the technology for the consumer market. These individual data points support the overall upward trend of spending estimates.[8]

The consumer robotics market could generate up to $6.5 billion dollars annually by 2017 and the industrial market appears on pace for $37 billion a year.[9] As a tangible indicator of potential, Google purchased eight key robotics companies in 2013. These companies represented the best in breed of consumer and military robotic applications.[10] The taxi-like service Uber, in a similar move, raided 40 of the best robotic minds from Carnegie Mellon University's staff last year from what was considered the premiere educational robotic institution in America.[11]

The impact of this societal trend and the impact on the military has been well researched. Peter Singer's Wired for War[12] is the definitive review of the concept of automating warfare, but it is also is a significant compilation of trend data. Singer highlights multiple sources, like Microsoft founder Bill Gates, that indicate robotic technologies will rise in a similar fashion to the information and computing technology boom that we experienced in the last 15 years. Christopher Cokers' Waging War without Warriors in 2002 is one of the best early conceptions of the inevitability of the automated future of war. "History is driving the West along a distinctive path, one leading to the dawn of the post-human era. Human beings and machines will evolve together."[13]

These observations are not limited to outliers. The most innovative and conceptual minds of our generation understand the fundamental way this will change our lives. Elon Musk and Stephen Hawking were marquee signatories of an open letter to the world describing the greatest future potential, and possible threat, to humanity as artificial intelligence and the robot arms race. Published by the Future of Life Institute, this letter included a set of priorities for the development of artificial intelligence and other robotic capabilities.[14]"A virtuous cycle takes hold whereby even small improvements in performance are worth large sums of money, prompting greater investments in research. There is now a broad consensus that AI research is progressing steadily, and that its impact on society is likely to increase." The letter continues with an assessment of the future of all types of autonomous systems,

> The establishment of shared theoretical frameworks, combined with the availability of data and processing power, has yielded

> remarkable successes in various component tasks such as speech recognition, image classification, autonomous vehicles, machine translation, legged locomotion, and question-answering systems.[15]

The external influences extend beyond society in general, as other nations and non-state actors move into the robotic space. Russia and China are making no secrets of plans to explore and field military robotics. Russian Deputy Prime Minister Dmitry Rogozin discussed Russian plans to create combat robotics laboratories, “We have to conduct battles without any contact, so that our boys do not die, and for that it is necessary to use war robots.”[16] One Russian military industrial journal openly describes a robot armored company size formation, along with how this unit could be converted with current technology.[17] China specifically, and Asia generally, are moving into military robotics rapidly and decisively. Industry estimates indicate Asian spending on military robotics will increase by 67% over the next three years[18]. China recently displayed advances in UAV technology at the 2013 Paris Air Show with an aircraft very similar to the US MQ-9 Reaper system. Other countries, such as South Korea and Israel, already have operational robotic platforms and possess the capability to feed the global arms market with robotic technology. The RAND study specifically notes that in terms of UGV technology, the US, and specifically the US Army is actually running behind some nations that have fielded and are employing operational UGV systems.[19] ISIL’s use of cheap quad-copter UAV’s during the battle of Kobani, Syria[20], highlighted in greater detail below, illustrates how the simplicity, ubiquity, and low cost of these platforms allow use by non-state actors. As the consumer market expands, more options for asymmetric use of automated systems become available as individuals and groups use these capabilities for purposes not originally intended.

The US military vision

The inevitability that robotics will integrate and become part of the fabric of our society is not lost on the leadership of the US Department of Defense (DoD). DoD articulates the vision of future technology in the form of the “third offset strategy”. Deputy Secretary of Defense Robert Work, speaking on 15 Dec 2015, described the five key components of the strategy.[21]

First are the autonomous deep learning systems. Systems used to both analyze big data, and to make decisions in scenarios where human decision-making speed is limited. Air and missile defense scenarios are most often highlighted as opportunities for this type of decision-making technology.

The second component is human-machine collaboration. Although not included in the Deputy Secretary’s speech, Clive Thompson’s *You’re Smarter Than You Think*, and the 2005 story of two chess amateurs best describes the potential of this component. The two chess players paired with a personal computer to assist in decision-making and defeated the world chess champion Garry Kasparov.[22] Human-machine pairing is intended to increase the speed and effectiveness of decisions. Augmented reality technologies, like the Microsoft HoloLens, have the potential to aid in a similar type of teaming that can directly enable land forces to operate complex systems will still maintaining awareness in the physical world.

The third is assisted human operations. Exoskeletons, combat software "apps", and wearable technology are just some of the examples that would be in the bin of assisted human operations.

The fourth focus area is advanced human- machine combat teaming. This area directly relates to the concept of this paper, and the idea that large quantities of small airborne and ground surveillance platforms employed tactically can have a strategic effect. Deputy Secretary Work specifically highlighted the Army's current plan to pair Apache AH-64 attack helicopters with MQ-1 Gray Eagle UAVs as an example of the type of human-machine teaming that is possible.

Finally, DoD intends to develop network-enabled semi- autonomous weapons that are also hardened to function in a complex electronic, cyber, and potentially nuclear environment. This pillar of the offset strategy would not be addressed by this paper's recommendations. DoD needs these types of robust systems, but as we are developing them, the commercially available platforms can increase our ability to understand and master human-robot teaming.

The Army Operating Concept nests under this third offset strategy and specifically addresses technological advances in both the principal document and in the Science and Technology appendix. However, human-machine teaming, the domain that is likely to have the most impact on the strategic land forces of the US, does not feature prominently.

The influence of robotic technology on society and civilization, along with the strategic vision of the US Department of Defense, will combine to create opportunities for the Army. In order to understand how to best seize those opportunities requires an analysis of the future threat.

The future threat

The Army Operating Concept describes a future enemy that avoids US strengths of firepower and precision, uses techniques of dispersion, intermingles with non-combatants, and defends urban complex terrain. This enemy evades US joint combat formations to mitigate our precision air and ground capabilities. This enemy will force a fight in a complex environment, likely urban terrain, where overmatch in the close physical space is key. The hybrid threat definition from TC 7-100 is one of the best to understand the type of force we are likely to confront. “The diverse and dynamic combination of regular forces, irregular forces, and/or criminal elements all unified to achieve mutually benefitting effects.”[23]

In Robert Jones’ article on Future War, he highlights ten trends in the future of warfare. First is the trend of increased potential for irregular warfare in urban areas, while exploiting infrastructural vulnerability. Additionally, any enemy will likely exercise principles of dispersal, in an attempt to stay concealed in urban or remote terrain.

The idea that the urban or remote environments will be a significant part of the future threat, and that the enemy will seek to avoid Joint Force capabilities in firepower and mobility, indicate that specialized capabilities will be needed to defeat this enemy.

Kevin Felix and Fredrick D. Wong explore the concept of war in a Megacity, and they indicate that a key challenge for the warfighter in dense urban environments is gaining and maintaining situational understanding.[24] Precision firepower is exceptionally difficult to employ if you don't know the location of yourself and of the enemy, and extremely complex if you add the three dimensional urban area and non-combatants.

