DIGITAL INFANTRY BATTLEFIELD SOLUTION

INTRODUCTION TO GROUND ROBOTICS

DIBS project

Part I

Milrem in collaboration with

Estonian National Defence College
Latvian National Defence Academy
Latvian Institute of International Affairs
Riga Technical University
University of Tartu

December 2016

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The book consists of collection of opinions by various authors from different countries and diverse research backgrounds to provide a multi-faceted review of the development of unmanned ground systems (UGS) in military use from different perspectives – to cover both the retrospective and prospective development of UGS as well as the current issues and challenges from military, technical and legal perspectives.

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INTRODUCTORY REMARKS: ROBOTIC WINGMEN IN NEXT GENERATION WARFARE

Kuldar Väärsi

Human life is the most precious asset that countries send to the battlefield. Unfortunately, any war involves risk to soldiers' lives. Can this be changed? Equally, will future military operations simply involve newer and more capable weapons, stronger and better-armoured vehicles, and armies equipped with smarter technologies? This is definitely one of the developments we will witness in the next few years. However, a completely different era is emerging where technology not only supports but also replaces humans on the battlefield.

The use of Unmanned Aerial Vehicles (UAV) has become an essential feature of land operations. This widespread technology is now systematically used by the militaries of almost all countries. Modern UAVs were used for the first time on a larger and more systematic scale by the United States (US) during the Persian Gulf War in 1991. While this was not immediately followed by rapid growth, we can clearly see not merely a linear, but an exponential increase in military investments in UAV development when we look at the growth curve.

Similar growth is expected to occur in the Unmanned Ground Vehicles (UGV) market. I would dare say that it is not if, but when.

The beauty and challenge of forward-looking innovation lies in the need to predict the behaviour patterns and mind-set of future generations. I was 13 years old when I saw a computer for the first time. It was an IBM 386. My 2-year-old daughter has already mastered the basics of using an iPad. It is obvious that her generation will have a different outlook on the world – starting with different motor skills and ending with different values. For us, it is difficult to predict how 'normality' will be defined by the next generation. However, it is not entirely impossible.

While it might be difficult to comprehend here and now, I would dare forecast that we are going to see an increasing number of UGV solutions deployed in increasingly complex military operations. These are not just high-tech gadgets used by infantry. These are completely new capabilities which will change the face of war and the balance of power.

In the medium term, smart autonomous solutions will replace humans in particularly dangerous or just unpleasant functions on the battlefield. In the long term, we will see unmanned infantry units performing specific tactical tasks. However, for this scenario we need to mature in three areas: technology, doctrine and ethics.

It is relatively easy to imagine remotely-controlled or semi-autonomous vehicles helping people as a transport (carrying the squad's supplies). A number of countries have already launched or are in the process of launching similar programmes. For example, the US Squad Multipurpose Equipment Transport programme.

Another immediate area is a security system equipped with a range of powerful sensors. Technology can see and hear far beyond the capability of our natural senses.

A more complex solution soon to be deployed to battlefield involves armed UGVs which will dramatically increase the fire-power of the squad or fire-team and could even substitute a member of the team.

Is it possible to replace humans with robots, at least at the level of a squad or a 'fireteam'? There are two problems to solve: tactical and ethical. From a tactical point of view, we need a solution that is comparable to a human in terms of flexibility and adaptability. By technical means I dare to say it is doable. If not today, then sooner than we expect.

I have explained the advantages of unmanned smart solutions on the battlefield on a number of occasions and quite often I have heard that there is nothing more efficient in a battle than a soldier. Many of them are convinced that this will also continue to be the case for the foreseeable future. To a large degree, I do not share that view. However there is one very important point – today, a human is the most universal soldier.

Universality is exactly this something we should keep in mind when developing robotic solutions. Single-task machines are ineffective, complicated to use and not flexible enough to adapt to changing needs.

A second area we need to focus on is the swarming of different robotic solutions on the battlefield. We are still very far away from a self-conscious artificial intelligence (AI) that can act and think just like a human. And should we even want it? On the battlefield, we need an AI that is emotionless, objective, rational and able to calculate probability. And in addition to all this, it should be able to avoid collision with trees and rocks. If we look at the existing technology, we have everything we need to create smart, autonomous, land-based solutions for a battle zone.

Technology can see and hear far beyond the capability of our natural senses. However, its ability to combine the collected data and draw conclusions remains still below the humans for today. Nonetheless sensor fusion and deep learning will, in the long term, enable machines to become better than humans also in this field. Therefore, in the more distant future, smart autonomous solutions will be more reliable and less error-prone in the battle zone than humans.

And it is just a matter of imagination to understand how much more efficient such a solution would be if equipped with high-end sensors, swarming and smart data exchange.

Combining different UGV's and UAV's will create better situational awareness; provide more information for precision targeting; and even predict the movement of enemies on target. Altogether, this will create supremacy on battlefield for whoever possess it. Even more efficient are such solutions in different ambush scenarios.

But the ethical question is: do we really want it and who is going to pull the trigger. Will humans make the final decision or are we ready to trust a robot with decision-making tasks? I would feel much safer if the decision is made by a human but perhaps it is just my inability to understand the mind-set of the next generation.

In the long term, the technology itself is not the limiting factor. Instead our ability and willingness to use technology, will set limits to our actions. The question is not just 'what for', but 'whether'. It is the question whether we want to minimise the involvement of humans in war and do we actually understand the consequences. It is not for me to say whether such development is good or bad. History has shown that such debates tend to be irrelevant – more effective solutions always win. The theme of today's conference is technology and I dare to say that in terms of technology everything is possible. If not today, then probably sooner than we expect because technology tends to develop exponentially and the next generations will define the next normality.

INTRODUCTORY REMARKS: THE ETERNAL QUEST FOR PEACE THROUGH WARS, AND WARS IN EVOLUTION

Dr. Māris Andžāns

The course of history has shown that conflicts have been an integral part of the conduct of relations among humans and the organisational entities they comprise, be it tribes, city-states, states, empires, other actors or alliances of such actors. Be the reasoning of the ever conflicting environment the nature of humans or regional or international systems of the respective times or other factors, prospects of eternal peace, however, remain futile.

The end of the Cold War came with expectations that the end of the bipolar stalemate and global confrontation would not only reduce risks of a global conflict, but also that the world would become more peaceful. However, the end of the Cold War facilitated the unfolding of regional security dynamics with subsequent regional conflicts, including in Europe. Most of the conflicts in Europe seemed to be settled or were 'frozen' by the beginning of the twenty-first century. Nevertheless, Russia's war with Georgia in 2008 and Russia's occupation of the Crimean Peninsula of Ukraine and the subsequent instigation of war in the Eastern Ukraine underlined also that Europe is not a war-free-area. At the same time, globalisation processes have not only increased the connectivity of states and societies, but also have facilitated the globalisation of threats – terrorism in particular.

Given the fact that history tends to repeat itself, the Baltic Sea region should also not be considered as a safe zone in face of different prospective 'hard security' threats, either emanating from Russia or non-state actors and factors. Small powers' resistance capabilities are very limited if they have to face a meaningful military power which is underpinned by highly developed military instruments that are complemented by economic, political, diplomatic, informational and other tools. To reduce this gap to the extent possible, technological progress is essential. Outmoded war fighting methods and technologies of the previous times can be usable if the opponent uses similar methods and technologies. Failure to keep up the pace with technological developments can considerably reduce any resistance capabilities and abilities.

The following collection of opinions by various authors from different countries and different research backgrounds provides a multi-faceted review of the development of unmanned ground systems (UGS) from different perspectives – to cover both the retrospective and prospective development of UGS as well as the current issues and challenges from military, technical and legal perspectives. They underline both the uncontested significance of the technological progress in the military field as well as the necessity for interaction and collaboration of different spheres and both governmental and non-governmental actors. They also underscore that effective technological progress is a multi-faceted process – that private sector entities are instrumental in developing new technologies, that such technologies have to be employed effectively and that they have to be adequately integrated in the existing organisational structures and the structures have to be developed, and that in such development not only the operational environment but also the legal aspects of operation have to be taken into account.

First, James Rogers provides an assessment of the future operational environment, asking whether the time is ripe for UGS to come into their own. Then Jānis Bērziņš sets the general framework by reviewing the development of UGS in a historical context. He also describes the current state of the play of the development of UGS as well as outlines both advantages of UGS and dilemmas the quest of autonomy of UGS entail. Zdzislaw Sliwa reviews both advantages of UGS and the current state of the play of their development in different countries, before outlining tendencies of their prospective development in the context of future warfare. To review the ethical issues in this context, Asta Maskaliūnaitė revisits Just War theory and outlines some of the challenges and dilemmas that unmanned vehicles entail in fighting a just war.

Among the technical articles, first, Tianbao Zhang provides a review of some substantial issues of UGS to cover power supply, artificial intelligence, autonomous driving, robots arm and sensors, as well as their development perspectives. Juris Ķiploks in his chapter reviews lessons learned from the historical development of military mobility systems and, based on that, focuses on military mobility issues in the future, with a particular emphasis on the hybrid-electric drive. Agris Nikitenko and Jeff Durst review several methods for autonomy assessment and quantification of intelligent unmanned systems as well as provide an outline of a new methodology to address the performance estimation issues of such systems.

Finally, as efficiency of unmanned systems depends on their integration with other elements of armed forces, Uģis Romanovs discusses the future role of UGS in military formations. He elaborates a concept of operation for digital infantry formations – infantry units that are force multiplied by UGS.

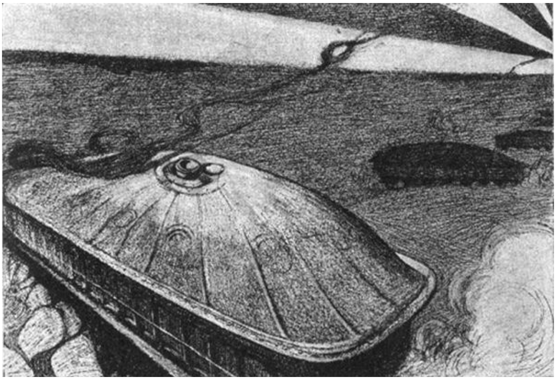
THE FUTURE OPERATING ENVIRONMENT: IMPLICATIONS FOR UNMANNED GROUND VEHICLES (UGV)

James Rogers

In 1903, H. G. Wells, the father of the genre of science fiction, had published in *Strand Magazine* a short story entitled 'The Land Ironclads'. This short story is often highlighted because Wells' foresaw the invention of formidable fighting machines, not unlike the Royal Navy's mighty ironclad battleships that ploughed through the seven seas. The only difference would be that these ironclads would use giant pedrail wheels, enabling them to move across the land. Wells' vision was decades ahead of his time: it came only a year after Frederick R. Simms' invention of the 'Motor War Car', a primitive vehicle armed with a single machine gun and some armoured plate. Indeed, the 'Land Ironclad' would not be realised until the power of the internal combustion engine became reliable enough and powerful enough to haul a large steel object over rough terrain for some distance with ordnance and a handful of men inside. Thirteen years later, during the apex of the First World War, this is precisely what occurred: British 'tanks' – so called because they resembled water tanks during manufacture, which was kept secret – made their debut on the battlefield. As they crawled over the trenches, witnesses said that they scattered their German opponents in their wake.

'The Land Ironclads' was also significant because it depicted, although perhaps few saw it at the time, certain aspects of the future operating environment, long before they became a reality. One the one hand, Wells' seemed to appreciate that technology would be driven by new needs, themselves a product of the problem of the existing operating environment of the early twentieth century. Wells' seemingly understood

Figure 1. The Land Ironclads (republished, 1904)



that industrial warfare – i.e. the fusion of mass logistics, the ability to mobilise millions of soldiers and the unrelenting and destructive firepower of machine guns and quick-fire rifled artillery – would lead, so long as both sides could sustain it, to a vicious stalemate. On the other hand, he seemed to appreciate that industrial warfare would not be undertaken primarily by professional soldiers, the mainstay of the British military thinking in 1903 – but rather by conscripts, who were clerks, factory workers and shopkeepers prior their enlistment. Moreover, it would not matter if they faced professional soldiers: the 'Land Ironclads' – as a technology – would simply allow them to punch through their enemies and crush their will to fight. This was sharply at odds with the dominant perspective of the time: the will to fight was still considered more important than an army's technological sophistication.

Today, the common belief is that the operating environment is also about to undergo a number of profound changes, themselves a product of technological design. Similarly to 1903, we may now be on the cusp of a series of new technological innovations that will fundamentally change the way Western armies fight. Whereas mechanisation was underway during the early twentieth century, today Western forces may be on the way towards the full automation of warfare. This chapter will assess these coming changes, to facilitate a better understanding of the character of the operating environment Western armed forces will likely be deployed in during the years ahead. The period in question covers the next twenty years, the time beyond which – given the acceleration of technological innovation – becomes near impossible to predict.

Tanks – Wells' 'Land Ironclads' – were designed to overcome the stalemate of industrially-sustained, systematised, trench warfare. Today, Western governments face a new challenge: they are increasingly disinclined to use their young people in the same way as their predecessors during the early twentieth century. In 1914, droves of young men, be they Austrian, British, French, German or Russian, either enlisted of their own volition or were conscripted to fight for their respective kings and empires, and pulverise their enemies into submission. 'Let's bash the Boche!' was the popular British warcry at the time. Hundreds of thousands of men on all sides were trained and sent to the front lines, to suffer under ghastly conditions; they were faced with death on a daily basis, or shellshock and disease. By contemporary standards, the casualties and fatalities were unimaginable. On the first day of the Battle of the Somme, 20,000 young British men perished in the mud of the battleline. The trauma of this experience may still be with us: the desire to use technology to overcome risk to one's own soldiers has grown progressively stronger – and, since the advent of 'post-modern' technology like advanced computers, networks and robotics, increasingly feasible.

Unmanned Aerial Vehicles (UAVs) – flying machines, seemingly with 'wizardry' and 'mystic' – were science fiction only thirty years ago; no longer.[1] Today, an aviator – perhaps now a misnomer, insofar as he or she no longer flies the aircraft – can control from an air station located in the United States or United Kingdom a Predator 'drone' flying thousands of kilometres away. Using the aircraft's cameras, these remote aviators can see what is happening on the ground with high-definition clarity, and launch lethal, precision attacks using long-range missiles at will. Western forces can now unleash death on their enemies by remote, perhaps on occasion without those opponents even knowing that they have even been struck. If warfare became something of a 'spectator sport' for Western civilians during the 1990s, today it is increasingly becoming so for those sent on their behalf to actually engage in any fighting.[2]

The West wants more of the same: its need for 'sanitised' and 'precision' interventions will likely continue to constrain the future operating environment, even more so than today. This is clear insofar as Western governments and publics seem – at least under current circumstances, and with notable exceptions – to be less willing to see their soldiers put into harm's way, or even, for them to unleash the full might of the West's war machine. If their countries are engaged in military operations, Western publics want them to be able to secure their government's political objectives in the least destructive way possible, with as few casualties – let alone fatalities – as possible and fast. Alternatively, bar some notable exceptions, such as Estonia and Lithuania, long gone are the days when governments could conscript large numbers of young men into national military service; aside the cost involved to general society, it is unknown whether such conscripts would serve any purpose besides 'national cohesion' or 'padding out' regular forces. Western governments, meanwhile, are increasingly indisposed to their will of their electorates. The two come together in symbiosis, not so dissimilarly to the Great War, when the British and French governments sought military advances like the tank to maintain their ability to sustain support for the war, by reducing the rate of killing. The only difference today is that Western governments have difficulty maintaining support for conflict if the fatalities reach 200 troops – let alone the 20,000 lost in a single day of battle in 1916.

This strategic need – allied to the advent of war as a spectator sport for Western observer and participant alike – means that, at least for the most advanced industrial powers, warfare will become less and less personal. It will become more and more remote; and Western citizens and armed forces alike will demand it. Western forces will be progressively removed from directly applying military force onto their enemies and opponents. Modern technology is now coming together to allow robots – whether flying in the air, ploughing through the sea, or traversing obstacles on the land – to do the fighting once done by men, and increasingly also now by women. In this sense, complementing UAVs, Unmanned Ground Vehicles (UGV) are one of the new technologies that will further work to remove Western soldiers from actual fighting. Due to the computer processing power and the advanced robotics needed to make them work, they have been the hardest of of unmanned systems to deploy in the operational theatre. It is much easier for computers to navigate through the air than it is for them to transverse the many forms of terrain and obstacles on the ground. However, the situation has been reached where we are potentially less than a two decades away until they replace individual soldiers in the field. Indeed, they are already starting to replace manned fighting machines, from tanks to armoured cars, to reconnaissance and support vehicles.