The final significant trend is the consolidation of the global population into urban terrain. Urban conflict is more likely simply because a much higher percentage of humans will live in urban and densely populated space. United Nations and World Health Organization (WHO) data support both an increase in total population, along with an increase in population density.[25] The chart below depicts WHO data on select Middle Eastern and southwest Asian countries that conform to the overall trend. Iran, Iraq, and Syria are all examples of countries that are anticipated to have greater than 70% of their population in urban environments by 2050.

	Population living in urban areas (%)				
Country	2050	2040	2030	2020	2010
Afghanistan	45.3	39.5	34.0	28.9	24.7
Egypt	56.5	51.4	46.7	43.8	43.0
Iran (Islamic Republic of)	83.9	81.9	79.4	75.7	70.6
Iraq	78.0	75.2	72.4	70.2	69.0
Israel	94.5	93.8	93.2	92.5	91.8
Jordan	89.3	88.1	86.6	84.8	82.5
Kuwait	98.8	98.7	98.6	98.4	98.3
Lebanon	91.7	90.7	89.6	88.4	87.2
Oman	86.5	84.8	82.8	79.7	75.2
Pakistan	57.5	52.0	46.6	41.2	36.6
Qatar	99.8	99.8	99.7	99.5	98.7
Saudi Arabia	88.7	87.4	85.9	84.1	82.1
Syrian Arab Republic	71.5	67.8	63.8	59.7	55.7
Tajikistan	41.0	35.4	30.4	27.5	26.5
Turkey	83.7	81.7	79.3	75.7	70.7
Turkmenistan	65.5	61.0	56.4	51.9	48.4
United Arab Emirates	90.8	89.7	88.5	86.8	84.1

Figure 1. World Health Organization population data.[26]

The Opportunity

The intersection of these four trends: the proliferation of cheap simple robotics platforms throughout the world, vision and direction of the "third offset strategy", the consolidation of populations into large urban centers, and threats that prefer to confront us asymmetrically to avoid direct engagement with our joint capabilities, provide an opportunity to leverage the three industry driven and commercially developed capabilities highlighted in the introduction.

Lethal technologies in the asymmetric environment will always be difficult to manage and employ based on the complex decisions required. However, providing the human decision maker with greater understanding and situational awareness, while reducing exposure and risk to force, has the potential increase effectiveness and change strategic outcomes. Some of the simplest and best emerging technologies in the commercial sector help us maintain a competitive advantage by providing the dismounted warfighter with tactical situational awareness and surveillance against a dispersed enemy in an urban area.

This assessment is not unique. Two Chinese scientists at the elite Chinese National University of Defense Technology introduced another observation on the types of missions and platforms that would be key into the future fight:

> Surveillance and counter-surveillance will become the major combat form on the ground battlefield in the future. Equipped with a large number of autonomous unmanned combat vehicles and a variety of small robots, and supported by unmanned logistics support vehicles, the light infantry troops will become the tentacles of the army on the battlefield. They will reach the regions deeply behind the front line occupied by enemy before the fire attack start, and steal into every corner of the battlefield to find all kinds of hidden enemy, to monitor important objects and to provide guidance for fire attack.[27]

US Joint Forces' urban warfare doctrine (JP 3-06), is consistent with the concept that surveillance capability can become strategic in application when operating in an urban environment. The ability to dominate an urban area to ensure strategic success can rely on the ability of numerous small units operating within the city itself. Situational awareness can be the key overmatch capability to attack an enemy that will disperse and intermingle with non-combatants.

The common theme of the criticality of situational awareness is one that can be directly solved with commercially available surveillance platforms.

> Cities may reduce the advantages of the technologically superior force. The physical terrain of some cities may reduce visual LOS [line-of-sight] as well as the ability to observe fires. It may also

> inhibit the command and control (C2) processes, some types of communications reliability, in addition to making aviation operations and airspace deconfliction extremely difficult.[28]

Commercially available systems provide a method to regain the technological advantage by overcoming the reduced line of sight and observation, with the potential to increase command and control processes through increased situational awareness.

Joint doctrine recognizes the critical nature of intelligence and situational understanding in an urban fight at every level, from tactical through strategic. "Intelligence support requirements are different and more demanding in urban areas."[29] Appropriate application of very tactical surveillance tools can lead to strategic outcomes when applied in quantity and scale. This is highlighted in the fundamentals of joint urban operations and in the case of surveillance support to Syrian Kurds fighting against ISIS as indicated below.

> Fundamentals of joint urban ops - Apply highly discriminate, destructive, or disabling force to disrupt an adversary's ability to pursue its objectives. Actively locate and attack enemy elements while minimizing impact on other elements of the urban environment.[30]

These small unmanned tools are exceptional for actively locating, and identifying enemy elements.

The ultimate payoff for a seemingly simple tactical and operational capability is a strategic outcome. This is currently on display in the fight against ISIS in northeastern Syria. Kurdish forces are using small, cheap, easy-to-use quad-copter drones as a surveillance asset to increase the lethality and effectiveness of their military elements[31]

Figure 2. Female Peshmerga fighter waiting on drone, NW Iraq (Sinjar)[32]

The siege of Kobani, Syria offered an opportunity to see the low barrier for entry. The picture (Figure 3.) below from a Twitter user affiliated with Syrian Kurds fighting in northeastern Syria shows how cheaply and simply the types of commercial platforms can be integrated for military purposes.[33] ISIS (Islamic State) elements besieged Syrian Kurds and Arabs in the Syrian city of Kobani from the fall of 2014 through early 2015. During this battle, the Syrian Kurds purchased commercial quad-copter UAVs, like the one pictured below, and used them to fly over the city of Kobani and capture still picture and video images of ISIS positions throughout the town. ISIS, in turn, used it's own drones to show the city of Kobani for propaganda purposes after airstrikes destroyed much of the city.

Figure 3. @macergifford Twitter photo – Syrian Kurd (YPG) Drone[34]

Current US Army Research, Development and Doctrine

There are currently many tactical robotics programs in various states of development throughout the US Army. LTC Robert Cannaday, Science and Technology Branch Chief, Concept Development Division (CDD), Capabilities Development & Integration Directorate (CDID) at the Maneuver Center for Excellence, FBGA, highlighted a recent test exercise conducted at Fort Bliss, TX as part of the NIE.

This exercise evaluated technologies to support Manned-Unmanned

Teams (MUMT). A dismounted infantry company tested a variety of automated systems in a force-on-force field exercise. These systems ranged from an automated 81mm mortar to a micro-UAV that easily fits in the palm of a human hand (photo below). CPT Thomas Brett, the company commander participating in the exercise, had the following comments,

> The systems that most increased lethality and effectiveness during the exercise were the surveillance platforms [SHRIKE quad-copter and PD150 mini-copter UAV], paired with the human interface application [Netwarrior] that helped me as the commander make decisions and employ firepower against the enemy - these same systems were also the most mature of the ones we tested.[35]

Figure 4. "Black Hornet Nano Helicopter UAV"[36]

CPT Brett also noted that, "the UAV systems were the simplest to use, and required the least amount of training - in most cases, it took less than two days of training. The interfaces were simple and smartphone app based - using technology that most soldiers have already been exposed to growing up or use personally every day."[37] However, there are legitimate concerns with the employment of mostly commercially based systems directly onto the battlefield.

Congressional testimony in November 2015 by Dr. Jonathon Bornstein, Chief of the Autonomous Systems Division Vehicle Technology Directorate at the Army Research Lab, highlighted many of the vulnerabilities of using commercial systems in a contested and complex combat environment. “Commercial usage generally focuses on benign, permissive, and structured environments. The military must design for adversarial, highly dynamic, and unstructured environments.” [38] Dr. Bornstein focused his remarks on the risk that commercial platforms are not inherently built to learn an unpredictable environment based on the capabilities required to make these systems commercially viable. On the other hand, almost all of the expected conditions of combat would require systems that can quickly learn and then adapt to the changing situation around them.

These same observations were reiterated in an interview with Brett Piekarski, MAST CTA CAM Branch Chief, Micro & Nano Materials & Devices U.S. Army Research Laboratory “there are quite a few commercial UAS [quad-copters] that are continuing to improve, but are not robust enough to operate in a GPS denied and completely unbounded environment – where the device is going to have to operate with a high degree of autonomy, avoid obstacles, and go beyond line-of-sight.”[39] Piekarski noted that one particular way the US Army is focused on maintaining a strategic technological advantage going forward, is by building our future systems capable of robust, reliable operations in a contested environments. This is contrasted with the type of systems that will continue to emerge in the commercial sector, where much of the operating environment can be controlled. The Army Research Lab tests and other research will eventually provide the Army with robust systems for fielding, but it may be many years before robust systems can be fielded.

The long development timeline and associated costs are risks that can be mitigated in the interim using commercial platforms. Both for surveillance/counter-surveillance capabilities, and for human-machine interface through commercially developed augmented reality (AR) systems. Commercial technologies are available now to fill an operational gap and the consumer market will drive innovations that the speed of the military developments systems will not be able to match. Applied at scale, these commercial platforms will create strategic outcomes for the anticipated threat and types of conflict we expect.

Mature commercial-off-the-shelf (COTS) platforms that offer basic capabilities to the operational force also provide an opportunity for rapid innovation that will prepare the force for the more robust systems that come later. We can build the operational “bench” of personnel familiar with robotic technology and doctrinal framework to support a human ground integrated force into the future.

These ideas do not require large Army program based and platform solutions. Surveillance is a mission set that directly correlates to the consumer requirements of the companies producing these COTS platforms. Streamlined human interface and augmented reality technologies also have tremendous consumer potential. Historical military technological innovation has been built around very specific military requirements, such as stealth technology or precision munitions. Our development of robotic technology has principally been maintained in the scientific and RDT&E community[40], and as good as these institutions are, they cannot keep pace with the commercial sector for advancements that are not unique to military requirements. DARPA recently cancelled a robot in development after $42 million in investment, because military evaluators complained about it being too loud.[41]

This has resulted in a potential vulnerability. The RAND study indicated that we could be 10 to 15 years behind in UGV development[42], and this estimate did not include how long it would take to the operational force to develop doctrine, and tactical TTPs to support employment. The RAND study also indicated that other countries are either ahead of us in operational fielding (Israel), or that bar to entry into this capability is so low that other nations/actors could move into this space ahead of US efforts.[43]

The Technology- Guardium, 3DR, DJI, and HOLOLENS

The importance of the UGV cannot be overstated and the following quote from the same two previously mentioned Chinese scientists highlights the opportunity and the view of other state military elements,

> Like [the] tank in 20th century, military UGV will become the main weapon of the Army in 21st century. Compared to the manned armored vehicles, many advantages of UGV, such as larger combat radius, lower weight, higher mobility, longer duration, high self-sustaining capacity, etc., have been appeared now. Military UGV should become an important aspect of the weapon

> development plan to improve the combat capability of the Army in the future.[44]

There are many UGV's in various stages of testing and evaluation. There are an extremely small number that have actual operational employment for any length of time. The one particular UGV consistently highlighted in journals and other media is the Israeli Guardium, an operationally employed UGV fielded to the Israeli Army, used for roving and static security patrols[45]. The RAND study highlights this particular platform's success and indicates that the Israel military has advanced beyond our capability with its employment. [46]

The Guardium is just one example of a developer building a commercially available system focused on a military application. However, it is unique in a number of aspects, to include the fact that it has been in operational employment by Israel since 2007.[47] The photo below and the associated video link from an IHS Jane's Defense review of the system in 2012 provide an overview of the Guardium as a surveillance platform. The developing company and Israel continue to improve this platform and it is still in operational employment today.

Figure 5. The Guardium UGV[48]

The Guardium was prominently noted in the RAND study[49] and multiple scientific papers, to include the study by the two Chinese scientists quoted at the beginning of this paper.[50] Foreign Policy identified the Guardium as the UGV most likely to present on the battlefield in an article in 2012.[51]

The Guardium also featured highly in a 2011 analysis of UGVs by two Turkish military officers conducting a study of commercially available UGVs[52]. These officers were participating in an MBA program at the US Navy Postgraduate School in Monterey, and conducted this research project while attending. The findings of that study provided a recommendation for specific requirements of the Turkish military, but the criteria and method they used is exceptionally applicable to US operational needs.

They analyzed numerous platforms relative to; Endurance, Automation (Navigation), Communications Networks, Mobility (Speed), and Payload capacity. They assigned values to these criteria and balanced their inputs relative to risk based on both maturity of the technology, and how well the criteria supported the requirement of the Turkish military. An example evaluation table is below:

Alternatives	MTs					Overall Scores
	1. Mission Length	2. Automated UGV Self-Control and Decision Making	3. Communications	4. Mobility	5. Mission Packages	
	MOEs					
	1.1. Endurance	2.1. Autonomous Navigation	3.1. Comms Network	4.1. Max Speed	5.1. Payload Capacity	
Izci (Baseline)						63
MDARS						48
GRUNT						69
Guardium						79
Criteria: (x = Scores) Red: x≤2, Yellow: 2<x≤4, Green: x=5						

Figure 6. UGV effectiveness evaluation matrix[53]

The table visually displays the results of the effectiveness assessment of the platforms. The two officers assigned common values to each capability criteria (mission length, automation, communication, etc.) and represented the comparative performance of each technology using a red (lowest comparative performance), yellow (moderate comparative performance), and green scale (best comparative performance).

The Guardium consistently scored at the top of their analysis. These observations are heavily influence by the maturity of the technology and its proven operational use. The website GIZMODO notes that in one operational scenario, the Guardium was employed to provide 103 hours of continuous surveillance after a mortar attack.[54] The Guardium may not be the optimal solution for the US military, but its proven operational employment makes it an excellent candidate for unit level operational evaluation and innovation.