A range of additional strategic trends – both social and technological – over the next twenty years will likely converge to accelerate the transition to unmanned systems, not least UGVs, by driving fundamental changes to the existing operational environment:

1. **Low population growth in Western societies**, particularly in European countries, will continue to sap at the ability of Western governments to raise personnel for military purposes. Moreover, most countries in Central Europe and Eastern Europe are facing not only population stagnation, but even outright decline. Germany, Spain and Poland – Europe's first, fifth and sixth and sixth most populous countries – are all expected to lose between 5%-8% of their populations over the next thirty years.[3] In addition, several European countries, even the largest European powers like Germany, France and the United Kingdom, are facing significant ageing within their population structures.[4] Further, similarly to today, many young European citizens will likely continue to gravitate towards careers with higher salary potential, i.e., within the civilian world. Taken in combination, these pressures will likely create an environment where technology will be sought to provide a solution to the crisis in manpower – particularly when the West's opponents might have large numbers of people in abundance and the willingness to put them in harm's way.
   - Like their aerial counterparts, but even more so, UGVs will become a means for Western governments to kill two birds with one stone: on the one hand, the use of UGVs will allow European and North American armed forces to compensate for the Western public's unwillingness to send their young people off to fight; on the other hand, they will compensate for the fact that there might be fewer young people to send off to fight in the first place. As they become more sophisticated, in other words, become capable of doing more on the battlefield, we might even begin to see the the automation

of warfare as such, akin to the mechanisation of warfare in the twentieth century.

2. **Growing geopolitical competition** is likely to afflict the world as countries such as China and India emerge as significant regional powers; as Japan, Australia and South Korea respond to their rise; as Russia continues to resurge and enact revisionist foreign policies; and as the weary Western powers – the US, UK, France and Germany – decline relatively in power.[5] In 2016, we already saw the halt in the decline in Western defence spending, even in a European context, as countries began to reassess their strategic needs in light of the new geopolitical realities. It is quite possible that, notwithstanding a collapse in China's industrial modernisation, the country will continue to drive systemic geopolitical change, which will not be confined only to East Asia – or even the Indo-Pacific. The next twenty years are likely to become increasingly volatile as multiple security dilemmas break out between several different actors, and as more money is poured into military-technological research. Moreover, these geopolitical rivalries – similarly to the past, during the periods of Anglo-German antagonism and US-Soviet struggle in the twentieth century – will almost certainly exacerbate so-called 'cross sector' or 'asymmetric' threats, and in potentially new and innovative ways. Indeed, the emerging powers, as well as the established Western powers, might seek to tie one another down in multiple proxy conflicts like those currently underway already in Syria between Russia and the West.
   - As defence spending increases to provide respective countries with the capacities to overcome the state of the geopolitical environment, UGVs may be one of the only ways Western countries can maintain an advantage over their potential opponents, while simultaneously maximising efficiencies with pressurised human and material resources.
3. **Environmental changes** may further compound the demographic and geopolitical problems, creating a volatile and combustible mix. The implications of global warming – stronger storms, drought and flooding – may begin to drive larger human catastrophes and migrations, and may – in turn – mandate an elevated Western military response, in terms of disaster relief or mitigation.

- UGVs may be adapted from their primary warfighting role, towards being able to assist with environmental catastrophes in the developing world, not only for humanitarian purposes, but to enhance the sending country's reputation in the new and more competitive geopolitical environment of the future. Swarms of UGVs may be able to fan through cities or rural areas affected by flooding, tsunamis or earthquakes, searching for signs of human life, or administering aid to inaccessible locations.

In addition to these trends, relation to the operational environment, a series of developments will also likely converge to affect the kinds of UGVs that will be developed in th future. These developments might include:

1. **Advanced manufacturing technologies** such as three-dimensional printing will likely continue to emerge and become increasingly sophisticated, at first for component parts for military equipment, and potentially, eventually allowing the the production of complete UGVs from mobile production facilities. These facilities could be deployed to the theatre of operations and used to produce all the necessary components, or certain replacement components, for a UGV for any operation.
2. **Revolutionary weaponry:** in late 2014, the United States installed its first weapon hitherto of science fiction – a directed-energy weapon (DEW), or laser – onto a US warship, *USS Ponce*. This weapon promises to revolutionise the way in which destructive energy is directed onto its target. The last revolution of this kind was in the fifteenth century, when cannon – firing irons shot – were installed onto castles and warships for the first time. Such weapons gave their holders such a competitive advantage that a process got underway, which lasted around a century, that fundamentally transformed European societies from the mediaeval age of warfare to the gunpowder age, with all the associated technological, political and social implications. Like with the transition to gunpowder, DEW promise to revolutionise the operating environment, to such an extent that those armed with them may be able to fundamentally alter the rules of the game, similarly to the way Europeans did in relation to their opponents during the early modern period or the industrial age. As Hilaire Belloc put it in his poem *The Modern Traveller* in 1898:

'Whatever happens, we have got, The Maxim Gun, and they have not'. The point being that a hail of bullets from an early machine gun could hold back hundreds, if not thousands, of native opponents. The Battle of Omdurman is a case in point here: with just a few thousand men, a handful of Maxim guns, and around fifty field guns, the British wiped out an entire Mahdi or Dervish army in a single engagement over the course of an afternoon. Dervish casualties ran at 55,000, while the British lost only 47 men.

The merging of DEW and UGVs (supported by UAVs, also armed with DEWs) may give Western armed forces – either in the context of territorial defence or in the context of expeditionary warfare – an untold advantage over any human defenders, particularly those the West is likely to face over the coming decades. This may even give Western governments the same level of preponderance over their opponents as the Victorians had over their adversaries during the nineteenth century, allowing Western military power to be extended almost anywhere, with no human losses. It may be said in the future that 'We have the UGV and the DEW, and they do not', relating it to Victorian parlance. This may even help the West redress the geopolitical balance, which for some time has been tilting against the West's favour.

3. **Novel energy sources, enhanced computer technology and improved robotics** will undoubtedly make themselves felt in the machinery of war over the next two decades. Already, sweeping advances have been made in battery technology – a spin-off of the move towards electric transport and mobile communications technologies, which have demanded lighter, more efficient and durable means of storing electrical energy. Tomorrow may witness the emergence of hydrogen fuel cells or other novel technologies, which might profoundly alter the durability of mobile machines, making UGV more durable and capable. Equally, it is one thing to bring to fruition either a single or even a small group of UGVs, but it would be quite another to utilise them in swarms, networked together and controlled by powerful central computers. A swarm of UGVs may eventually be able to fan through and neutralise hostile targets in the dusty cities of the developing world – where Western armed forces are almost certain to continue to be

deployed. Moreover, increasingly sophisticated robotics will allow UGV to become progressively more capable, not only in navigating the ground on which they are based, but also the human world.

CONCLUSION

Much like the development of the 'Land Ironclads' – the tank, along with a plethora of other subsequent land-based fighting machines – the development and incorporation of UGVs will undoubtedly have profound implications for the future operating environment, and the preponderance of Western military power more generally. But by themselves, UGVs do not promise anything more than what manned systems can bring to the battlefield: they can only promise greater effectiveness and efficiencies, insofar as they do not need sleep and cannot experience the horror of war, with its inevitable emotional impact. However, when seen as a means to overcome the demographic and cultural challenges afflicting contemporary Western societies – especially in conflict-weary Europe – amplified with the advent of certain next-generation technologies, they promise to help re-establish the West's strategic and military lead, as well as ability to enhance its own defence and reach and affect political change in other regions of the world. In turn, they will undoubtedly shape the future operating environment, and in turn be shaped by it, much like with the 'Land Ironclad', which rapidly became a major tool in overcoming the deadlock in the conflicts of the early twentieth century.

ENDNOTES

[1] Cohen, Eliot. 1994. The Mystique of US Air Power. *Foreign Affairs*. 1995, Vol. 73, 1.

[2] Colin McInnes. 1999. Spectator Sport Warfare. *Contemporary Security Policy*, 1999, Vol. 20, 3.

[3] Eurostat, 2016. *Population*. http://ec.europa.eu/eurostat/web/population-demography-migration-projections/statistics-illustrated accessed 20 November 2016.

[4] Eurostat, 2016. *Population*. http://ec.europa.eu/eurostat/web/population-demography-migration-projections/statistics-illustrated accessed 20 November 2016.

[5] James Rogers, 2009. From Suez to Shanghai: The European Union and Eurasian Maritime Security. *Occasional Paper No. 77*. Paris: European Union Institute for Security Studies, 2009.

UNMANNED GROUND SYSTEMS IN FUTURE WARFARE

Dr. Jānis Bērziņš

The idea of using unmanned ground systems (UGS) in warfare is not new, albeit their development today is still considerably behind air and naval systems. Most probably, this is a direct result of the complexity of the terrain and the consequent difficulty to develop systems able to cope with it. Nevertheless, with the technological development of recent years, military UGS have been increasingly used in military operations. They are an important component of the concept of Network Centric Warfare (NCW), which is expected to change warfare in the future. This chapter analyses the developments of UGS, their significance in NCW and discuses some ethical issues surrounding their use.

The first UGS was arguably the Land Torpedo. It was patented in 1915 by Victor Villar and Stafford Talbot. It was a very simple system designed to transport a land torpedo clearing a channel through obstacles like barbed wire. It was a tracked vehicle platform using a two-cylinder engine with no reverse gears and a very simple control cable. It is not known if it was ever manufactured.[1]

The Soviet TT-26 tanks, also known as Tele-tanks, were the first UGSs to be deployed in the field. Developed in the 1930s, they were used during the Second World War and the Winter War of 1939-1940 in Finland. Another tank controlled the Tele-tanks from a distance between 500 and 1,500 meters. The Tele-tanks were armed with machine guns, flamethrowers, and smoke canisters, and also could carry 200-700 kg bombs and chemical weapons and were driven manually outside combat operations. Germany also had its UGS called the Beetle Tank or Goliath Tracked Mine. It was a one-meter-long tracked vehicle that carried 75 kg of explosives and was used as anti-tank, anti-infrastructure, or bridge demolition device. It was connected to a control box by a triple-strand of telephone wires which were easy to damage.[2]

Around 1948-1949, the British developed a fully autonomous UGS called 'Elsie'. Elsie was able to respond to contact with objects and had phototube eyes that could sense light. The next development was Johns Hopkins University's 'Beast' in the late 1950s. It could move around the university's corridors until its batteries ran low. Then, it would use optics to find black wall sockets to recharge itself. Later in the end of the 1960s the first fully autonomous UGS was developed by Stanford University and SRI.[3] Nevertheless, by the 1980s the vast majority of UGSs were still tele-operated. It was only after 9/11 that the United States (US) Armed Forces started seriously deploying UGSs in the theatre.

Their applications include intelligence, surveillance, and reconnaissance, disaster response, chemical, biological, radiological and nuclear materials detection; transport and logistics; counter-mine and counter-improvised explosive device missions; repair missions under enemy fire. By the end of 2006, their number increased from practically zero to around 5,000 with plans to reach 12,000 by the end of 2008.[4] They are used 'to search caves and buildings for insurgents, detect mines, and ferret out roadside bombs'[5] By 2030 they are expected to replace one-fourth of US combat soldiers.[6]

These systems already proved to be a good substitute for humans in the 'Three Ds' domain (dull, dirty, dangerous). Military missions can be incredibly tedious and physically and psychologically exhausting. Unmanned systems do not need to sleep and eat and can monitor the field until their batteries are out with the same level of efficiency.[7] Making a comparison to industrial development, the advent of unmanned military systems might have a similar effect as the creation of the steam engine. In other words, it might increase the military efficiency of missions.

The next step for UGSs is the quest for autonomy. Today, all current land-based tactical unmanned vehicles are not autonomous. They still have to be remote-controlled by a human, either through the use of wire or wireless, making them vulnerable to interception and jamming as a result of electronic warfare. Increasing their autonomy would reduce

Figure 1. UGS and their Possible Applications

UGS	Capability Class	Potential Applications
Small robotic building and tunnel searcher	Tele-operated ground vehicle	Mine detection, mine clearing, engineer construction, explosive ordnance disposal/unexploded ordnance materials handling, soldier-portable reconnaissance/surveillance
Small-unit logistics mover	Semi-autonomous preceder/follower	Supply convoy, medical evacuation, smoke laying, indirect fire, reconnaissance/surveillance, physical security
Unmanned wingman ground vehicle	Platform-centric autonomous ground vehicle	Remote sensor, counter-sniper, counter-reconnaissance/infiltration, indirect fire, single outpost/scout, chemical/biological agent detection, battle damage assessment
Autonomous hunter-killer team	Network-centric autonomous ground vehicle	Deep reconnaissance, surveillance, and target acquisition, combined arms (lethal direct fire/reconnaissance/indirect fire for small unit defense or offense), static area defense, military operations in urban terrain reconnaissance

Source: US National Defence Council.

their dependence from links to command and control centers, allowing them to operate in hostile electronic warfare environments. It would also create many possibilities as, for example, making completely unmanned convoys reality.[8] A possibility is even to consider completely autonomous systems able to decide when to open fire. Although it opens many possibilities for employing UGSs in warfare, there are many important questions still to be discussed, including ethical, safety, moral and legal issues. A possible development could be the separation of unmanned systems between defensive and offensive, forbidding the latter.[9]

UGSS AND THE FUTURE OPERATIONAL ENVIRONMENT

The current operational environment is getting increasingly asymmetric. In the future, it is to expected that warfare will be characterised by the simultaneous employment of traditional, unconventional, hybrid, non-linear, and asymmetric methods.[10] Threats will emanate from states, non-state actors, or both, at the same time. States might use non-state actors as mercenaries to avoid attribution or civilians in non-combat activities to free military personnel to go to combat zones. Non-state actors might pretend to be a state or another non-state actor as a diversion. To avoid symmetric battles with conventional forces, these actors will use advanced and simple and dual-use technologies, from improvised explosive devices to precision-guided rockets, mortars and artillery.

The following five characteristics are expected to have high impact in land force operations[11]:

1. *Increased velocity of momentum and human interaction and events*, as a result of the diffusion of information by the internet, especially social media. It accelerates and amplifies the interaction between threats, militaries, governments and people. At the same time, disinformation and propaganda shapes support for specific political objectives, making necessary to be able to give a quick proper response.
2. *Potential for overmatch*, meaning the application of capabilities or tactics that can make the opponent unable to respond appropriately. They include long-range precision fires, air defence systems, electric fires, unmanned aerial systems – UAS, Anti-Access/Area Denial (A2/AD) capabilities and cyberspace capabilities, just to mention few.
3. *Proliferation of weapons of mass destruction* such as chemical, biological, radiological, nuclear, high-yield explosives (CBRNE) and direct energy weapons will make the theatre of warfare increasingly inhospitable for humans. Armed forces need to develop reconnaissance capabilities to be able to spot the presence of such weapons and destroy enemy forces, securing territory.
4. *Spread of advanced cyberspace and counter-space capabilities*, making threats to be able to use the cyberspace to affect tactical operations.

This includes enemy global positioning satellite jamming capabilities making precision fires incorrect. Armed Forces will have to develop capabilities to support joint operations through reconnaissance, offensive operations or raids to destroy the enemy's space and cyberspace capabilities which are land based.

5. *Demographics and operations among populations, in cities, and in complex terrain* will make the opponent to conduct operations in urban areas or other complex terrain, exploiting dissatisfaction among the population and weak governance to establish asymmetric conditions. Because it is inevitable to avoid involving the civilian population, it is necessary to develop decentralized combined arms and joint capabilities, and teams able to operate in complex and uncertain environments.