The 3D Robotics and DJI Quad-copters

The argument most often used for not using small commercial UAVs resolves to the inability for these systems to autonomously navigate cluttered and unbounded environments[55]. The common capability gap is the commercial platforms lack sensors and software to autonomously function in an environment with numerous three dimensional obstacles, like heavily urban areas. DARPA cites this gap specifically in recent tests of the Fast, Lightweight, Autonomy Program (FLA), a project specifically designed to test small UAV autonomy in exceptionally cluttered environment, like the interior of a residential building.[56] However, DARPA's approach to solving this challenge is to modify existing *commercial* quad-copter platforms. In this particular test, it was a modified DJI Flamewheel 450 that served as the base model. A quick Internet search indicates that a base model of this platform can be purchased commercially for less than $500 per unit.

Figure 7. DJI Flamewheel 450[57]

Wide fields of opportunities exist near this price point from other UAV developers. This offers the potential to leverage consumer competition, currently on display between systems from 3DRobotics and DJI, as a method to increase the speed of innovation.

The purpose of both the UGV and UAV platforms is to increase surveillance and situational understanding. Applied at scale, in a swarm-like scenario, these small systems have the potential to strategically change the battlefield by increasing precision and lethality.

The soldier's interface

The human interface technology is perhaps the most revolutionary platform that exists in the commercial sector. The prime example is the augmented reality device from Microsoft called the Hololens.[58] Augmented reality is described as the application of a virtual image projected onto physical reality. The easiest way to conceptualize the system is to imagine a "Heads Up Display" (HUD). The Hololens builds on this concept by first being "wearable" technology. A user places the Hololens on the head like a set of goggles. The photo below represents the current form factor of the device. Secondly, the Hololens projects a three dimensional image onto the screen of the device that you can interact with by means of gestures, driven by gaming technology from Microsoft's Kinect device. The advantage and application for soldiers is the same as a HUD for pilots; the device provides additional information while still allowing the user to operate in the environment. The implications of human-machine teaming are enormous.

In even the best of unmanned applications today, the user operates the device through a separate screen, such as on a tablet, that cause the user to take himself/herself away from focus on the physical world to operate the device. The Hololens offers the potential to both control and receive data from the device while providing the capability to maintain awareness in the physical world. A critical requirement for both pilots and soldiers.

Figure 8. The Microsoft Hololens[59]

The Humans

The most critical element in effectively leveraging these commercially available platforms is not a piece of technology; it is the human working with the technology. The commercial sector also offers some opportunities in this domain, although there is a delayed realization of the impact. Programs that encourage enthusiasm and basic skill development in robotics are increasing in popularity throughout the US. Many schools and universities have also implemented codified educational programs to answer the demand of the commercial sector. In a study published by the American Engineering Association, the need for additional capacity in robotic education was highlighted along with a recommended curriculum for higher education institutions. The authors were blunt in their assessment of the critical nature of the educational path required for the US workforce to compete in an environment with massive growth in robotics.

> It is critical, therefore, that educational institutions adequately respond to this high demand for robotics specialists by developing and offering appropriate courses geared towards professional certification in robotics and automation."[60]

The Army will need to address the human educational and development aspects and may need to look to the commercial sector for best practices. The time required for these training and developmental programs can vary greatly.

Commercial robotics companies are in a constant state of improving user interfaces to reduce the training requirements for any end user of their technology, to include soldiers. In an interview with Andrew Culhane of TORC robotics in Blacksburg, VA, he described their methodology for building the human-machine interface, "The standard we try to use….is no more than two days of training for the soldier, and we can have it in the field."[61] However, there is still risk that once a human-machine team is employed in combat, training may not offset the challenges of a complex, chaotic environment.

The soldiers' ability to adapt to this new technology may not rely solely on an applied robotics education. When Mr. Culhane was asked the most important skill required for successful use of the technology, he did not indicate a hard science or math related area. "We've [TORC Robotics] found that enthusiasm for the technology trumps all other traits and skills." The ability to have the individuals using the platforms to be open minded and enthusiastic about the use was more important than if they were mechanically inclined or computer literate.

A survey conducted to support this research paper in January and February 2016 tested this concept and attempted to determine if there were other opportunities to develop skills and a desire in individuals prior to enlistment age. The sample size was exceptionally small with only 22 respondents out of 45 individuals receiving the survey. However, all individuals were all members of commercial robotics companies and university robotic lab students. This group had self-selected in some fashion that would indicate "enthusiasm for the technology". The survey attempted to determine if there were common experiences, or participation in robotic programs prior to enlistment age, that influenced their enthusiasm for robotic technology.

The results indicated that while the respondents strongly agreed that early robotic education was extremely important, fewer than 5% had any robotics education prior to the collegiate level. When surveyed about the most important skill required to successfully master robotics, 66% indicated that basic mechanical knowledge provided the most advantage. However, the comments overwhelmingly indicated that "video game" type skills were the most helpful in application and control of robotics systems.[62] In all anecdotal discussions with the respondents, the subject of enthusiasm for the technology was indicated as extremely important.

On the subject of early education, the FIRST programs (**F**or **I**nspiration and **R**ecognition of **S**cience and **T**echnology) received the strongest support with 64% of those surveyed indicating that these programs were the best early education opportunities. FIRST is a non-profit public charity based in Manchester, New Hampshire that seeks to encourage enthusiasm in science and technology. Originally founded in 1989, the organization built two robotic competitions in the late 1990's, The FIRST Lego League (grade school) and FIRST League (high school) programs, that have become exceptional forums for