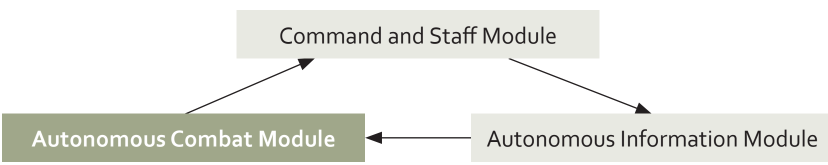
The answer for these challenges is Network Centric Warfare. It can be defined as

> a war in which the combat strength of a troop (force) grouping is increased by the creation of an information-communication network linking information (intelligence) sources, control bodies and means of destruction (suppression). This can be done by giving the participants in operations reliable and complete information about the situation practically in real time.[12]

It presupposes (i) the organisation of forces on the networking principle with higher autonomy; (ii) it is global; (iii) the notion of battlefield includes emotions, figurative perception of reality, the adversary state of mind, in other words, instruments of Reflexive Control; (iv) without global communications among forces command and control is impossible; (v) the proportion of non-military tools of coercion has a dramatic increase, at the same time there are no distinct state and national limits; (vi) the abandonment of the classical hierarchical command and control system for horizontal links between the parts involved.[13]

Instead of having divisions of between 15,000 and 20,000 troops, a Network Centric Warfare one has between 3,000 and 5,000 troops. Each unit is an autonomous combat module, able to independently conduct combat operations. Depending upon the conditions, smaller modules like a detached battalion, a reinforced company, or even a platoon or small special operations unit. It is of fundamental importance that each individual unit has to have the necessary degree of autonomy and capability to successfully perform its missions.[14] The autonomous information module assures the cooperation between each independent combat module and the command and staff module. This is done by establishing a single information space based on an aggregate database of loops of information about the adversary, own troops, and the combat environment collected by the autonomous combat and command and staff modules. It has to include data on own troops, intelligence, navigation field, weather conditions, just to cite few. This information database is to be used to provide continuous command and control, inform one's own troops, misinform the adversary including by disrupting its information systems, protect one's own information systems and create psychological pressure on the opponent.[15] Figure 2 shows the nodular structure of a network-centric organisation.

Figure 2. Modular Structure of a Network-Centric Organisation[16]



Within this context, unmanned ground systems are one additional factor shaping future warfare. In this sense, it is not correct to believe that these systems alone can completely transform command and control, fires and manoeuvre, sustainment, intelligence and other aspects of the operational environment. In other words, 'the novelty of a technology has never ensured success in its own right – it is the integration of innovation into effective methods and means that gives a strategic or tactical edge'.[17]

Nevertheless, their application of UGS is fundamental for boosting its efficiency. Therefore, it should not be a surprise that Russia has been building a significantly large amount of UGSs, from golf-cart-size vehicles to tanks, while at the same time arming them.[18] Also, that is why most major countries keep heavily investing in UGS research and development, which, along with related advances in networked warfare technologies, will radically transform how kinetic battlefield operations are conducted in the not too distant future.

The presence on battlefields of humans who themselves engage in the delivery of direct fires (such as through the use of a rifle) will increasingly be minimized. Instead, humans will be steadily replaced by ever more sophisticated UGSs, which will conduct kinetic operations as part of a synchronised network-controlled array of interlinked sensors and weapons mounted on various mobile platforms, located on the ground, in the air, at sea and in space – of which many will move and operate wholly or partially automated. Those future UGSs will use artificial intelligence (AI) to make decisions related to the use of lethal force against human targets.

This concept of network-controlled automated warfare, of which UGSs will form an integral part, has been widely accepted as either desirable or at least inevitable. As put by Major General Xu Hang, president of China's People Liberation Army (PLA) Academy of Armoured Forces Engineering in Beijing "unmanned ground vehicles will play a critical role in future ground combat. Realising that, we have begun to explore how to refit our armoured vehicles into unmanned ones. Though we have yet to develop unmanned tanks, it is surely an irreversible trend that computers will gradually replace humans to control those fighting machines.[19]

In this case, the replacement of a human operator towards an artificial intelligence system enabled device with the control to decide to kill a person by itself poses a severe ethical dilemma. Currently, an armed US Air Force drone (such as the 'Predator' drone) which is employed to destroy a pre-selected high-value human target (such as a terrorist leader) will only fire its missiles if the ground-based remote human operator is deliberately deciding to do so. Therefore, before determining if it is necessary to fire, the human operator can observe the target in near-real-time through a video-link displayed on the drone's control console.

The ability to watch the target guarantees that the human operator can reasonably attribute hostile intent or at least confirm the target's ability to engage in hostile combat.

By contrast, once an autonomous armed UGS has been assigned its targets by a remote human operator, might subsequently manoeuvre and deliver sustained fires based on decisions arrived at through the use of its artificial intelligence. It is well possible that the UGSs might not be able to detect a change in intent or ability of its targets. As a result, they might keep engaging human soldiers even though they now signal their wish to surrender or who have become incapable of resisting. Even if the human operator of the MRK 'Wolf-2' could recognise such changes, he might not be able to prevent the UGS from delivering continued fires because the communication link between the UGS and the operator has become severed. According to the Geneva conventions, it is a war crime to kill soldiers who wish to surrender or who no longer have the means to resist.

FINAL REMARKS

Although increasing in relevance, the use of UGS is tiny in comparison to air and naval systems. This is probably because of the difficulties imposed by irregular terrain. Nevertheless, the continued development and fielding of UGSs, especially armed and automated UGSs connected to a network and capable of operating in a synchronised fashion together with other sensors and automated mobile weapon platforms will radically transform the future of warfare. The most significant change will be the replacement of humans on the battlefield with automated armed vehicles using AI to engage in combat, reconnaissance and surveillance, mine detection and clearing, supply convoy, medical evacuation, counter-sniper, counter-reconnaissance/infiltration, indirect fire, chemical/biological agent detection, battle damage assessment, among others. It is also to expect that with the evolution of artificial intelligence, UGSs will perform attack tasks. The result is a serious ethical dilemma, because those decisions may cause unintended war crimes.

All countries wishing to retain a credible capability to wage war or defend themselves from armed aggression should either conduct their own networked UGS research and development or at least have access to networked UGS technology or technology which can defeat networked UGSs through membership in a military alliance which is equipped accordingly. To address the ethical dilemma posed by armed automated UGSs operated by AI the international community should establish a binding set of rules to either prevent or at least mitigate and sanction the commission of war crimes committed by automated UGSs and related technology.

ENDNOTES

1 Finn, Anthony, and Steve Scheding, Developments and Challenges for Autonomous Unmanned Vehicles: a Compendium (Berlin: Springer-Verlag, 2010), p. 11.

2 Ibid., 12–13.

3 Ibid., 13–14.

4 Singer, Peter Warren, Wired for War: the Robotics Revolution and Conflict in the Twenty-First Century (New York: The Penguin Press, 2009).

5 Carafano, James J. and Andrew Gudgel, "The Pentagon's Robots: Arming the Future." in Competitive Technologies for National Security Review and Recommendations, ed. James J. Carafano, Andrew Gudgel and Alane Kochems (Washington, DC: The Heritage Foundation, 2008), p. 29.

6 Atherton, Kelsey D. "Robots may Replace One-Fourth of U.S. Combat Soldiers by 2030, Says General," Popular Science, January 22, 2014, http://www.popsci.com/article/technology/robots-may-replace-one-fourth-us-combat-soldiers-2030-says-general

7 Singer, Peter Warren, Wired for War: the Robotics Revolution and Conflict in the Twenty-First Century (New York: The Penguin Press, 2009).

8 International Institute for Strategic Studies, "Conflict Analysis and Conflict Trends," The Military Balance 2014 (London: International Institute for Strategic Studies, 2014), 9–22.

9 Krishnan, Armin, "Automating War: The Need for Regulation," Contemporary Security Policy, 30, no. 1 (2009).

10 The term 'hybrid' should be understood as a full range of different modes of warfare including conventional capabilities, irregular tactics and formations, terrorist acts, including indiscriminate violence and coercion, and criminal disorder (Hoffman 2007). Although there are similarities, it is not the same as Russian 'New Generation Warfare.'

11 TRADOC, The U.S. Army Operating Concept (AOC): Win in a Complex World 2020-2040 (Fort Eustis, VA: U.S. Army Training and Doctrine Command, TRADOC Pamphlet 525-3-1, 2014), p. 11–12.

12 Dulnev, Kovalyov, Ilyin, Асимметричное противодействие в сетецентрической войне, Военная Мысль № 10/2011, стр. 3–8, http://militaryarticle.ru/voennaya-mysl/2011-vm/10357-asimmetrichnoe-protivodejstvie-v-setecentricheskoj

[13] Raskin, A. V., V. S, Pelyak, S. A. Vyalov, "Kontseptsiya setetsentricheskoy voyny: za i protiv (The Concept of Network-Centric Warfare: Pro and Contra)." Voyennaya mysl' (Military Thought), p. 7.

[14] Ibid.

[15] Raskin, A. V., V. S, Pelyak, S. A. Vyalov, "Kontseptsiya setetsentricheskoy voyny: za i protiv (The Concept of Network-Centric Warfare: Pro and Contra)." Voyennaya mysl' (Military Thought), p. 7.

[16] Ibid.

[17] Johnson, Robert A., "Predicting Future War," Parameters, 44, no. 1, (2014), p. 69.

[18] Mark Pomerlau, What's Ahead for Gound Vehicles?, C4ISRNET (2016). http://www.c4isrnet.com/story/military-tech/uas/2016/07/14/whats-ahead-unmanned-ground-vehicles/87042796/

[19] Lei, Zhao, "PLA Working to Develop Unmanned Armored Vehicles." China Daily USA, July 23, 2014. http://usa.chinadaily.com.cn/china/2014-07/23/content_17902555.htm

THE TENDENCIES OF UNMANNED GROUND VEHICLES DEVELOPMENT IN THE CONTEXT OF FUTURE WARFARE

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Advanced technologies of the information age, recognised also as the digital age, have significantly influenced all domains of social life as they have constantly demonstrated new capabilities allowing evolution of every area of humanity's activities. Their evolutionary character looks like an unlimited set offering endlessly new solutions which are encouraging their adaptation to fully exploit emerging opportunities. New technological discoveries have found very quickly military applications, thus becoming an inherent component of contemporary military operations with considerable potential to change the future battlefield. The reasons are rather pragmatic as there is clear understanding that advanced weapons systems and equipment, along with leadership competences, allow the achievement of superiority over enemies when conducting any type of warfare. The race in that domain is constantly ongoing involving nations and non-national entities and it could be compared to a conventional arms race, moving into new domains including space and cyber space.

Contemporary conflicts have evolved from Cold War type conventional force-on-force struggle toward asymmetric conflicts asking for new conceptual solutions. Next, the modern battlefield started to be more dynamic, non-linear, troops become more dispersed, weapon systems more lethal and huge armies were reduced as of economic reasons and threat assessments. A requirement to make quick and vital decisions on the dynamic battlefield based on the constant flow of information to surprise the enemy proved to be key to victory. It has been related to decision making processes, mission command requirements and physical sphere allowing the conduct of real time operations taking into account all operational factors, namely time, space and force. Combat with asymmetric enemies proved to be even more challenging as in many cases it was even a problem to identify who is the enemy or to distinguish fighters and terrorists from civilians. The combat situation changes every second and reaction time is of critical importance. In parallel, Western democratic societies have required governments to enhance their security against both conventional and unconventional enemies including limiting casualties among their own soldiers and civilians. In this sense, unmanned vehicles have been deployed with promising results in support of soldiers, insofar as they are ready to operate in all terrain and weather conditions to hit a target faster than men. Additionally, a loss of an unmanned platform has far fewer consequences for decision-makers and societies; equally, should such vehicles be captured, they will not generate shocking media coverage and cannot be tortured or held hostage by terrorists, thereby limiting the media effect on one's own population. It is especially true in the case of US and other democracies where no man should be left behind and where an enemy does not respect international law. The global war on terrorism was one of factors that supported further development of unmanned ground vehicles (UGVs) including research on their application in inhabited areas limiting the risk for soldiers.

UGVS' UTILISATION

Recent conventional and asymmetric conflicts revealed that the utilisation of unmanned vehicles in a variety of roles was more and more common and effective when supporting friendly operations. The experiences and applications have created new solutions and ideas opening untraditional ways of using crewless options. In that area, the US was lead nation, investing funds into research projects fully understanding that it was about preserving its dominant role as a global military power. It is quite natural that US combat experiences have been analysed by other nations recognising capabilities linked with automation of the battlefield. That race has been very intensive in recent years in relation to all dimensions of combat. As an effect, as for now, we are dealing with

> artificially intelligent systems and robots that are stronger than humans, that can venture places where people cannot go (such as Mars), that are smarter than people in certain cases (e.g., in chess), and so on. We are no longer truly surprised when machine artefacts outperform humans in new domains.[2]

Ronald Arkin even suggests in his research thesis for the US armed forces that 'robots not only can be better than soldiers in conducting warfare in certain circumstances, but they also can be more humane in the battlefield than humans.'[3] Ralph Peters, meanwhile, sees a role for ground robots when conducting urban warfare to secure outposts, selected areas and advises that 'robotic systems push deeper into the urban area, followed by armoured reconnaissance 'moving fortresses' or combination of separate vehicles, delivering fire power and dismountable forces to hostiles zones.'[4] Urban terrain was especially important for UGVs as of its complexity including variety of surfaces, stairs, narrow passes and as of complex population design causing a problem to recognise who is an enemy and who is not. The asymmetric conflicts in the urban terrain proved one important disadvantage as they are still not able to fully distinguish between enemy and friend and could even be a source of friendly fire.

The tests of land remotely controlled systems for military applications were introduced during the First World War, e.g. an American experimental remote controlled mini-tank 'Wickersham Land Torpedo'. On the eve of the Second World War, a remotely controlled tank buster 'Goliath' or Russian wireless remotely controlled 'Tele-tank' were introduced. Those designs started to be developed much faster after the war as of new technological discoveries. The new developments were specially advocated by UAVs which from support missions were transferred into combat missions; UAV 'Predator' was a symbol of that revolution. One of requirements was the need to limit casualties among soldiers. They were to be replaced by unmanned platforms equipped with artificial intelligence, equipment and armament allowing tasks to be conducted in difficult terrain, in a contaminated environment and in difficult weather conditions. Norman Friedman is linking it with a tendency to concentrate and focus humans only in those spots which are critically important and the rest should be covered by non-human assets.[5] The automation is to limit casualties among soldiers as those are costly to be trained and fragile to be lost, e.g. as of media effect. Moreover, unmanned systems could cover more tasks than soldiers allowing their numbers to be reduced. It is based on variety of sensors and operational systems mounted on UGVs, allowing them to react faster for a threat and to decisively use weapon with high precision. They are to be force multipliers based on unique characteristics. The US is a leading nation in developing technologies with military applications and it refers toward unmanned systems based on maturing concepts of their use in future conventional and asymmetric conflicts. According to Ronald Arkin, the major motivators are as follows:[6]

- Force multiplication – fewer soldiers are needed for a given mission; an individual soldier can now do the job of what took many before;
- Expand the battlespace – combat can be conducted over larger areas that it was previously possible with less resources and manpower;
- Extending the warfighter's reach – enabling a soldier to see much further than before and to attack targets located far away very effectively;
- Casualty reduction – could replace people in the most dangerous combat zones and they could conduct the most hazardous missions for soldiers.

Currently one of best known research organizations is the US-based Defence Advanced Research Projects Agency (DARPA), which has been conducting research for more than fifty years to 'make pivotal investments in breakthrough technologies for national security.'[7] It is very successful in developing innovative solutions as it is closely cooperating with academics and governmental partners investing funds (budget for FY 2015 reached US$2.9 billion) in promising and desired projects. According to a report released in 2015, DARPA's major areas of interest include: rethinking complex military systems, mastering the information explosion, harnessing biology as technology and expanding the technological frontier.[8] By enabling

> faster development and integration of breakthrough military capabilities in today's rapidly shifting landscape, DARPA is working to make weapons systems more modular and easily upgraded and improved; assure superiority in the air, maritime, ground, space and cyber domains; improve position, navigation and timing (PNT) without depending on the satellite-based Global Positioning System; and augment defences against terrorism.[9]

The new technologies are to complement friendly forces to fight both conventional and asymmetric enemies as those two types of current and future opponents are also increasingly relying on very sophisticated technologies. This is essential for land forces as those are lately exposed toward direct attacks in variety of environments including urban areas. New capabilities provided by unmanned platforms are important solutions to safe life of soldiers and to strike using up-to-date information and support from land, sea and air based systems.