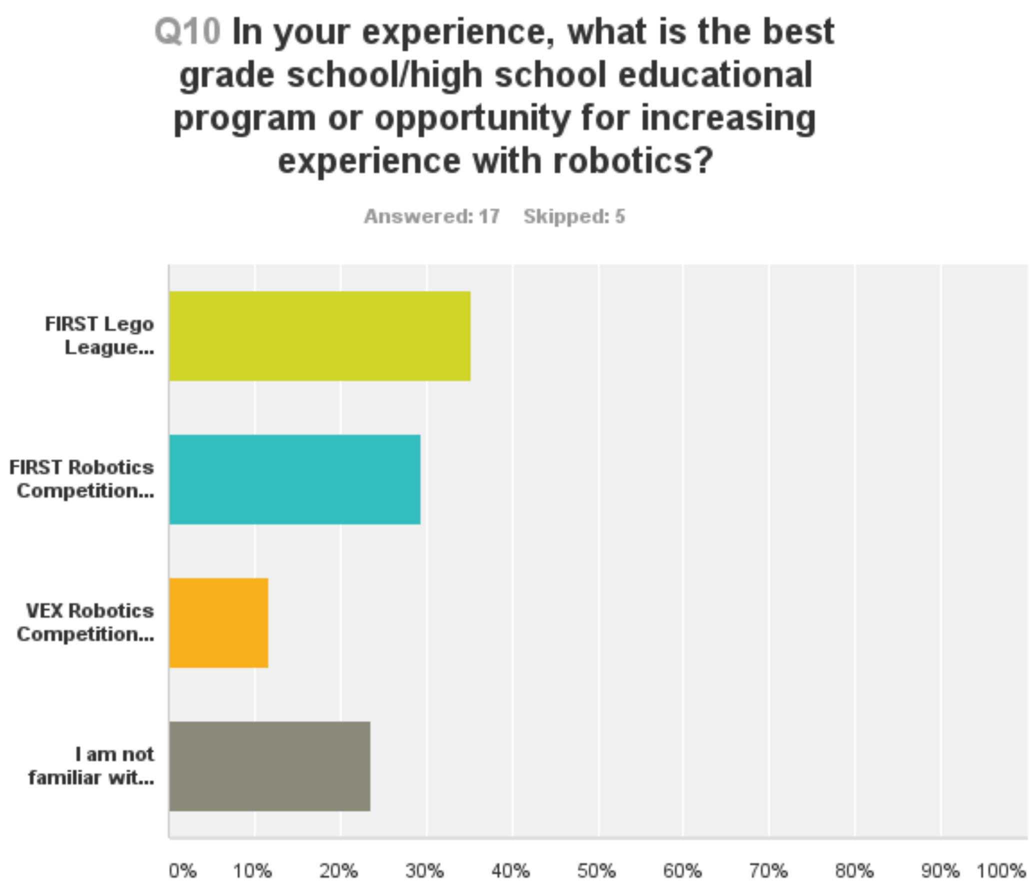

Figure 9. Recognition of early education programs in robotics[63]

young people to interact with robotics. Those surveyed indicated by a small margin that FIRST Lego League was a better opportunity (35% support) than FIRST League (29% support) because it targeted individuals at a much younger age (figure 9).

Overall, the personal experience of those surveyed would indicate that early education programs did not play a critical role in their own development, but strongly agreed with the concept that early robotics opportunities are very important for young people (figure 2 below).

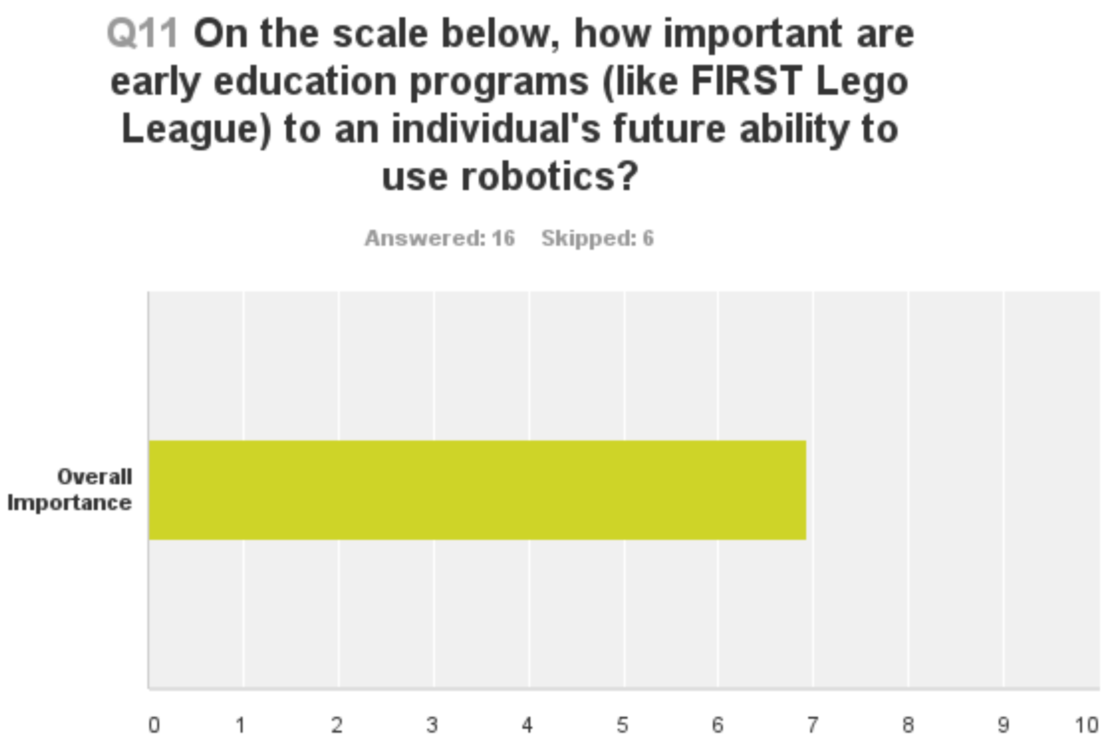

Figure 10. Early education- 1(least important) to 10(most important)[64]

Focusing investment or sponsorship in program's like FIRST Lego League should be targeted at those locations where we know that we are much more likely to draw Army recruits into the force. There have been numerous studies conducted on the demographics of Army recruits, to include multiple studies on the regions most heavily represented. In a 2009 study, for instance, indicated that a young individual from the southern United States was 68% more likely to join the military than his/her peer in the northeast.[65] The Army itself maintains excellent location based demographics as part of its recruiting effort. The information needed to target "enthusiasm for technology" type programs at the specific locations where we can have the most potential impact on future recruits is available and reliable.

TORC's Andrew Culhane also mentioned FIRST Lego League as an excellent program for creating enthusiasm, "The Lego league robotics is something we sponsor, invest in and support"[66]

Mixing the technologies: The air-ground teams and swarms

The potential in each of these three component areas is truly realized when they are combined and then employed at scale. There are numerous studies and experiments that indicate that "mixed" UGV and UAV technology can provide even greater advantages than the sum of the individual parts. The technology and software solutions to make this initial step are available and ready to be tested.

The basic building block for the conceptual model is the human-air-ground robot team, similar to the MUMT experiments but focused on enabling commanders with increased capability for a single function – greater situational awareness through surveillance. At its simplest; this team would consist of a UGV, a UAV, and a dismounted soldier or small element of soldiers. The combination of these tools provides an increase in situational awareness and multiplies the effectiveness of dismounted soldiers deployed into an urban or complex environment. The ground vehicle component as support platform for the COTS surveillance is crucial, and an observation that was proven during the NIE. CPT Thomas Brett's comment, "the vulnerability to these small UAV surveillance platforms is power. As a dismounted element, we need another ground system to serve as a base for charging and transporting the UAV systems."

This is not a novel concept. DARPA, the National Labs in Idaho, and numerous research elements of the DoD have pursued human-air-ground robot teaming for more than 10 years. However, there are multiple examples of successful integrations in the commercial and scientific sector.

In a 2013 successful practical experiment conducted by the Centro De Automa´tica y Robo´tica[67], engineers designed a mechanism and protocol for navigation and obstacle avoidance for an air-ground robot team. The experimenters used a small-wheeled UGV and a small quad-copter UAV. Unique to this test was the single camera, or imagery sensor, on the UAV. The single camera drives down overall cost, and makes their system applicable to a host of commercially available UAVs on the market today.

In a more recent 2015 experiment, a team from Carnegie Mellon conducted an experiment with a UGV platform, based on a Segway Personal Transporter, which also served as a carrier for hexacopter UAV platform. This research was sponsored by the USMC and demonstrated an autonomous air-ground robot team, as well as the software and algorithm for operation in real environments.[68] The significance of this experiment is in the tactical application of the UGV providing the base and support for the UAV element.