The US is not the only country developing unmanned capabilities as those were recognised by other nations and extremist organisations. Russia has been active lately, within the modernisation of its armed forces, to move innovative programmes ahead recognising that it is behind in that domain. After analysing the utilisation of unmanned vehicles, especially in air space by the US in Iraq, Pakistan and Afghanistan Moscow decided to do more. Even during the war in 2008, Georgian forces were using Israeli drones effectively showing a Russian lack of well-developed solutions. It is an effort to regain a better position on that market, as 'a mere 20 years ago, Moscow was an undisputed leader in this field: In the 1980s, it manufactured 950 Tu-143 reconnaissance UAVs alone.'[10] The new concepts of unmanned platforms are under development by research institutes and used during tests and exercises. Russian Defence Minister Sergei Shoigu's intent 'to spend 320 billion roubles (about $8.8 billion) by 2020 on a program of supplying the Russian armed forces with unmanned aerial vehicles', is supporting attentiveness into looking for unmanned land based vehicles.[11] Similarly, China has recognised a need to invest into unmanned and automated systems in support of military and non-military operations. Again, it is linked with contemporary experience in the field and new options offered by a dynamically developing research and technology sector in the country. There are other reasons as expressed by Paul Springer[12], who claims that the People's Liberation Army is challenged to recruit the proper number of skilled candidates for military service, and one of possible solutions is the replacement of men in some areas by new technologically developed systems. Funds on research and development (R&D) are raising and 'China is the world's second largest investor in R&D with a forecast spending of $396.3 billion for 2016', meaning a 6.3% increase compared to 2015.[13] It is strong support for military industry and an opportunity to win international markets and to sell products abroad as China has many contractors and partners in developing countries including weapon sales. It includes developments of systems with stealth characteristics.[14] According to an US report to Congress, 'some estimates indicate China plans to produce upwards of 41,800 land- and sea-based unmanned systems, worth about $10.5 billion, between 2014 and 2023, and those are already incorporated in military drills.[15]

UGVs will continue development as those have been recognised as effective support for any operation in all type of environment. Initial attention on aerial systems has evolved into other domains of engagement space. It is supported by general interest of the armed forces of the major military powers requiring new and overwhelming capabilities. Another supportive impulse is connected with commercial options as a market for that type of platform is growing, encouraging investors. An example could be business-related success of Israeli companies like Israel Aerospace Industries which is producing, among others, many land systems including unmanned ground vehicles[16]. Israel is one of leading nations regarding technologically developed unmanned systems and export is important part of its business profit. In general, the progress of UGV is based on range of possible tasks to perform like: reconnaissance, force protection, terrain surveillance, combat utilisation etc. Their utilisation will influence future armed forces and law enforcement services and their growing autonomy and reliability will change battlefield. The challenge is that the R&D sector is requiring significant investment in people and infrastructure and it is obvious that only developed nations will afford investing into sophisticated security options. It will enhance competition and will create a gap in relation to smaller countries struggling with national economy shortfalls giving advantage over them.

UGVS – CLASSIFICATION AND CHARACTERISTICS

Contemporary UGVs are no longer slow wire-controlled devices used for very limited tasks. Currently they are remotely controlled by operators sitting in safe locations; they are armed and ready to operate over extended periods of time, preserving full readiness to act. UGVs are multirole platforms as they could be configured for a specific mission at short notice. They do not possess features specific for soldiers which could stop them from performing any risky missions and number of variants is limited only by human imagination and technological boundaries – disappearing with every new discovery. Researchers from the Military University of Technology in Warsaw describe UGVs' tasks as follow:[17] destroying defended infrastructure and logistics system;s reconnaissance of enemy territory, contaminated areas, water obstacles and minefields; operations in urbanised terrain, surveillance and annihilation of defended sites and weapon systems (including reconnaissance and annihilation of improvised explosive devices in asymmetric environment); operations in contaminated areas when there is even minimal threat for soldiers; suppling of ammunition, equipment, medical means and food for troops at a frontline; evacuation of wounded allowing soldiers to continue combat. The classification of UGVs based on US Future Combat Systems (FCS) methodology is as follows: small/light (14–180 kg or 31–400 lbs), small/medium (181–1 130 kg or 401–2 500 lbs), small/heavy (1 131–9 000 kg or 2 501–20 000 lbs) and heavy (over 13 500 kg or 30 000 lbs).

Another classification was prepared to guide industry concepts as follows:[18] soldier UGV (small soldier-portable reconnaissance and surveillance robots); mule UGV (1-ton vehicle suitable for an RSTA or transport/supply mission) and armed reconnaissance vehicle (6-ton vehicle to perform the RSTA mission, as well as a fire mission, carrying a turret with missile and gun systems) – some examples are presented in Figure 1.

Figure 1. Selected UGV of the Joint Robotics Programme
Source: Rob Maline, 'Joint Ground Robotics Enterprises,' (Arlington, National Defence Industrial Association, March 22, 2012).

The Committee on Army UGV Technology recognised another categorisation closely related to progress in creating more autonomous vehicles. It divided UGVs into four classes:[19]

1. Tele-operated ground vehicle (TGV) – a human operator controls a robotic vehicle from a distance and he is to conduct all cognitive processes. TGV has sensors and communications link to visualise its location and movement; they come in all sizes.
2. Semiautonomous preceder-follower (SAP/FUGV) – could be in all shapes and sizes and they have advanced navigation capability minimising operator interaction. It can do cognitive processes to select the best route to traverse a selected objective.
3. Platform-centric autonomous ground vehicle (PCAGV) – can be assigned a complex tasks/missions and will execute it acquiring information from other sources and is responding to additional commands from a controller, but without requiring further guidance.

It could deliver lethal weapons and requires fail-safe interrupt mechanisms. PC-AGVs should be able to carry out assigned missions in a hostile environment and should have survivability and self-defence approximately the same as similar manned vehicle sent on the same mission.

4. Network-centric autonomous ground vehicle (NCAGV) – their level of autonomy is sufficient to operate as independent nodes in a net-centric warfare model based on information from the communications network. They can incorporate data in their mission execution and respond to appropriate information requests and action commands received from the network, including resolution of conflicting commands. They should be the equivalent of manned systems and could be similarly tasked.

These categories could differ in countries but they are being implemented intensively and the only difference is as of technological development of a military industry and total value of contracts. US armed forces made significant progress within the Future Combat Systems (FCS) programme run between 2003 and 2009. The programme included a variety of UGVs concepts as presented in Figure 2 and included a range of combat and support platforms. Those are integrated in a complex network merging both manned and unmanned systems to increase effectiveness of the whole as a system of systems. Such the joint approach is aimed to create deadly fusion of capabilities within an area of operations creating superiority of friendly forces when facing both conventional and asymmetric enemies.

DARPA was cooperating closely with the Army Research Laboratory (ARL) in the Robotics Research Programme and although FCS was cancelled many of its projects have been continued. The focus has been on primary metrics as: endurance; mobility, and payload fraction followed by secondary ones as: airdrop-ability; robustness to crash; reliability; signature, and cost.[20] When fielding new weapon systems, RAND's 'Talon Sword' robot – armed with a machine gun – was tested in Iraq and Afghanistan. Its upgraded version, MAARS (Modular Advanced Armed Robotic System – Figure 3), is an even better armed robot (M240B machine gun, four 40mm grenade launcher tubes). It was

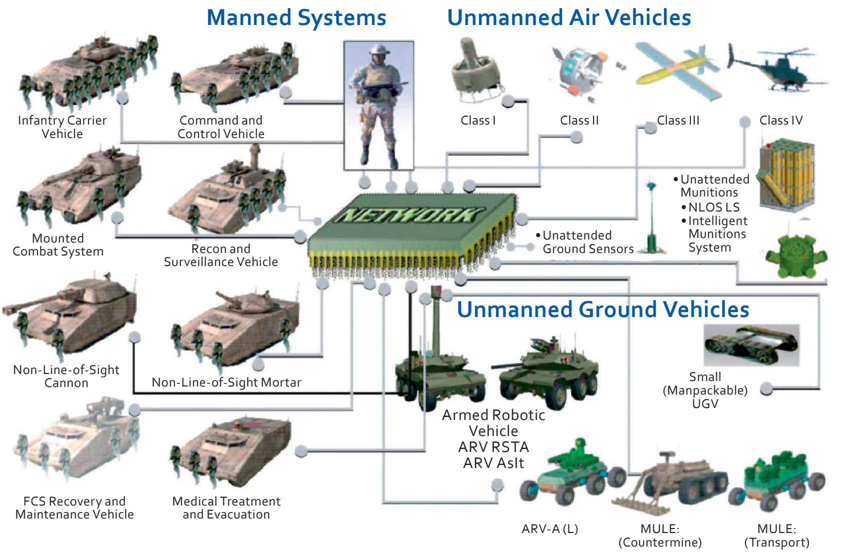


Figure 2. UGV as a component of the Future Combat Systems

Source: Future Combat Systems (FCS), Global Security.org.

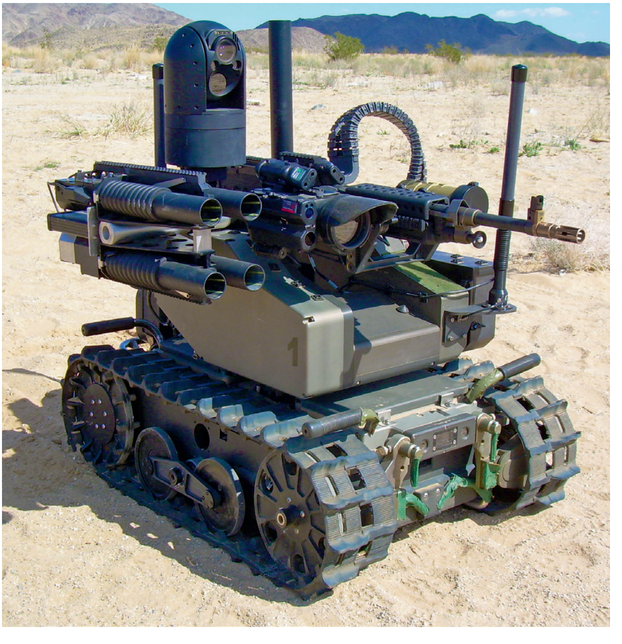


Figure 3. MAARS (Modular Advanced Armed Robotic System)

Source: "Modular Advanced Armed Robotic System," QinetiQ North America (QNA) Company, https://www.qinetiq-na.com/products/unmanned-systems/maars/ (accessed September 21, 2016).

tested by the Marine Corps in July 2016 and one of advantages is that it is simple to operate and it 'keeps warfighters at a safe distance away from enemy fire.'[21] The Marine Corps Gladiator Tactical UGV sports a lethal weapon and will have an option to possess also non-lethal and crowd control systems. Well-known Boston Dynamics' 'Big Dog' with artificial intelligence and well developed navigation system ready to support soldiers or Lockheed Martin's MULE (Multifunction Utility/Logistics and Equipment) are further influencing the battlefield in many ways. All the projects are funded by DARPA along with heavy UGV concepts using tanks and other combat vehicles.

In Europe, an example of a UGV is the first French operational combat robot 'SYRANO' (Système Robotisé d'Acquisition pour la Neutralisation d'Objectifs) and it is designed to acquire and destroy targets. It has been developed by consortium of CAP Gemini Corporation, SAGEM Company, GIAT Industries based on request from the French *Direction générale de l'armement* (Government Defence Procurement and Technology Agency). The robot has been build using combat vehicle 'Wiesel' AWC (see Figure 4) and is designed mainly for an urban environment with small size, good armour protection and a variety of sensors, enabling effective terrain surveillance. The 'Syrano' was also an effect of the fact that 'robots and drones appeal to French political and military leaders as a less expensive, more dependable means to enhance military effectiveness. As such, it is not surprising the France is home to a number of the largest robotics and UAV producers in the world'.[22] Indeed, in recent conflicts, many cases were connected with urban combat, e.g. in Vietnam or Iraqi[23] used by asymmetric enemies looking for options to cause casualties and to mitigate technological advantage of Western-style armed forces.

Russian NITI 'Progress' company has developed a prototype of a tracked robot 'Platforma-M' which is remotely controlled, mobile armed platform with own opto-electronic observation systems. It could be used 'for gathering intelligence, for discovering and eliminating stationary and mobile targets, for firepower support, for patrolling and for guarding important sites. The unit's weapons can be guided, it can carry out supportive tasks and it can destroy targets in automatic or semiautomatic

Figure 4. The French combat robot SYRANO.

Source: „Pierwszy francuski autonomiczny robot militarny Syrano" (The first French Autonomous military robot Syrano), Asimo.pl Polish Robotics Portal (2010), http://www.asimo.pl/modele/syrano.php (accessed September 27, 2016).

control systems.'[24] The robot could be armed with grenade launchers, machine guns and even laser-guided anti-tank missiles. Other armed prototypes are 'Wolf-2' mobile robotic system, the 'Shooter' ('Strelets') having a machine gun fixed atop a tracked chassis. A 10-ton 'Uran 9' robot tank is heavily armed with 'a machine gun, 30mm cannon that fires 350 to 400 rounds per minute, a coaxial 7.62mm machine gun and a battery of supersonic guided missiles.'[25] It is ready to be deployed in line with infantry to deliver fire support having 'cutting-edge laser warning system, target detection, high-tech identification and tracking equipment.'[26] It is followed by a heavy UGV based on BMP-3 named 'Strike' and it will have even more combat power.[27] The projects are still under development as they are supposed to enter service in 2018 or later but those are presenting Russian tendencies toward future UGVs.

The unmanned ground systems are also used for other purposes replacing people in all weather and terrain conditions in day and night. An example is the security system covering the demilitarised zone on the Korean Peninsula as 'South Korean forces have installed a team of robots along the border with North Korea.'[28] SGR-1 robots produced by Samsung are equipped in heat and motion sensors and armed with

5.5mm machine gun and 40mm grenade launcher and could engage target from as far as 2km and they do not 'leave room for anything resembling human laziness.'[29] Nevertheless the final decision to fire belongs to an operator. A similar system 'Sentry-Tech' is used by the Israeli Defence Forces to cover the border with Gaza 'to eliminate Palestinians' Hamas operatives from approaching the border, laying ambushes, mines and improvised explosives (IEDs) and target Israeli border patrols.'[30] A few turrets are operated by one operator who is making decisions about engaging targets. The system is supported by 'Guardium Unmanned Security Vehicle' being an 'autonomous fence and border protection system designed and manufactured by IAI's Lahav Division.'[31] It could travel autonomously and could be used for military purposes as force protection platform to protect bases, airfields, and logistics stocks or to monitor specific area. The solutions and applications are limited only by clear recognition of military needs and researchers and engineers' imagination supported by technologies to deliver what is expected. The race will never end as it is promising direction of development of weapon systems allowing achieving superiority. The examples presented above show that there are many tendencies behind UGV development and those differ in size, weight, armament, sensors and those are based on the future role on the battlefield.

Implementation of UGVs is not only about building them but also about developing doctrines and procedures to make them operational in the combat environment, which is more complex every year. The reason is that proper tactics is supporting full exploitation of emerging capabilities. The UGVs are mainly used to support land forces by fulfilling variety of tasks ahead of and within units' formations. However, their growing autonomy is offering new options. The advanced autonomic systems are well suited for new net centric warfare concepts by employing 'swarm tactics'.[32] The tactics is allowing single vehicles to be located in a distance from each other but when a high value target is identified they on order could attack simultaneously. It is making them less vulnerable as of their dispersion and is allowing an operator to deliver devastating synergy effect and next to disperse again into standby mode. The units will be able to communicate with other ground and aerial ones sharing information. Network capabilities allow for the full control of all assets and an enemy would have a challenge to see any concentration of units and even if one is destroyed it is not harming the 'swarm' as a whole. Such studies are under consideration in the US in relation to Future Combat Systems. In January 2003, the Assistant Secretary of Defence organised a conference to 'examine swarming for its potential as an operational concept for future ground forces and for unmanned intelligence, surveillance, and reconnaissance (ISR) swarms.'[33]A RAND report recognises that in relation to swarming 'the technical tools to support it already exist', and that 'moving toward swarming is going to be more a function of cultivating an appropriate turn of mind and a supple, networked military form of organisation than it will be a search for new technologies.[34]

Also small armies are looking for such solutions to mitigate the limited funds and size of their forces. For example, the Australian Defence Force is 'developing innovative networked sensor technologies, and testing autonomous unmanned vehicles to offset the small size of their military.' Indeed, it is 'testing network communications that will allow one operator to control a formation of unmanned aerial vehicles that can be programmed to peel off independently for surveillance, or to launch an attack.'[35] The challenges could be related to magnetic spectrum and electronic warfare capabilities as those could have an effect of unmanned vehicles causing them to be non-operational if affected.

CONCLUSION

The development of UGVs and other ground systems is occurring across different vectors but there is a general trend to invest in such technologically developed solutions for military purposes. It is not only linked with combat functions but also to enhance combat service and support capabilities of the land forces. This trend will likely continue and a variety of possible platforms will influence the way future operations will be conducted. The tempo of technological change is growing, supported by education and science, giving an advantage to developed nations, particularly the US. By supporting research and technology, the country is able to encourage bright people from all over the world to join national academic and research centres and they are paying back by their innovative concepts implemented by organisations like DARPA. The addition of other countries to this struggle has elevated the competition. Unmanned platforms could be used as a political tool to pressure smaller nations, replacing the 'little green men' with 'little moving tanks'. The political risk and cost will be lower and definition of war status more complicated. Research in the field of automation of warfare will be continued and more autonomous UGVs will be more often part of combat, combat service and combat service support capabilities. The process is not reversible as there are promising results already in that filed. The successful utilisation of UAVs for support and combat missions is opening the way for broader ground applications. Other nations, such as China, Russia, France and the United Kingdom, will continue to invest in military industry and education to develop their own concepts and not to rely on reverse engineering of US designs. In general, US armed forces will influence future battlefields more than their possible opponents.

Unmanned systems with growing autonomy are a future reality and research will make them more capable and independent in making their own decisions. They will also be an important supplement of soldiers' capabilities and it is expected that 'teams of autonomous systems and human soldiers will work together on the battlefield, as opposed to the common science fiction visions of armies of unmanned systems operating by themselves.'[36] The UGVs have many advantages as in mass production they could be more cost effective; the costly training of crews is not required; the men casualties will be avoided; they will be able to operate without weather and terrain limitations based on specially design sensors; the reaction time will be limited as such platforms are not tired etc. Their response time is not limited by abilities of human brain to act against threat e.g. could be force protection systems monitoring specific areas. The reaction time, not limited by emotions and excitement, is to be counted in milliseconds but it is the outcome that scientists will be able to predict and develop. Future UGV development will need to solve some challenges related to complex land domain and it will include:

integration with air based platforms; improved command, control and communication; expanded resistance for external interference; better adaptability to terrain and weather conditions; improved mechanical and technical systems; better protection against enemy fire, specialisation in tasks performed; capability to conduct fight with enemy based UGVs. The range of problems to solve is significant but it is a promising direction of further development of combat systems. Human control will however be still necessary to ensure that systems are not reacting against false targets as an effect of enemy deception as those could even be innocent people. However, platform- and network-centric autonomous ground vehicles' developments are limiting the role of operators. The utilisation of UGVs limits costs related to training of soldiers operating specialised systems; allowing them to be kept on 24/7 readiness; limits the risk of casualties; and prevents the moral and political consequences of friendly soldiers being taken as prisoners of war, especially in hands of terrorists. Within an international, coalition environment it will enhance the flow of information inside a well-organised system, allowing better situational awareness and faster reaction to threats by activating UGVs swarms. It will be based on trust and a willingness to operate and cooperate among allies.

There are also recognised risks based on experiences connected with unexpected reactions and casualties among civilian and harmless population or even using friendly UGVs by the enemy if capable of taking control of them. Today, hackers can already try to attack and disrupt electronic systems by electronic warfare equipment. Such assets are relatively cheap and could be exploited by people possessing specific knowledge. Unmanned systems still face challenges when applied for conventional combat as an enemy capability to engage them in kinetic or non-kinetic ways is growing. Radio-electronic warfare and cyberwar assets are able to isolate or deny their use limiting all expectations toward them and it could have significant impact on operations if alternative solutions are not available. Another challenge is preservation of communication and control to avoid denying the flow of orders, influencing every single UGV and system as a whole. As for now UGVs used during conflicts proved to be effective against terrorism and the armed forces of less developed nations but that type of enemy was not capable of opposing them effectually. Utilisation of unmanned platforms has naturally led to research to develop assets to negate their use, often with much lower costs than expected. Todd Humphrey asserted 'to Homeland Security agents that spending around $1,000 on equipment and designing an application able to send signals to the drone's GPS receiver he is able to gain complete control of the vehicle.'[37] It contains a message and a warning.

There are some dilemmas connected with unmanned systems as the law clearly does not define their utilisation – an issue particularly for democratic nations as those tend to respect international law. There is also a disorder connected with terminology as nations and organisations do not use the same terms and that factor is played asking for recognised international definitions; this is not achievable in short term. Moreover, terminology used in English is based on a variety of translation and those often do not reflect the full meaning. DARPA is among those organisations that recognise that unmanned solutions are not only related to technologies and 'leadership and team members also understand that, in this pursuit, the Agency's work will at times raise ethical, legal, security or policy questions that cannot and should not go unaddressed.'[38] Currently it is the beginning of evolution led by research institutes based on military requirements. It is clear that all the systems operating in all domains of the battlefield will be united into one system-of-systems, allowing the merging of information from land, air, sea and outer space to achieve desired effect of combat missions. There are some moral dilemmas connected with emerging autonomous systems as 'if the military keeps moving forward at its current rapid pace toward the deployment of intelligent autonomous robots, we must ensure that these systems be deployed ethically, in a manner consistent with standing protocols and other ethical constraints.'[39] Especially as it is estimated that during the first five years of President Obama in office drone attacks caused the death of as many as 2,400 persons.[40] It caused validated criticism as strikes may 'violate the national sovereignty of the nations where they are used; constitute targeted assassinations that are illegal under international law; and be responsible, even regardless of how far terrorists and insurgents may constitute legitimate targets, for also killing many innocent civilians.'[41] Deadly attacks by drones on Pakistani territory are well known and those caused many protests. Similar attacks took place in Yemen, Iraq, Libya and Somalia and according to Pew Research Centre they caused a general perception that the US is acting very unilaterally and is not taking into consideration the interests of other nations and it is not concerned about international law.[42] Similar dilemmas must be discussed in all nations investing in unmanned, more autonomous systems. Christopher Coker in *Warrior Geeks* estimates that until 2035, most robots will be autonomous but probably unable to make a cognisant judgment, but they certainly will be able to act at their own discretion, to select targets according to their will, and even to reject people as decision-makers.[43] Until then, the military will have complete trust in their ability to learn quickly and to reprogram themselves. It will evolve especially the tactical level as operational and strategic decisions will still be taken by people.

The armed forces' fascination with unmanned platforms reflects the overall tendency in many branches of business where people have been replaced by industrial robots. Modern armed forces are facing an additional challenge as many are composed of active duty, professional personnel. The next problem is that modern weapon systems are not as simple as before so the quality and numbers of soldiers after mobilisation could not match needs. Unmanned platforms could be important force multipliers to perform some military related functions to supplement professional armed forces, thereby releasing troops to perform the essential tasks of missions. It is also a reflection of a social trend of aging populations in developed nations and rivalry between national industry and other sectors with the military to select and contract the best persons.

It is possible that 'autonomous, networked and integrated robots may be the norm rather the exception by 2025.'[44] It is in line with developments as 'the modern and postmodern trend in Western militaries has been to increase the proportion of tasks executed by machines while reducing the number of soldiers.'[45] Gordon Johnson claims that tactical autonomous combatants (TACs) 'will not replace humans on the battlefield' but they 'will bring a whole different way of conducting combat or managing conflict than we've ever experienced before.'[46] He recognises that TACs will transform warfare the same way as tanks did, particularly when allied to nanotechnology, advanced batteries, new energy sources (solar energy and fuel cells), automation, autonomisation, robotics, command and control systems and so on. The broader application of UGVs will be that commanders could use them to avoid the unnecessary sacrifice of soldiers' lives, safe in the knowledge that the machines could be replaced. The advantages of UGVs were captured aptly by Gordon Johnson of the US Joint Forces Command: 'They don't get hungry. They aren't afraid. They don't forget their orders. They don't care if the guy next to them has just been shot. Will they do a better job than humans? Yes.'[47]

ENDNOTES

1 The author writes here strictly in a personal capacity.

2 Ronald Arkin, "Ethical Robots in Warfare," IEEE Technology and Society Magazine (summer 2009): 30.

3 Ibid.

4 Ralph Peters, Fighting for the Future: Will America Triumph? (Mechanicsburg: Stackpole Books 2001), 97–98.

5 Norman Friedman, Unmanned Combat Air Systems, (Annapolis, Naval Institute Press 2010), 46.

6 Read also: Ronald Arkin, Governing Lethal Behavior in Autonomous Robots, (Boca Raton, Chapman & HALL/CRC, 2009), xii.

7 About DARPA and its major areas of research read in details on the Agency Website: http://www.darpa.mil/about-us/mission (accessed September 27, 2016).

8 Breakthrough Technologies for National Security, (Arlington, DARPA 26 March 2015), 4–9.

9 „DARPA Shares Its Vision for the Future", DARPA, http://www.darpa.mil/news-events/2015-03-26-2 (accessed September 27, 2016).

10 UAV – Unmanned Aerial Vehicle. Dmitry Litovkin, "Russia to bring first unmanned combat aircraft into service by 2020", Russia Beyond the Headlines, June 22, 2014, http://rbth.co.uk/defence/2014/06/22/russia_to_bring_first_unmanned_combat_aircraft_into_service_by_2020_37609.html, (accessed September 27, 2016).

11 Ibid.

12 Paul Springer, Military Robots and Drones: A Reference Handbook, (Santa Barbara, ABC-CLIO 2013), 87.

13 The 2016 Global R&D Funding Forecast, (New York, Industrial Research Institute 2016), 22.

14 Franz-Stefan Gady, "Will Beijing Deploy 42,000 Drones to Secure the South China Sea?" the Diplomat May 12, 2015, http://thediplomat.com/2015/05/will-beijing-deploy-42000-drones-to-secure-the-south-china-sea/ (accessed September 27, 2016).

[15] Office of the Secretary of Defense, Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2015, April 7, 2016, (36) Washington, Government Printing Office.

[16] See: "Land Systems," the Israel Aerospace Industries Website, http://www.iai.co.il/2013/16118-en/Business_Areas_Land.aspx (accessed September 28, 2016).

[17] Krzysztof Baszuk, Leszek Szczęch, „Rozwiązania pojazdów bezzałogowych," Zeszyty Naukowe Akademii Marynarki Wojennej (Research Papers of Naval Academy) Year LI No 4 (183), Gdynia (2010): 7–8.

[18] RSTA – reconnaissance, surveillance, and target acquisition. Technology Development for Army Unmanned Ground Vehicles, (Washington, National Academy of Sciences, the National Academies Press 2003), 2.

[19] Classes are based on: Ibid.

[20] "Future Combat Systems (FCS)," Global Security.org, July 7, 2011, http://www.globalsecurity.org/military/systems/ground/fcs-ugv.htm (accessed September 27, 2016).

[21] "Modular Advanced Armed Robotic System," QinetiQ North America (QNA) Company Website, https://www.qinetiq-na.com/products/unmanned-systems/maars/ (accessed September 21, 2016).

[22] Springer, Military Robots and Drones: A Reference Handbook, 72.

[23] About implications of urbanized terrain read also: Zdzislaw Sliwa, "Facing the Complex Battleground: Urbanized Terrain," Baltic Security and Defence Review, Vol. 11 ed. 2, (2009): 130–142.

[24] "Russia's Platform-M combat robot on display in Sevastopol (VIDEO)," Autonomous Nonprofit Organization "TV-Novosti", July 20, 2015, https://www.rt.com/news/310291-russia-military-robot-sevastopol/ (accessed September 29, 2016). Maksymilian Dura, "Propagandowe pokazy rosyjskich robotów przeciwdywersyjnych," Defense24, August 3,2015, http://www.defence24.pl/241240,propagandowe-pokazy-rosyjskich-robotow-przeciwdywersyjnych (accessed September 29, 2016).

[25] See also a video about the 'Uran 9' robot tank: "Deadlier Than Terminators: Watch Russia's Unique Robotic Tank in Action," Sputnik News, March, 27 2016, https://sputniknews.com/russia/20160327/1037037253/russia-robot-tank.html (accessed September 29, 2016).

[26] Ibid.

[27] Dmitri Jurow, "«Удар» роботом с 4000 метров: каким будет БМП-3 будущего," ТРК ВС РФ ЗВЕЗДА, April 26, 2016, http://tvzvezda.ru/news/opk/content/201604250751-bbjq.htm (accessed September 29, 2016).

[28] Mark Prigg, "Who goes there? Samsung unveils robot sentry that can kill from two miles away", the Daily Mail September 15, 2014, http://www.dailymail.co.uk/sciencetech/article-2756847/Who-goes-Samsung-reveals-robot-sentry-set-eye-North-Korea.html#ixzz3i19Gebu9 (accessed September 29, 2016).

[29] Ibid. See also: „Samsung Techwin SGR-A1 Sentry Guard Robot," Global Security.org, July 11, 2011, http://www.globalsecurity.org/military/world/rok/sgr-a1.htm (accessed September 29, 2016).

[30] "Lethal Presence: Remotely Controlled Sentries Assume Guard Roles", Defense Update, 2009, http://defense-update.com/products/s/271108_sentrytech.html (accessed September 29, 2016).

[31] "Land Systems," Israel Aerospace Industries, 2013, http://www.iai.co.il/2013/17483-31663-en/Business_Areas_Military_Land_UGV.aspx (accessed September 28, 2016).

[32] Friedman, Unmanned Combat Air Systems, 2.

[33] About the swarming concept for military applications read in details in: Sean Edwards, Swarming and the Future of Warfare, (Santa Monica, RAND Corporation 2005), 4.

[34] John Arquilla, David Ronfeldt, Swarming & the Future of Conflict, (Santa Monica RAND Corporation 2005), 5.
[35] Clay Wilson, Network Centric Operations: Background and Oversight Issues for Congress, (Washington, Congressional Research Service 15 March 2007), 28.
[36] Arkin, Governing Lethal Behavior in Autonomous Robots, 9–10.
[37] Perluigi Paganini, "Hacking Drones … Overview of the Main Threats," General Security June 4, 2013, http://resources.infosecinstitute.com/hacking-drones-overview-of-the-main-threats/ (accessed September 29, 2016).
[38] Breakthrough Technologies for National Security, DARPA, 6.
[39] Arkin, Governing Lethal Behavior in Autonomous Robots, 10.
[40] Bruce Pilbeam, "Reflecting of War and Peace", in International Security Studies. Theory and Practice, ed. Peter Hough et all. (New York, Routledge 2015), 99.
[41] Ibid., 99.
[42] Pew Research Centre quoted in: Andrew Moran, "Terrorism", in International Security Studies. Theory and Practice, ed. Peter Hough et all. (New York, Routledge 2015), 157.
[43] Christopher Coker, Warrior Geeks. How 21st Century Technology is Changing the Way We Fight and Think About War, (London, C. Hurst&Co 2013), 149.
[44] Maryann Lawlor, "Robotics Concepts Take Shape," The Armed Forces Communications and Electronics Association (AFCEA), Fairfax 2003, http://www.afcea.org/content/?q=robotics-concepts-take-shape (accessed September 24, 2016).
[45] Peters, Fighting for the Future: Will America Triumph? , 98.
[46] Gordon Johnson quoted in: Maryan Lawlor, "Robotics Concepts Take Shape," AFCEA International.
[47] Ronald Arkin, Governing Lethal Behavior in Autonomous Robots, 7.

ETHICAL CHALLENGES OF THE UNMANNED TECHNOLOGY. REVISITING THE JUST WAR THEORY

Dr. Asta Maskaliūnaitė

INTRODUCTION

During the last decade, 'war without warriors' has become increasingly less a fiction and more of a reality. The implications of the use of 'unmanned' technology, consequently, are ever more important and ever more widely discussed. A large part of this discussion focuses on the changing character of war due to these new developments and especially the ethical challenges of employment of such technology and its challenges to (the mostly Western) understanding of fighting a just war, usually referred to as Just War theory.

In this article, the major themes in this discussion will be presented, particularly focusing on the changing roles and positions of combatants and non-combatants. The first section will focus on what Paul W. Kahn framed as the 'paradox of riskless warfare' and look at the discussion of the effects of asymmetry in war. Next, the ideas of the detractors of this type of argumentation will be presented and finally, the focus will come to rest on the implications for the civilian population of the new modes of conducting war and the extreme challenge it poses not only to just war theory, but also to the practical waging of war and our understanding of war as such.