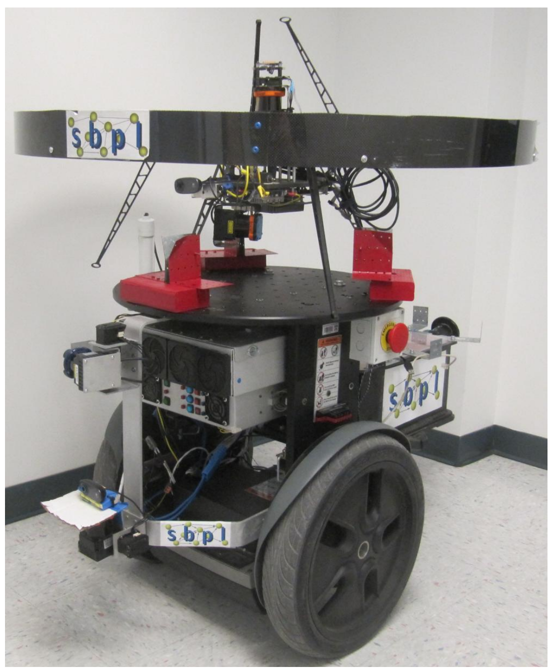

Figure 11. Photo of the Carnegie Mellon UAV/UGV pairing[69]

In another practical operation conducted by a team from Portugal an air-ground robot team conducted soil sampling in coastal mudflats. The UAV would scan and map the operational area, and then UGV would move along the best path identified by the UAV to the sampling point/points. The UGV would then return, clean it and recharge the next mission.[70]

This concept, when combined the scale of and potential of UAV “swarms”, can provide overmatch where it is most required. UAV swarms have consistently been shown to be viable and effective with small UAV systems. A 2010 demonstration in Switzerland displayed a swarm of micro UAV’s that were networked and specifically designed for commercial, cheap, prototyping of swarm tests.[71] The demonstration was cited by researchers at the Turkish Air War College as a method where cheaper, smaller, more readily available commercial systems in a swarm could create similar effects as more expensive, larger, single systems in a mission like electronic attack (jamming enemy signals).[72]

The Risks

The technologies highlighted above are not panaceas. These examples are intended to represent the trend that the commercial sector will dominate the small robotics and technology development, but that military employment of these systems will have strategic consequences. The recommendations listed in the section below must be framed relative to the risks of employment of automated or near autonomous technology.

In the three commercial areas identified above, each one will require operation in an environment with extremely high uncertainty and the information the systems will provide will a high degree of cognitive skill to utilize for making a decision or judgment. This means that each system will require human teaming for successful employment. The paradigm for understanding the relationship between uncertainty and the relative strengths of human and computer decision making is highlighted below in an illustration from Dr. Mary Cummings' paper "Man versus Machine or Man + Machine?"[73]

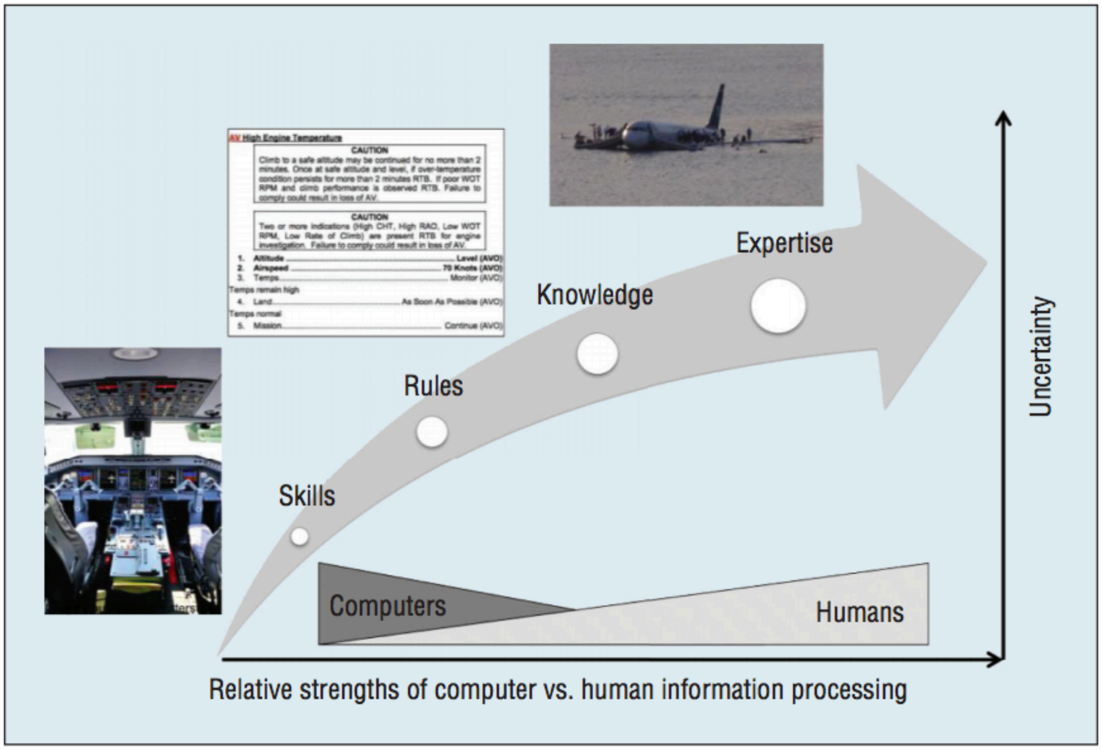

Figure 12. Relative computer vs. human strengths[74]

This illustration indicates the higher risk and greater challenge for employment of highly automated technologies. The very high end of the arrow are those tasks that require a great deal of knowledge base and expertise, and most military tasks would fall into this category. This paradigm reinforces the concept that our principal mitigation measure will be to create human and machine teams as we leverage technology into the future. The US Army has recognized this in the Manned-Unmanned Teaming concepts as noted above.

The augmented reality (AR) technologies would seem to be immune to this paradigm, but the risks with the tactical and strategic employment of AR are quite similar. The human's ability to maintain situational awareness in the highly uncertain environment of combat could be compromised by the potential distractions of the information being placed in his/her line of vision while wearing the AR device. There is not currently enough scientific study or evidence to indicate whether this will be a qualitative improvement over the current arrangement in many tactical situations, where the individual military member is having to consume the same data from the screen of a smartphone or a computer.

Recommendations

There are three significant recommendations emerging from this assessment. First, the Army should move quickly to leverage the developments in the commercial sector relative to UAVs and UGVs and insert directly into the operational force. Purchasing commercial UAV and UGV surveillance systems and providing them to operational units to use in surveillance and counter-surveillance missions best accomplish this. The current operational environment in Iraq and Afghanistan facilities this type of fielding based on the static nature of US forces conducting missions from fixed base locations. The Science and Technology and Research and Development communities must continue to develop more robust and capable versions of these platforms, but in the near term there is an opportunity to seize the advantage of quantity and low price point to drive doctrine, innovation, and operational employment. In order to mitigate some of the risk of introduction of new technology, the Special Operations community could lead the effort to incorporate and evaluate these technologies prior to providing to the operational force.