THE PARADOX OF RISKLESS WARFARE

Paul W. Kahn wrote his famous article 'The Paradox of Riskless Warfare' in reflection of the Kosovo bombing campaign, long before the use of drones became the order of the day.[1] With the rise of this increased use of the unmanned technology to fight conflicts in remote places, the insights that he proffers are even more important. In his article he states that the unique moral characteristic of the battlefield is the distinction between the combatant and the non-combatant. Combatants themselves are 'licensed, legally and morally, to try to injure or kill' other combatants, because they act in a kind of 'self-defence vis-à-vis the other.'[2] As Kahn further explains, the combatants on the battlefield are the creatures of no autonomy, whose individual free choice is suspended and so is the judgement of the objectives for which they are employed.[3] Here the requirement of reciprocity becomes of paramount importance. As Kahn explains:

> Combatants are allowed to injure each other just as long as they stand in a relationship of mutual risk. The soldier who takes himself out of combat is no longer a legitimate target. The morality of the battlefield, accordingly, is a variation on the morality of individual self-defence.[4]

At the same time, all armed forces try to minimise the risk of being killed or injured for their own combatants and maximise the possibility of killing or injuring the enemy. This may lead to the 'paradox of riskless warfare' which 'arises when the pursuit of asymmetry undermines reciprocity.'[5] In this case what occurs is 'a violation of the fundamental principle that establishes the internal morality of warfare: self-defence within conditions of reciprocal imposition of risk.'[6] If there is no such imposition, Kahn argues, war should give way to policing. Policing has a different dynamic and different moral outlook. In policing, the principle is that 'only the morally guilty should suffer physical injury.'[7] In such a case, the rules of engagement should be rethought, collateral damage will no longer be acceptable and the actions of security forces in the international sphere would be held to the same standards as those of internal law enforcement.

In their investigation of the riskless war, Henriksen and Ringsmose link the unease with the armed drones to Martin van Creveld's investigation of war and its changing character. According to van Creveld, war should not be seen as a simple rational instrumental activity pursued by the states, as in von Clausewitz, but rather as a 'social activity' that is pursued by separate individuals, who have an interest in becoming warriors and developing certain virtues that are associated with being a 'good warrior', not because they are deeply engaged in furthering some state objectives. Indeed, many of them would be quite pressed to answer what those objectives actually are.[8] Here, again, the idea of reciprocity is of paramount importance. It is only by exposing oneself to the risk of being killed that such warrior virtues can actually be achieved, or as Van Creveld puts it, 'killing people who do not or cannot resist does not count as war.'[9] According to Henriksen and Ringsmose, the unease with drone warfare may be seen to stem from the societal understanding of warfare through such warrior ethos. As they write, and it is worth quoting it at length:

> … while it might be at odds with our western self-perception in matters military and a politically correct understanding of war as something inherently horrible that must be governed by a strictly rational and instrumental approach and never glorified and honoured in its own right, the current uneasiness about too much asymmetry in war reveals that warrior virtues and ethical norms about the proper conduct of war still inform our perceptions of war.[10]

This latter quote offers a rather different understanding of the 'principle of reciprocity'. It presents this principle through a lens of some romantic (or nostalgic) view of the warrior and combat, while dismissing some quite practical implications of this principle that are appealing. That is because the principle is based only on the mutual right of combatants to kill one another, but also on the right of non-combatants to avoid being killed. There is nothing romantic or nostalgic in this interpretation, which is at the heart of Just War theory and which thus links with very practical (legal) implications combatant non-immunity with non-combatant immunity.

Kahn discusses this idea in his piece. He argues: 'In situations of extreme asymmetry, the distinction between combatants and non-combatants loses its value for moral discrimination.'[11] This happens because the distinction is based on the level of threat that each poses. If one side removes its combatants from the reciprocal threat-posing, it also undermines the power of the distinction between the combatants and non-combatants. As Kahn explains, 'Scrupulous adherence to lawful targets by an asymmetric power is unlikely to support a perception of legitimacy. In the absence of reciprocal risk, what had traditionally been seen as fair is likely to be seen as morally arbitrary and, if arbitrary, then an act of victimization of the powerless.'[12] Even more so, 'For the asymmetrically powerful to insist on the maintenance of the combatant/noncombatant distinction has the appearance of self-serving moralising.'[13] This, in turn, can lead to the justification of terrorism, for, if the weaker side has no chance of striking at a well-protected combatant of the enemy, it is faced with a dilemma where the only options available to it is 'to either surrender or transgress civilian immunity.'[14] Consequently, until the move Kahn suggests from warfare to policing takes place in legal, moral and also practical terms, 'we are likely to remain in this paradoxical situation in which the military's capacity for riskless application of force makes our own lives substantially riskier.'[15]

Suzy Killmister further elaborates on such idea with the focus on the implications for Just War theory and the principle of civilian immunity. She argues that the use of remote weaponry and the removal of one side from the physical contact limits the possibilities of retaliation for the actor under attack. In this situation only the following options are available: 'We are left having to claim that superior military technology engenders a superior moral claim, such that anyone targeted by remote weaponry is morally obliged to submit and/or surrender. Or we must claim that in situations of remote warfare, the principle of civilian immunity cannot hold. In such situations remote weaponry has the consequence of rendering just war theory either an ally of the powerful, or obsolete.'[16]

In short, Killmister deepens the argument already advanced by political philosophers, starting from Sartre and going through to Goodin and currently the Critical Studies on Terrorism school,[17] who see in the asymmetry of military capabilities between adversaries as justification for some parties to engage in terrorist activity. Killmister's argument is more convincing, however. So-called terrorist groups, seeking legitimacy, try to engage security forces and the military. The line between insurgency and terrorism can be quite thin and crossing it seen as deplorable. Yet, the military, in the environment described by Killmister, has removed itself to the deep bunkers on the other side of the world, attack upon it is impossible. The options available for the weaker side are thus limited to surrender or else the disregard for the civilian immunity of the adversary. In these circumstances, just as Kahn observes, the increased safety for military personnel implies less safety for civilians of the country that can thus become targets of retaliatory terrorist attacks.

The major implications of unmanned technology following these investigations rest in the changing realities of the field and their impact on the relationship between the non-combatant immunity and combatant non-immunity. Before delving deeper into this issue, however, it is worth also exploring the arguments of those who suggest that the use of the unmanned technology is not only a right, but even an imperative for the contemporary armed forces.

CRITICISM: IMPERATIVE OF FORCE PROTECTION AND IMPLICATIONS OF JUST CAUSE

While some researchers express misgivings about the use of 'riskless' technology and its implications, the temptations for its use for policy-makers and the armed forces themselves are clear. They can also find support in ethical arguments. In a powerful defence of unmanned aerial vehicles (UAVs)[18] Bradley Jay Strawser argues that it is imperative for the armed forces to use such technology, especially if one is fighting for a just cause. He develops what he calls the Principle of Unnecessary Risk and explains it in a following manner:

> It is wrong to command someone to take on unnecessary potentially lethal risks in an effort to carry out a just action for some good; any potentially lethal risk incurred must be justified by some strong countervailing reason. In the absence of such a reason, ordering someone to incur potentially lethal risk is morally impermissible.[19]

Strawser does, however, himself see some issues with this type of argument, as the wish to protect one's forces at any cost can easily lead to the application of all kinds of rather unsavoury tactics. As Uwe Steinhoff mentions in her article, if the safety of one's own military is increased even the use of poison gas becomes ethical, the only barrier against its use presently being that it is illegal under international law.[20] Strawser tries to go around this issue by adding one more requirement to the aforementioned force protection imperative – that of just cause. As he writes, 'the first question for the morally permissible use of any weapon technology is, of course, whether military action itself is morally justified. If it is not a justified undertaking in the first place, then it does not matter if it is carried out via a crossbow, a sniper rifle, or a UAV; it is morally impermissible regardless.'[21]

Jeff McMahan uses a similar argument in his 'Foreword' to the book by edited by Strawser, *Killing by Remote Control: The Ethics of an Unmanned Military*.[22] He argues against Kahn's description of the morality at war by focusing on the justness of the cause. In his examples, both the use of remotely controlled weapons by a state against which aggression happens or in case of humanitarian intervention, which is supposed to put a stop to genocide, are equally morally permissible. He criticises Kahn even more robustly, claiming that 'a view that rules out "riskless warfare" because it justifies killing in war only as the exercise of individual rights of self-defence by combatants on the battlefield, thereby making the aims of their war irrelevant to the justification of their action, cannot be the correct account of the morality of warfare.'[23]

The question of distinction between *ius in bello* and *ius ad bellum* is thus at the heart of the McMahan's argument and though this argument can be very appealing, the idea that the 'right side' should be held to different moral standards than the 'wrong side' they may also open up a Pandora's box. Simply put, the question is – who decides who is right and who is wrong? McMahan suggests that we can 'enlist the consciences of ordinary soldiers in the effort to prevent the initiation or continuation of unjust wars',[24] which seems to be, in fact, as utopian an idea as that of banning the 'riskless' technology. The contemporary focus on information warfare and the hybrid warfare is a good reminder that there are different truths for different people and there are practical reasons for keeping to *ius in bello* even when everyone thinks their fight is more just than that of the other. The moral problem in the use of the unmanned technology, therefore, arises not so much from the justness of the cause, but from the mentioned before condition of asymmetry.

COMBATANT NON-IMMUNITY AND NON-COMBATANT IMMUNITY

The question of extreme asymmetry, in turn, brings us back to the question of non-combatant immunity. The major issue that the theory of Just War grapples with during its thousands of years of history is: who can be legitimate targets of killing and injuring in a war? This is a complicated question, which only has an unambiguous answer for extreme pacifists. The rest of the ethical theorists deal with this issue in different ways, which should be explored if we want to find out what are the possibilities of addressing this issue with regards to unmanned technology and within the framework of Just War theory.

In her work, Uwe Steinhoff distinguishes four approaches to the distinction of who are the morally permissible targets in war and those who are not. These are: the moral guilt theory; the convention theory; the self-defence theory; and the justifying emergency theory.

The moral guilt theory is the oldest in the just war tradition. In it, only those who are responsible for unjust war are legitimate targets. In a version of this framework, the notion of combatant is explained by Jeffrey Murphy as those located 'anywhere within the chain of command or responsibility – from bottom to top.'[25] This theory has proven quite problematic in actually distinguishing the targets as it is not always clear who is actually responsible for such a war or for the attacks within such a war. The politicians who order such an attack should be the most obvious targets, but the many supporters of the attack, the majority of which could be civilians are also legitimate targets. The theory thus poses innumerable practical problems of distinguishing those liable to be killed and not.[26]

The convention theory tries to do away with the problems in moral guilt theory by interpreting non-combatant immunity as a 'useful convention.'[27] According to this theory, the principle of non-combatant immunity is a useful convention to which the competing sides should adhere to as it minimises damage done to the community and allows it to recover even from the worst conflict. It is further strengthened by the rule-utilitarian principle, which implies that 'those rules should be adopted and followed that maximise human happiness.'[28] In this case, it is beneficial for conflicting sides to forego, in a sense, the possibility to kill indiscriminately with the idea that the same principle will be kept by the other side. Yet, it is important to note that even if one side starts disregarding this principle, the convention still holds and whichever side abandons it can be seen morally (and often also legally) guilty, without regarding the question of who was first to violate it.

The self-defence theory argues that 'immediate aggressors would be legitimate targets of attack'[29] In the strict version of this theory it is only those who pose a direct threat that can be attacked back and injured or killed. This strict principle is seen as problematic, because if only the direct attackers can indeed be killed, the responsibility for the conflict seems to be removed from those who actually ordered the attack (the politicians) and put exclusively to those wielding the guns. In this case, an extreme version of this argument goes, children coerced into uniform are legitimate targets while those who coerced them and put them in danger are not.

As self-defence is the notion Kahn is advocating, it is worth going back to his argumentation. As we saw in Kahn, the combatant non-immunity stems from the lack of autonomy and the principle of reciprocity, where each of the combatants are allowed to pose risk to another in a kind of principle of mutual self-defence. As non-combatants are excluded from this reciprocal risk-posing, attacking them is immoral. If one of the parties in a conflict removes its military from a risk-taking position, it should be continued, for the created asymmetry implies that only one side takes some kind of risk, while another side does not take any risk whatsoever. The logical conclusion in this situation has to be the one reached by Kahn – that the only way to salvage the distinction between non-combatants and combatants and confer some kind of immunity on the former, is to deal with the situation of such asymmetric warfare as policing and follow the rules of policing instead of those of the war fighting.

Though Steinhoff is right to point out the dubious morality of 'mowing down children' in uniform, the self-defence theory can, in fact be salvaged by looking at it as a justification for the convention that the convention theory is talking about. The only explanation as to why a convention which connects the possibility to kill (and die) with the uniform and why it is thus maximising human happiness is if it is linked to the level of risk that the combatants pose to one another. This type of reciprocity, which does not exist between the non-combatant and combatant, no matter how much the former might be supporting the war effort, seems essential for the just waging of war.

The last principle mentioned by Steinhoff is that of justifying emergency. It goes further than the self-defence theory in outlining the conditions in which an attacker can be justified in taking life of the other. It claims that in a conflict situation, not only the immediate threat, but also less imminent dangers can justify the killing. While, for example, in the self-defence theory it is forbidden to kill a sleeping soldier, because they do not cause immediate threat, using this theory such an attack can be legitimate. In this sense it is a variation on the previous account and one which allows for attacks on a wider basis.

To conclude, the self-defence theory in combination to the convention theory seems to be best suited to evaluate the status of non-combatant immunity and its relation to combatant non-immunity. In this combination it also becomes clear that the use of unmanned technology by one side only and its removal from risk on the battlefield poses serious challenges to the actual convention and to the 'maximisation of human happiness' that it is supposed to convey.

ALTERNATIVE ELABORATIONS AND CONCERNS

The arguments offered above do not represent the exhaustive list of ethical considerations with regard to advances in technology that lead to 'riskless' warfare. Another direction taken in this discussion is the easing of constraints on war that such 'riskless' technology represents. The argument here goes in a similar line as that of the development of non-lethal weapons and notes that without the image of blood and gore in war, without the risk of death and injury for fellow soldiers (or, in the case of non-lethal weapons, also for enemy soldiers), settling disputes by military means or intervening in conflicts militarily becomes a tempting option, easy to take by the democratic citizenry, which is usually averse to such deeds. Even such advocates of the use of the unmanned technology as Strawser admit that this may be a problematic issue writing that 'the asymmetry created by the UAVs lowers the *jus ad bellum* threshold such that more unjust wars might be conducted because the risks of war to a nation-state could become so minimal'.[30]

Another set of arguments, advanced, for example, by Robert Sparrow, suggests that due to the impossibility to locate responsibility for the actions of autonomous machines, 'moral and legal responsibility and not mere causal responsibility'[31] mandates reconsideration on the use of such systems in warfare. In fact, the author claims, the lack of locating this responsibility should mean that 'it will be unethical to deploy autonomous systems involving sophisticated artificial intelligence in warfare.'[32]

Yet, a third set of arguments could focus on the concrete examples of the use of unmanned technology and the current reality of it being used by Western countries, primarily the United States, against less-developed countries, primarily in areas such as Pakistan or Yemen. Both Kahn and Steinhoff mention this argument, with Steinhoff especially forcefully claiming that while there might not be anything intrinsically wrong with the unmanned technology:

> In our world, however, military superiority is used to intimidate and coerce others, and it is employed in wars that are morally problematic at the very least and often undergirded by colonialist, imperialist, or downright racist motivations that remind those on the receiving side of such technology all too much of the times allegedly past, where the self-proclaimed *Herrenmenschen* and the harbingers of civilization discipline the brutes, mostly by killing them.'[33]

Her solution is the same as that of Kahn's – in the circumstances of extreme asymmetry, a policing framework should be applied, not that of war.

CONCLUSIONS

It is in the position of non-combatants that the use of 'riskless' technology has most ethical and practical implications. The main paradox of riskless warfare that it is more and more riskless for the armed forces and more and more dangerous for civilians. The just war theory becomes challenged to the extreme in this situation, as its reliance on the distinction between combatants who can justifiable be killed and non-combatants who cannot justifiably be killed is shaken. The unease with the technology of unmanned fighting machines thus becomes not a merely philosophical issue of little practical import, but a real life-and-death issue for the civilians caught up in a conflict.

Yet, as Henriksen and Rigsmose rightly observe, 'riskless warfare' is here to stay. Where they are probably less right is in dismissing it as just 'something we will have to live with.'[34] Such a conclusion is unacceptable as there are simply too many people who might have to die with it as well. Thus, the real challenge is to think about not only the technology that can protect the combatant, but also that which would protect the non-combatant. Therefore, we would do well to stick to the conclusion of Kahn – that asymmetric warfare should give way to policing with the different standards that it implies – and the persecution, exclusively, of the morally guilty, the standards of protection of those who are innocent, and the mechanisms of accountability for accidents or intentional misdeeds.

ENDNOTES

1. Paul W Kahn, "The Paradox of Riskless Warfare" (Yale Law School, 2002).
2. Ibid., 2.
3. This echoes the traditional Just war theory and also legal distinction between the *ius ad bellum* and *ius in bello*.

[4] Kahn, 3.
[5] Ibid., 2.
[6] Ibid., 4.
[7] Ibid.
[8] Anders Henriksen and Jens Ringsmose, "Drone Warfare and Morality in Riskless War," Global Affairs 1, no. 3 (2015): 287.
[9] Quoted in Ibid.
[10] Ibid., 288.
[11] Kahn, 5.
[12] Ibid., 6.
[13] Ibid.
[14] Suzy Killmister, "Remote Weaponry: The Ethical Implications," Journal of Applied Philosophy 25, no. 2 (2008): 122.
[15] Kahn, 7.
[16] Killmister, 122.
[17] For the discussion of Sartre's unpublished Rome lecture note, where he discusses the conditions for terrorist violence, see, e.g. Ronald E Santoni, Sartre on Violence: Curiously Ambivalent (Penn State Press, 2010). An influential philosophical account on the justifications of terrorism is that of Robert E Goodin, What's Wrong with Terrorism (Polity, 2006). For a representative of the CTS account, see Richard Jackson, "An Argument for Terrorism," Perspectives on terrorism 2, no. 2 (2010).
[18] As UAVs are part of the title of the article, such a name will be further used in discussion of this author's ideas. His argumentation, however, can easily be extended to other forms of 'riskless' technology.
[19] Bradley Jay Strawser, "Moral Predators: The Duty to Employ Uninhabited Aerial Vehicles," Journal of Military Ethics 9, no. 4 (2010): 344.
[20] Uwe Steinhoff, "Killing Them Safely: Extreme Asymmetry and Its Discontents," in Killing by Remote Control: The Ethics of an Unmanned Military, ed. Bradley Jay Strawser (2013), 201.
[21] Strawser, 362.
[22] Jeff McMahan, "Foreword to Killing by Remote Control," in Killing by Remote Control. The Ethics of Unmanned Military, ed. Bradley Jay Strawser (Oxford: Oxford University Press).
[23] Ibid., xiii.
[24] Ibid., xiv.
[25] Quoted in Uwe Steinhoff, On the Ethics of War and Terrorism (Oxford University Press, 2007), 71.
[26] "Killing Them Safely: Extreme Asymmetry and Its Discontents," 188; On the Ethics of War and Terrorism, 61–63.
[27] For the most influential account, see, George I Mavrodes, "Conventions and the Morality of War," Philosophy & Public Affairs (1975).
[28] Steinhoff, "Killing Them Safely: Extreme Asymmetry and Its Discontents," 190.
[29] Ibid., 188.
[30] Strawser, 358.
[31] Robert Sparrow, "Killer Robots," Journal of applied philosophy 24, no. 1 (2007): 67.
[32] Ibid., 74.
[33] Steinhoff, "Killing Them Safely: Extreme Asymmetry and Its Discontents," 207.
[34] Henriksen and Ringsmose, 290.

UGV DEVELOPMENTS IN 2020–2030 IN TERMS OF TECHNOLOGIES

Tianbao Zhang

SECTION 1: INTRODUCTION

A broad definition of an unmanned ground vehicle (UGV) is: a vehicle that operates while in contact with the ground and without an onboard human presence.[1] The Army plans to use UGVs for such things as weapons platforms, logistics carriers, and surrogates for reconnaissance, surveillance, and target acquisition (RSTA), both to increase combat effectiveness and to reduce the number of soldiers placed in harm's way.[2] UGVs can be divided into mainly three categories: (1) a soldier UGV, a small soldier-portable reconnaissance and surveillance robot; (2) a mule UGV, a 1-ton vehicle suitable for an RSTA or transport/supply mission; and (3) an armed reconnaissance vehicle (ARV) UGV, a 6-ton vehicle to perform the RSTA mission, as well as fire missions, carrying a turret with missile and gun systems.[3] The purpose of utilising UGVs is to assist soldiers, and strengthen their specialty in terms of expanding sensing and firepower cover range with advanced technologies. Furthermore, UGVs with larger sizes have some features like faster moving speed, larger payload, and so on. For difference purposes, UGVs may have various configurations, and essentially they are based on a mobile platform. The most common configuration is probably a mobile platform carrying a firearm system with the necessary reconnaissance and fire control system, forming a 'killer machine'. There are numerous discussions and research publications on the topic of ethics in using this type of UGV on the battlefield, e.g. 'Alienation from the Battlefield: Ethical Considerations Concerning Remote Controlled Military Robotics'[4], 'From killer machines to doctrines and swarms, or why ethics of military robotics is not (necessarily) about robots'[5], only to name a few.

Although killing and destroying are the basic forms that are inevitable in any warfare, reducing casualty of his own side is rather a highlight in the 21st century. The focus of this essay is on the future technology development of UGV in the sense of being smarter and more capable so that the combatants can have the best control of the battlefield.

In the following parts of this essay, the power supply system of UGVs will be introduced in section 2.1; the current and future development of artificial intelligence relevant to UGV will be discussed in section 2.2; the autonomous driving in civil application, the development trends and its reference relation with UGVs will be discussed in section 2.3; the changes in the future battlefield with applications UGVs in combination with robots will be reviewed in section 2.4; the UGV related sensors will be discussed in section 2.5; followed by a brief conclusion in section 3.

SECTION 2.1: THE POWER SUPPLY OF UGV

The essential feature of a UGV is mobility. The duration of the power supply is undoubtedly one of the most important indicators for evaluating a UGV, aside from the working temperature range. The most common power supply form for UGV is battery and electric motors, especially for small and middle sized UGVs. The combination of batteries and electric motors has some advantages over combustion engines: they are quiet, mechanically simple, therefore easier to maintain and repair. Another feature of electric power is, there is no heated exhaust, which is preferable for hiding UGVs' infrared signature. It is a vital consideration for surviving in battlefields.

From Figure 1 and Figure 2, the advantages of each power technology can clearly be identified. Fuel cell systems can outperform battery system by a factor of 2-8 (within the 100–1500 watt power range).[6] So, is it true that the fuel cell system is the perfect power supply for UGVs? Maybe not as it seems in Figure 1. For example, the most popular fuel for fuel cells is hydrogen. The supply of hydrogen is not comparable to the conventional energy sources, like diesel, gasoline or electricity, due to the

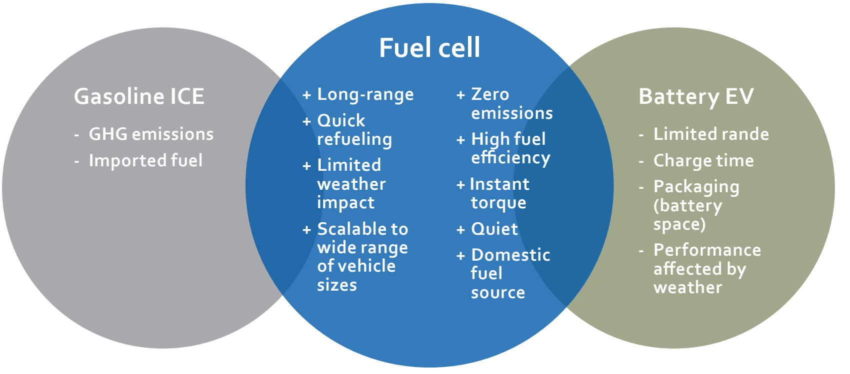


Figure 1. A comparison amongst petrol internal combustion engine (ICE), battery electric vehicle and fuel cell technologies.[7]

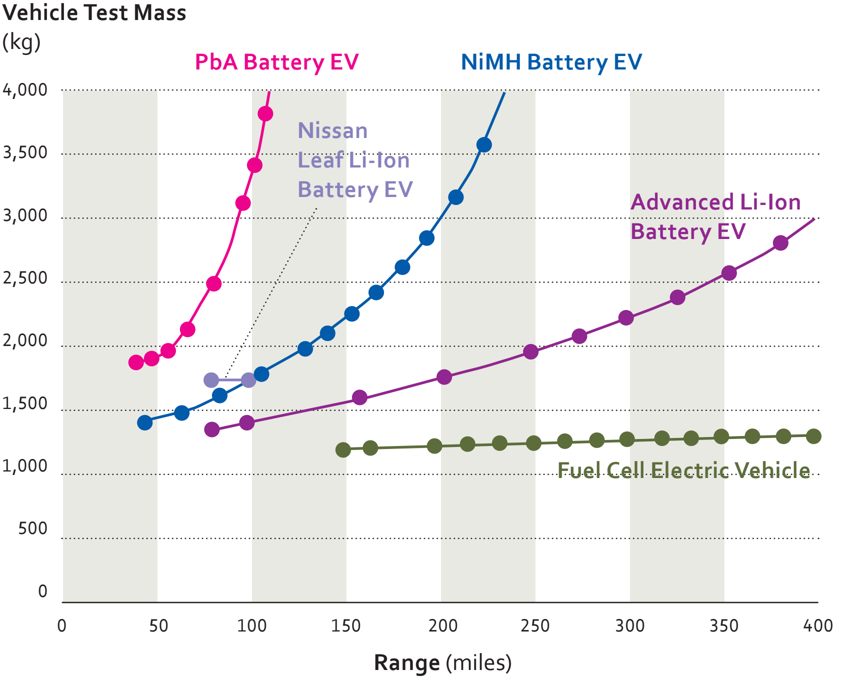


Figure 2. Vehicle test mass* versus driving range for different batteries.[8]

* The mass compound of a vehicle in order to have longer range.

production scale. It is also a question whether the production scale will expand rapidly, regarding to the uncertain needs from the civil market, e.g. fuel cell electric automobiles, which is a big factor. In the coming five years, the civil market should have promoted a preferred solution for cars, the development experience of which could be referred to serve the researches in UGVs. During the period 2020–2030, the benefits of utilising the new mature power supply technology will show up, and UGVs will have longer range, with less compound mass.

Currently, there are approaches to combine different technologies, for example, power management method in an electrical hybrid power source (EHPS) based on flatness control and fuzzy logic control,[9] and a report of ‘Control of a Lead-Acid Battery/Fuel Cell Hybrid Power System for a UGV’ showed the optimisation algorithms are important to make the best use of those hybrid power systems.[10] There are also products which utilize diesel-electric drive, one of the standouts is the UGV from an Estonian defence solution provider MILREM. This UGV, weighting 850kg, can work efficiently for eight hours with a fully charged battery

Figure 3. The UGV from MILREM with firearm system mounted.[12]

and tapped up gas tank.[11] The supercapacitors used in MILREM's UGV also ensures reliability when starting the vehicle in cold conditions or after prolonged periods in storage.[13]

In the period 2020–2030, the popularity of electronically driven UGVs is expected to rise, due to their beneficial features. Most likely the power will be supplied by the form of a hybrid of fuel cell, supercapacitor and battery. The market for supercapacitors is estimated to reach US$4.8 billion in 2020, with a five-year compound annual growth rate (CAGR) (2015 to 2020) of 19.1%[14] The interests of car manufacturers, e.g. Tesla, is a major prompt for this growth. At the same time, the applications of supercapacitor/battery in automobiles will be a 'proving ground'. There are some new approaches in fuel cell technologies, like feeding fuel cell with petrol,[15] or new type of catalyst to accelerate the production rate of hydrogen.[16] There are also improvements in battery technologies, e.g. lithium iron phosphate battery shows high energy density and large charge-discharge cycles.[17] Those breakthroughs may offer possibilities of a jump in fuel cell technology, enabling the UGVs to have longer working range.

The motor is the direct actuator which is responsible for the movement of UGVs. The reliability, energy efficiency, dynamic performance and output power density indicate how well a motor fits in a UGV's application. An all-wheel drive (AWD) UGV equipped with an individual electric motor for each wheel offers tremendous potential to control the angular velocity for each individual wheel and thus raise UGV's energy efficiency.[18] One of the approaches in optimisation of a motor's efficiency is focused on considering the motor's carrier harmonics.[19] In combination with supercapacitors, the energy from braking the UGV could be recycled, therefore extending the driving distance of an electric-powered UGV.[20] Fault-tolerant motor drives can be achieved by partitioning and redundancy through the use of multichannel three-phase systems or multiple single-phase modules, in order to reach high reliability.[21] These efforts are all aiming at a goal to use the energy most efficiently, i.e. prolonging the UGV's working duration as much as possible.

SECTION 2.2: THE DEVELOPMENT OF ARTIFICIAL INTELLIGENCE (AI)

What is artificial intelligence (AI)? The definition of intelligence is given as 'intelligence is the ability to make the right decision given a set of inputs and a variety of possible actions.'[22] In the early-age of artificial intelligence, those are called Strong AI. Strong AI is focused on building AI as a sapient entry with human-like intelligence, self-awareness, and consciousness.[23] The development of AI experienced a short winter in 1970s, due to going astray by understanding an artificial neural network partially, which re-emerged in 1980s, coming with the new concept of Weak AI, which is focused on solving specific problems, compared to Strong AI.[24] An example of Weak AI is AlphaGo, an AI system developed by DeepMind, being able to defeat Lee Sedol, one of the world's best Go players. AlphaGo is good at Go playing, but may not be as competitive as other dedicated AI system for other specific goals, e.g. FreeTTS from Carnegie Mellon University in the field of speech synthesis.

There are concerns of how to keep UGVs with firearm systems from abusing the power of firearms. In a few decades, it is foreseeable that Strong AI will be developed so dramatically, that it is reliable enough to be given total autonomy as a killer machine. For the time being, though, the final decision of 'to be, or not to be' is still going to be made by the tele-operators behind the screens, rather than the killer machines themselves. It is more likely that Strong AI systems will be applied in peace-oriented scenarios, like domestic caring, disaster rescuing, warehouse management, and so on. Meanwhile, there is a focus on researching Weak AI, which could enhance the existing machines in some certain capabilities, like object avoidance, target identification, industrial process control, and so on.

Looking at the development of AI in recent years, it has made quite big progresses in natural language processing, objects recognition and so on. For example, as shown in Figure 4, the system with the power of artificial neural network (ANN) can separate items in a rather sophisticated picture, and describe them in natural language.[25] This is quite exciting, because by getting the information from the

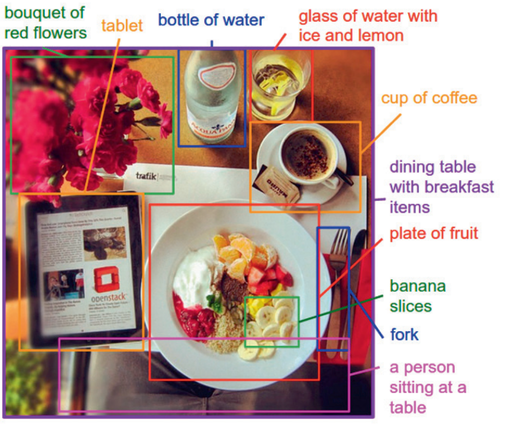


Figure 4. Generating natural language descriptions from an image with artificial neural network (ANN).[26]

images, the machine can understand what is happening around it, and then it can respond accordingly. In current UGV applications, the UGVs often need instruction from the tele-operators, especially for delicate movements. One reason is because the UGVs are not capable to understand the information acquihired from the sensors, like the camera. With impressive results, AI applications normally need huge amount of training data, and considerably demanding computational power. Another challenge is in processing and understanding video in real time, which is more meaningful, considering the quickly changing environment. In the future, AI technology is expected to develop continuously, benefiting from the growth of computational power (either by increasing the integration scale or by optimising the computer architecture for scientific usages), and the emergence of clever AI algorithms.

SECTION 2.3: AUTONOMOUS DRIVING

UGV's are similar to autonomous cars, in the manner that they both are ground vehicles and not operated totally by human drivers. Despite the fact that UGVs are often highly goal-oriented customised mobile platforms, autonomous cars are mostly based on some types of cars in the market. A major difference is that UGVs are often considered for military usage, while autonomous cars are mostly under development for civil applications. The tasks UGV can manage include but are not limited to: deactivating explosives, patrolling, transportation, reconnaissance and rescue.[27] UGVs are suited to perform daily routine and boring tasks with pin-point precision and efficiency.[28] In this way, there is an intersection between UGV and autonomous cars, in the aspect of cruising tasks, regardless of the road conditions and environment. The development and reliability validation of autonomous driving algorithms, e.g. object detection, auto-braking, and so on, are based on a large number of on-road testing. Due the inherited advantage that autonomous cars are accessible and widely researched all around the world, and can be conveniently tested on the road, the mileage has been increasing rapidly, e.g. Tesla has confirmed that Tesla's fleet was adding about one million miles of data every day.[29] It is foreseeable, that autonomous driving technology will be soon robust and reliable enough facing complicated situations. In this process, the development of UGVs could refer to the techniques in autonomous driving, and improve the on-/off-road passing capability in a faster pace. UGVs then will serve as a supplement to soldiers on the ground and eventually replace them in the future.[30] This will liberate soldiers to some extent from boring repetitive routines, harsh environment, dangerous ambush and so on.