Innovation at the unit level during wartime has shown to be effective. James A. Russell's book discussing wartime innovation looks at case studies from Operation Iraqi Freedom that show methods for successful wartime innovation when smaller units are empowered to develop their own techniques.[75] This context revolved around counterinsurgency tactics, but the fundamental principle of providing tools to the unit level and letting innovative ideas move up into doctrine may be more applicable for this type of technology. Our youngest soldiers are often the most technologically proficient. There are tools and platforms available now to bridge the gap between research and development and operational innovation. The individual system price point, previously prohibitive, has now lowered to a point to make it worth investing in some operationally proven platforms. The Army would give them to the force – and accept the fact that we will likely not life cycle replace these systems, but we will have the opportunity to learn and maneuver from the bottom up.

Second, the Army should establish a separate and distinct branch to become experts in the operation of robotic capabilities, similar to the creation of the Cyber Branch. The Robotics Corps would develop the experts and leaders needed to manage these technologies and systems into the future. The expertise in robotic capabilities currently resides in science, technology, and combat development functions within the Army. To effectively employ robotic overmatch capabilities, then we will need experts in the operational force at the lowest levels. The cyber domain is an exceptionally important battlespace, but the direct and expert use of technology in the physical landpower domain is more critically important to the Army.

Third, the Army should invest in early education robotics programs, such as FIRST Lego League, and specifically target the establishment or reinforcement of programs at the geographic locations that are most likely to produce entry level soldiers for the Army. Additional research is necessary and recommended to indicate specific programs that may have greater long term effectiveness, but there is low risk and potentially high payoff for providing any STEM related education programs at locations where we recruit higher percentages of the force.

Conclusion

History provides a glimpse of the future of war. As the internal combustion engine changed the physical world of combat at the turn of the 20th century, robotics will change the physical world of combat in the 21st. Andrew Culhane from TORC robotics commented, “Nobody knows which robotic tech is going to stick, but there is a sense it is all (society) going to change.”[76] The military organizations that understand and seize the opportunity of the societal shift will be the successful land forces of the next century. Mr. Culhane also observed that, “Once we have driverless cars… We will expect driverless convoys”.[77]

Our dominance as a land power in the next century will be challenged by the ubiquity and low cost of robotic systems, both from state, non-state, and especially hybrid actors. Our ability to lead the development human-robot teams and the doctrine and techniques to employ them, is a critical aspect of the US's ability to maintain strategic overmatch in the battlefields of the future.

Endnotes

[1] John Gordon IV, John Matsumura, Anthony Atler, Scott Boston, Matthew E

[2] Ibid. 112.

[3] Ibid. 112.

[4] Ibid. xviii.

[5] Patrick Marshall, "Robotics and the Economy: The Issues," *CQ Researcher* 25, no. 34 (25 Sep 2015): 796.

[6] Ibid. 796.

[7] Larry Downes, "America can't lead the world in innovation if the FAA keeps dragging its feet on drone rules," *Washington Post*, 8 Oct 2014.

[8] Alistair Barr and Mike Ramsey, "Google Brings in Chief for Self-Driving Cars," *Wall Street Journal (Online),* 14 Sep 2015.

[9] Michael C. Horowitz, "The Looming Robotics Gap," *Foreign Policy* no. 206 (05 May/Jun 2014): 64.

[10] Erik Sofge, "Why is Google building a Robot Army?," *Popular Science* 284, no. 3 (Mar 2014): 56.

[11] Clive Thompson, "Uber Would Like to Buy Your Robotics Department," *New York Times (Online)* no. (2015-10-04 2015):

[12] P. W. Singer, *Wired for war : the robotics revolution and conflict in the twenty-first century* (New York: Penguin Press, 2009)

[13] Christopher Coker, *Waging war without warriors? : the changing culture of military conflict* (Boulder, Colorado: Lynne Rienner Publishers, 2002), 157.

[14] Future of Life Institute, "An Open Letter- RESEARCH PRIORITIES FOR ROBUST AND BENEFICIAL ARTIFICIAL INTELLIGENCE," 23 January 2015

[15] Ibid.

[16] Daniel McGlynn, "Robotic Warfare: THE ISSUES," *CQ Researcher* 25, no. 4 (23 Jan 2015): 75.

[17] Leonid Orlenko, "Breakthrough Robots," *Military-Industrial Courier*, 23 Sep 2015.

[18] Michael C. Horowitz, 64.

[19] John Gordon IV, John Matsumura, Anthony Atler, Scott Boston, Matthew E Boyer, Natasha Lander and Todd Nichols, "Comparing US Army Systems with Foreign Counterparts," 106.

[20] Nazir Ridha, "Syrian opposition downplays Islamic State use of drones in Kobane," *Al-Sharq al-Awsat (London, England)*, October 29, 2014

[21] Deputy Secretary of Defense Bob Work*,* "The Third U.S. Offset Strategy and its Implications for Partners and Allies", public speech, Willard Hotel, Washington, D.C., January 28, 2015.

[22] Clive Thompson and J. Gregory Dees Memorial Collection, *Smarter than you think: how technology is changing our minds for the better* (New York: The Penguin Press, 2013), 4

[23] US Deparment of the Army, *Hybrid Threat,* TC 7-100 (Washington, DC: U.S. Department of the Army, November 26, 2010), v.

[24] Kevin M. Felix and Frederick D. Wong, "Megacities: Pros And Cons, The Case for Megacities," *Parameters* 45, no 1. (Spring 2015): 28.

[25] United Nations, Department of Economic and Social Affairs, Population Division (2015). World Urbanization Prospects: The 2014 Revision, (ST/ESA/SER.A/366).

[26] Ibid.

[27] Liu Xin and Dai Bin, "The latest status and development trends of military unmanned ground vehicles," *The Institute of Electrical and Electronics Engineers, Inc. (IEEE)*, Conference Proceedings (November 2013): 537.

[28] U.S. Joint Chiefs of Staff Publications, *Joint Urban Operations*, Joint Publication 3-06 (Washington, DC: U.S. Joint Chiefs of Staff, November 20, 2013), I-5.

[29] Ibid. I-8.

[30] Ibid. I-9

[31] Tom Batchelor, "ISIS get taste of their own medicine as Kurdish troops use DRONES in fight against jihadis,"18 Jan 2016. *Express UK,* online article, http://www.express.co.uk/news/world/635740/Islamic-State-Kurdish-forces-drones-fight-ISIS-Syria (accessed 29 Jan 2016).

[32] David Sim, "Meet some of the Kurdish women fighting ISIS every day,"30 April 2015. *businessinsider.com,* online article, http://mobile.businessinsider.com/meet-some-of-the-kurdish-women-fighting-isis-every-day-2015-4 (accessed 29 Jan 2016).

[33] Tom Batchelor, "ISIS get taste of their own medicine as Kurdish troops use DRONES in fight against jihadis,"18 Jan 2016. *Express UK,* online article, http://www.express.co.uk/news/world/635740/Islamic-State-Kurdish-forces-drones-fight-ISIS-Syria (accessed 29 Jan 2016).

[34] Ibid.

[35] CPT Thomas Brett, U.S. Army Company Commander, telephone interview by author, January 22, 2016.

[36] Richard Watt, photograph, Black Hornet UAV, 29 May 2015, http://www.popsci.com/american-special-forces-test-hummingbird-sized-drone

[37] Ibid.

[38] Jonathan Bornstein, *Advancing the Science and Acceptance of Autonomy for Future Defense Systems*, Statement to the House Armed Services Committee, Subcommitee on Emerging Threats and Capabilities, 114th Congress, 1st Sess. (Washington, DC: U.S. Department of the Army, November 19, 2015), 2.

[39] Brett Piekarski, U.S Army MAST CTA CAM Branch Chief, telephone interview by author, January 15, 2016.

[40] John Gordon IV, John Matsumura, Anthony Atler, Scott Boston, Matthew E Boyer, Natasha Lander and Todd Nichols, "Comparing US Army Systems with Foreign Counterparts," 106.

[41] Anthony Cuthbertson, "US Army scraps $42m DARPA robot for being too noisy," *International Business Times UK*, 29 December 2015.

[42] John Gordon IV, John Matsumura, Anthony Atler, Scott Boston, Matthew E Boyer, Natasha Lander and Todd Nichols, "Comparing US Army Systems with Foreign Counterparts," 112.

[43] Ibid. 112.

[44] Liu Xin and Dai Bin, "The latest status and development trends of military unmanned ground vehicles," 537.

[45] John Gordon IV, John Matsumura, Anthony Atler, Scott Boston, Matthew E Boyer, Natasha Lander and Todd Nichols, "Comparing US Army Systems with Foreign Counterparts," 107.

[46] Ibid. 107.

[47] IHS Jane's International Defense Review, "IHS Jane's overview of G-NIUS' Guardium Unmanned Ground Vehicle family," September 12, 2011. *YouTube.com,* online video, https://www.youtube.com/watch?v=_nvC7B3f7K0 (accessed 29 January 2016).

[48] Ibid.

[49] John Gordon IV, John Matsumura, Anthony Atler, Scott Boston, Matthew E Boyer, Natasha Lander and Todd Nichols, "Comparing US Army Systems with Foreign Counterparts," 107.

[50] Liu Xin and Dai Bin, "The latest status and development trends of military unmanned ground vehicles," 534.

[51] John Reed, "Tomorrow's Weapons Today," December 21, 2012. *ForeignPolicy.com*, online article, http://foreignpolicy.com/2012/12/21/tomorrows-weapons-today/ (accessed 5 January 2016).

[52] Serkan Kilitci and Muzaffer Buyruk**,** *An Analysis of the Best Available Unmanned Ground Vehicle in the Current Market with Respect to the Requirements of the Turkish Ministry of National Defense*, MBA Professional Report (Monterey, CA: Naval Postgraduate School, December 2011), 103.

[53] Ibid.

[54] Andrew Tarantola, "This Unmanned Patroller Guards Israeli Borders for Days on End," September 14, 2012. *Gizmodo.com,* online article, http://gizmodo.com/5943055/the-g-nius-guardium-guards-golan-like-a-golem (accessed 15 January 2016).

[55] Greg Watry, “DARPA Program Seeks to Use Commercial Drones”, February 16, 2016. *rdmag.com*, online article, http://www.rdmag.com/news/2016/02/darpa-program-seeks-use-commercial-drones (accessed 26 April 2016)

[56] Outreach@darpa.mil, "FLA Program Takes Flight - Program to develop fast, lightweight autonomous air vehicle completes first flight data tests," February 12, 2016. *darpa.mil,* online press release, http://www.darpa.mil/news-events/2016-02-12 (accessed 18 February 2016).

[57] "DJI Flame Wheel F450 with Naza-M V2, GPS, and Landing Gear "*B&H Photo and Video,* *http://www.bhphotovideo.com/bnh/controller/home?O=&sku=1080059&gclid=CjwKEAiA9JW2BRDxtaq2ruDg22oSJACgtTxcmbh8ShrzplfgvtPiPucU_RxThVugC-wLmHtb6_-1ZxoCj7vw_wcB&is=REG&ap=y&m=Y&Q=&A=details* (accessed 18 Feb 2016).

[58] Microsoft, "Microsoft Hololens," https://www.microsoft.com/microsoft-hololens/en-us (accessed 2 January 2016).

[59] Ibid.

[60] Aleksandr Sergeyev, Nasser Alaraje, Scott Kuhl, Michael Meyer, Mark Kinney and Mark Highum, "Innovative Curriculum Model Development in Robotics Education to Meet 21st Century Workforce Needs," American Society for Engineering Education, (2015): 1.

[61] Andrew Culhane, TORC Robotics engineer, interview by author, TORC Robotics, 7 January 2016.

[62] Robotic Experience Survey, survey by author, Jan-Mar 2016, SurveyMonkey.com

[63] Ibid.

[64] Ibid.

[65] Renaud Bellais, *The Evolving Boundaries of Defence : An Assessment of Recent Shifts in Defence Activities,* Contributions to conflict management, peace economics and development; v. 23. (Bingley: Emerald Group Publishing Limited, 2014), 179.

[66] Andrew Culhane, TORC Robotics engineer, interview by author, TORC Robotics, 7 January 2016.

[67] Mario Garzón, João Valente, David Zapata and Antonio Barrientos, "An Aerial-Ground Robotic System for Navigation and Obstacle Mapping in Large Outdoor Areas," *Sensors* 13, no. 1 (2013):

[68] Jonathan Butzke, Andrew Dornbush and Maxim Likhachev, "3-D Exploration with an Air-Ground Robotic System," Intelligent Robots and Systems (IROS), (IEEE, September 28, 2015): 3241.

[69] Ibid.

[70] Pedro Deusdado, Eduardo Pinto, Magno Guedes, Francisco Marques, Paulo Rodrigues, Andr´e Lourenc¸o, Ricardo Mendonc¸a, Andr´e Silva, Pedro Santana, Jos´e Corisco, Marta Almeida, Lu´ıs Portugal, Raquel Caldeira, Jos´e Barata, Luis Flores, "An Aerial-Ground Robotic Team for Systematic Soil and Biota Sampling in Estuarine Mudflats," November 2015, *researchgate.net*, online research paper, http://www.researchgate.net/publication/281590122 (accessed January 2, 2016): 7.

[71] Polat Cevik, Ibrahim Kocaman, Abdullah S. Akgul and Barbaros Akca, "The Small and Silent Force Multiplier: A Swarm UAV--Electronic Attack," *Journal of Intelligent & Robotic Systems* 70, no. 1-4 (Apr 2013): 602.

[72] Ibid. 605.

[73] Mary (Missy) Cummings, "Man versus Machine or Man + Machine?," *The Institute of Electrical and Electronics Engineers, Inc. Intelligent Systems (IEEE)*, (October 2014): 2.

[74] Ibid.

[75] James A. Russell, *Innovation, Transformation, and War: Counterinsurgency Operations in Anbar and Ninewa Provinces, Iraq, 2005-2007* (Stanford: The Stanford University Press, 2011), 211.

[76] Andrew Culhane, TORC Robotics engineer, interview by author, TORC Robotics, 7 January 2016.

[77] Ibid.