SECTION 2.4: ROBOT ARMS

Depending on the size and power of UGVs, they could be equipped with a forklift, backhoe, bulldozer, and so on, either customised, or built in configurable structure, like the UGV from MILREM. Configurability is a plausible feature, as it can increase the versatility, and make the logistical support and maintenance much easier. Among all these possibilities, one powerful configuration of UGVs is as a mobile platform *and* robot arm. This configuration enables the UGV to accomplish more complicated tasks, which requires flexible control strategies, multipledimensional movements and relatively accurate executions. Since 1954, when the first industrial robot was invented, the technology in robotics has been constantly developed. The application of industrial robots has drastically increased the production proficiency, production quality stability, e.g. in automobile and micro-electronics industries. In recent years, the development of robotics has come to a new upsurge in two major streams: (1) among hobbyists and students, thanks to the popularisation of open-hardware like Arduino; (2) the fields where robots were not the mainstream solution before, e.g. robots for medical purposes. This trend draws a lot of attention from the traditional industrial robot manufacturers, e.g. KUKA and ABB, and shows a bright picture of the future of robotics. It also lowered the threshold of monetary and knowledge requirement for entering the world of robotics. This is plausible, because the enlightening of the students, who are potentially researchers or developers for robotics, is objectively preparing a think tank for the future. Even though their products may not be that impressive now, given some time – by 2020–2030, when current students will step into the next stage of their education or career – they will have progressed further and may bring out astonishing results. This prediction is based on the IT development history since the 1950s.

For a robot, some of the major development goals are: (1) heavier payload; (2) higher execution accuracy; (3) more intelligent for compliant tasks. To be specific in a UGV's application with robots, the payload is highly related with the design of the UGV's mobile platform; the absolute execution accuracy may not be that practical, as the working environment for UGV are often rough, e.g. the terrain may vary from combinations of rocky, sandy, muddy or snowy and sloppy ground to bushes or forests, which will contain plenty of uncertainties and external disturbances. On the contrary, the intelligence of robot arms hasn't been thoroughly developed as the former two goals, which industrial robots are quite good at already. In terms of compliance, there are two directions of approach: active compliance and passive compliance. The former one is normally done in software, e.g. torque control, with the help of machine vision, torque/force sensor. The advantage of utilising active compliance control is that it allows to upgrade the existing robots to have compliance capability, and the control result is more predictable as the robots have various sorts of sensor information. Passive compliance is the approach that construct or house the robots with compliance materials, in order to avoid manoeuvre exceeding the safety limits unexpectedly.

Why is compliance control is important? Because as the end-effector of an intelligent robot, the compliance capability is the minimum requirement when interacting with the real world, especially for some complex tasks in sophisticated scenarios. For example, when the UGV, equipped with a robot arm, is executing a task to de-activate explosives, a hard-material gripper with limited flexibility is doubtfully sufficient. A compliant 3-figure gripper from ROBOTIQ, as shown in Figure 5, is capable to apply compliant tasks like handover or material-handling in unconstructed environment, in a similar way to human hands. Although 3-finger grippers are more capable than 2-finger grippers, there is still room for improvement. It is foreseeable that by the year 2020, mature grippers with more than 3 fingers will be available on the market. By then, there will be a new trend to study compliant control with flexible robot fingers, aiming to accomplish more complex tasks. For example, with a powerful robot arm and elegant robot fingers, and a smart 'brain', a battlefield ambulance UGV is capable to execute battlefield rescue with the following features: (1) quick response; (2) no combatants required to be present in the scene. It might be too early to expect a machine to execute battlefield surgery totally autonomously, but fetching the injured (causing minimal secondary damage in the process) to a safer place for shelter and further treatment will be quite reasonable to occur before 2030. As a consequence,

Figure 5. 3-finger gripper from ROBOTIQ.[31]

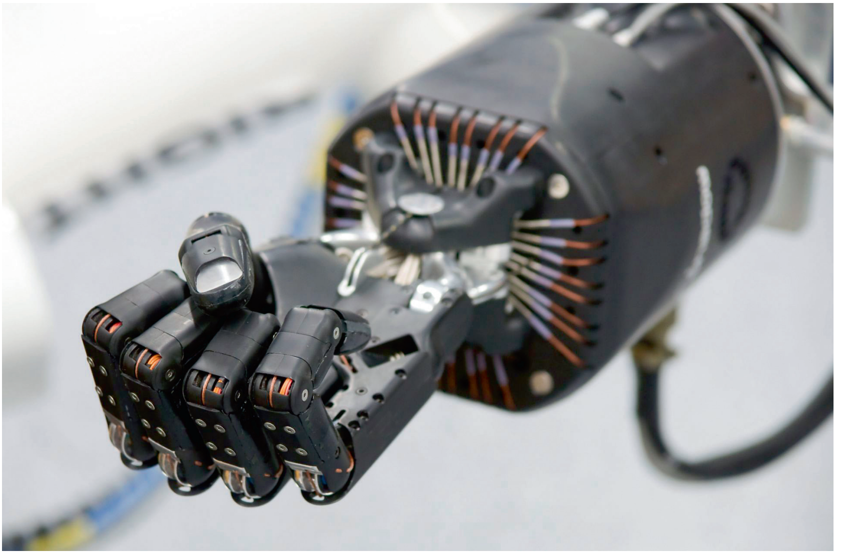


Figure 6. 5-finger gripper.[32]

more soldiers' lives may be saved. In this way, the sniper's tactic may change, which is wounding combatants rather than killing them, in order to divert opponents. This can be an example of how UGVs will change the tactics in the future battlefield.

SECTION 2.5: SENSORS

The purpose of applying sensors on UGV systems is mostly one of the following: improving the manoeuvre capability of the UGV itself, extending the sensing capability of the tele-operator or accomplishing certain tasks. One of the initial needs for UGVs is to accomplish chemical, biological, radiological and nuclear (CBRN) detection tasks, as those target fields are potentially hazardous and even vital to soldiers. Nanotechnologies' application (e.g. graphene) in biology and chemical sensors,[33] nuclear sensor,[34] and algorithms improvement in radiological sensing[35] and their respective future works will offer faster and more accurate identification in detection tasks. The trend is to offer more modular, smaller-in-size and more integrated CBRN sensors. Combining with advanced simultaneous localisation and mapping (SLAM) techniques, which can share the hardware/software resources with autonomous driving,[36] UGVs equipped with CBRN sensors can map the unknown target field precisely in cartography and the CBRN environment, which are good references for commanders to make operational plans.

The development of autonomous driving is also closely connected to the development of sensors. In an autonomous vehicle, several or all of the following sensors are used to collect information: camera (daylight and night vision), LIDAR, millimetre wave/ultrasonic radar and so on. The reason to use all or combinations of them is, they have different optimal working range, and can collect information from difference dimensions from their surroundings. For example, the advantage of LIDAR is that it can offer 3D geometry information with high resolution from a wide variety of working range, and have less influences from weather and lighting conditions, compared to cameras. The limitation for LIDAR application is the price. As LIDAR is also preferable to be used in autonomous cars, the price is expected to decrease due to the large demands in market in the coming years (2020-2030). Similarly, the cameras with higher resolution and larger dynamic range will come into application, as a result of the development in semiconductor industries. With more powerful sensors – higher resolution, longer working range, better stealth features while working) – UGVs are expected to have stronger capability for autonomous driving and RSTA tasks.

SECTION 3: CONCLUSION

With an overview of the technology development related with UGV from different aspects, it is likely that by the 2020s, UGVs will become more intelligent, more powerful and will be used in wider applications. Even when all underlying technologies for a UGV application have reached technology readiness level (TRL) 6 – the point when a technology component or subsystem has been demonstrated in a relevant environment – a great deal of work will be required for integrating specific technologies into one or more UGV systems capable of accomplishing future combat systems (FCS) missions.[37] But with the research and development efforts from the UGV manufacturers (e.g. ECA, ICOR Technology, iRobot, Mechatroniq, MILREM and many others) and numerous research institutes and universities, the challenges will be overcome one by one. UGVs will help us to have more efficient RSTA, more powerful ARV and less casualties on the future battlefield.

ENDNOTES

1 Wikipedia contributors, "Unmanned ground vehicle," Wikipedia, The Free Encyclopedia, https://en.wikipedia.org/w/index.php?title=Unmanned_ground_vehicle&oldid=742019573 (accessed October 1, 2016).

2 Committee on Army Unmanned Ground Vehicle Technology; Board on Army Science and Technology; Division on Engineering and Physical Sciences; National Research Council, "Technology Development for Army Unmanned Ground Vehicles", ISBN: 978-0-309-08620-2, 2002.

3 Rose Millard F., "Technology Development for Army Unmanned Ground Vehicles." Committee on Army Unmanned Ground Vehicle Technology, Board on Army Science & Technology, National Research Council (2002).

4 Wifferen Loes van., "Alienation from the Battlefield: Ethical Considerations Concerning Remote Controlled Military Robotics." Master Thesis, Utrecht: The University of Utrecht, 2011.

5 Coeckelbergh Mark. "From killer machines to doctrines and swarms, or why ethics of military robotics is not (necessarily) about robots." Philosophy & Technology, 24(3), 269–278, 2011.

6 Jeff Baldic et al., "Fuel cell systems for long duration electric UAVs and UGVs." Proc. SPIE 7707, Defense Transformation and Net-Centric Systems 2010, 770703 (April 27, 2010); doi:10.1117/12.851779.

7 Elizabeth Chun, "Tucson fuel cell: the next generation electric vehicle", December 2013, http://www.hyundailikesunday.com/2013/12/09/tucson-fuel-cell-the-next-generation-electric-vehicle/

8 EV Weight, http://www.cleancaroptions.com/html/ev_weight.html .

9 Majid Zandi et al., "Energy Management of a Fuel Cell/Supercapacitor/Battery Power Source for Electric Vehicular Applications," in IEEE Transactions on Vehicular Technology, vol. 60, no. 2, pp. 433–443, Feb. 2011. doi: 10.1109/TVT.2010.2091433.

10 John A Broderick, Dawn M Tilbury, and Ella M Atkins, "Control of a Lead-Acid Battery/Fuel Cell Hybrid Power System for a UGV: Experimental Report", Automotive Research Center, a U.S. Army Center of Excellence for Modeling and Simulation of Ground Vehicles Led by the University of Michigan, December 2014.

[11] MILREN research and development, http://milrem.ee/en/research_development .

[12] Graphene ultracapacitors to power new multipurpose UGV, http://www.electricvehiclesresearch.com/articles/8446/graphene-ultracapacitors-to-power-new-multipurpose-ugv .

[13] Ibid.

[14] Ibid.

[15] Kwon Byeong W. et al., "High-Performance Molybdenum Dioxide-Based Anode for Dodecane-Fueled Solid-Oxide Fuel Cells (SOFCs)." Energy Technology 2.5 (2014): 425–430.

[16] Morales-Guio Carlos G. et al., "Hydrogen evolution from a copper (I) oxide photocathode coated with an amorphous molybdenum sulphide catalyst." Nature communications 5 (2014); Sun Yujie et al., "Electrodeposited cobalt-sulfide catalyst for electrochemical and photoelectrochemical hydrogen generation from water." Journal of the American Chemical Society 135.47 (2013): 17699–17702.

[17] Hassoun Jusef et al., "An advanced lithium-ion battery based on a graphene anode and a lithium iron phosphate cathode." Nano letters 14.8 (2014): 4901–4906.

[18] Salama Mostafa, and Vladimir V. Vantsevich. "Mechatronics Implementation of Inverse Dynamics-Based Controller for an Off-Road UGV." ASME 2015 International Mechanical Engineering Congress and Exposition. American Society of Mechanical Engineers, 2015.

[19] Yoshida Yukihiro et al., "Efficiency Optimization of SPM Motor Considering Carrier Harmonics Based on Electric and Magnetic Networks." IEEJ Journal of Industry Applications 3.6 (2014): 422–427.

[20] Nian Xiaohong, Fei Peng, and Hang Zhang. "Regenerative braking system of electric vehicle driven by brushless DC motor." IEEE Transactions on Industrial Electronics 61.10 (2014): 5798–5808.

[21] Cao Wenping et al., "Overview of electric motor technologies used for more electric aircraft (MEA)." IEEE Transactions on Industrial Electronics 59.9 (2012): 3523-3531.

[22] Jones M. Tim. "Artificial Intelligence: A Systems Approach: A Systems Approach." Jones & Bartlett Learning, 2015.

[23] Ibid.

[24] Ibid.

[25] Karpathy Andrej, and Li Fei-Fei. "Deep visual-semantic alignments for generating image descriptions." Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. 2015.

[26] Ibid.

[27] Odedra Sid, Stephen D. Prior and Mehmet Karamanoglu, "Investigating the Mobility of Unmanned Ground Vehicles", presented at International Conference on Manufacturing and Engineering Systems, Huwei, Yunlin, Taiwan, 2009.

[28] Igor Pejic, "Autonomous Weapon Systems and US Military Robotics: Unmanned Aerial and Ground Vehicles (UAV and UGV)", SouthFront: Analysis & Intelligence, February 2016.

[29] Fred Lambert, "Google's self-driving car vs Tesla Autopilot: 1.5M miles in 6 years vs 47M miles in 6 months", Electrek, March 2016.

[30] Igor Pejic, "Autonomous Weapon Systems and US Military Robotics: Unmanned Aerial and Ground Vehicles (UAV and UGV)", SouthFront: Analysis & Intelligence, February 2016.

[31] Compliant gripper with 3-fingers from ROBOTIQ http://robotiq.com/products/industrial-robot-hand/

[32] A picture of robot hand with 5-fingers http://www.esa.int/Our_Activities/Space_Engineering_Technology/Publications

[33] Liu Yuxin, Xiaochen Dong, and Peng Chen. "Biological and chemical sensors based on graphene materials." Chemical Society Reviews 41.6 (2012): 2283–2307.

[34] Mamin H. J. et al., "Nanoscale nuclear magnetic resonance with a nitrogen-vacancy spin sensor." Science 339.6119 (2013): 557–560.

[35] Lin Hsien-I. "Searching a radiological source by a mobile robot." Fuzzy Theory and Its Applications (iFUZZY), 2015 International Conference on. IEEE, 2015.

[36] Wei Junqing et al. "Towards a viable autonomous driving research platform." Intelligent Vehicles Symposium (IV), 2013 IEEE. IEEE, 2013.

[37] Committee on Army Unmanned Ground Vehicle Technology; Board on Army Science and Technology; Division on Engineering and Physical Sciences; National Research Council, "Technology Development for Army Unmanned Ground Vehicles", ISBN: 978-0-309-08620-2, 2002.

AUTONOMOUS SYSTEMS AND AUTONOMY QUANTIFICATION

Dr. Agris Nikitenko and Jeff Durst

This chapter presents several methods for autonomy assessment and quantification of intelligent Unmanned Systems (UMS). While the importance of UMS in civil or military application has a solid increasing trend over the past decade and the number of commissioned UMS in defence and security sectors has reached many thousands, still the question about their performance assessment before or during the mission is open. Since military operation planning and execution is related to complex risk assessments and resource estimations a simple metric number representing an expected UMS performance potential within the given mission would be more than welcome. This chapter provides a detailed outline of new methodology developed to address the performance estimation problem. The methodology proposes a single metric Mission Performance Potential (MPP) that characterises the expected performance of a given UMS for a defined mission within the specific environment. Thereby the novel method provides a tool for predictive performance estimation instead of retrospective ones proposed by other methods, which are outlined within the chapter.

INTRODUCTION TO PROBLEM DOMAIN

UMS – regardless of operation domain: water, underwater, ground or air – play an increasingly important role in modern warfare, which increases the overall mission planning and execution complexity especially in difficult environments. A key capability of future UMS will be a true autonomy enabling them to operate and cooperate to achieve a common goal and lead the mission to its success. The current scientific and industrial trend regardless of the application domain moves towards this future of truly autonomous systems. The future visioning concepts that highlight the main benefits and the key challenges are Industry 4.0[1] and Society 5.0[2]. While both of them are being developed in different contexts i.e. industrial and social, they have a lot of common:[3]

- Both emphasise the role of Big Data and artificial intelligence as the key enablers of future systems, building smart manufacturing plants and smart environments;
- Highly integrated and cooperative Internet of Things (IoT) devices will enable the gathering and accumulation of a wide range of data enabling agile control and management of systems;
- Cyber security and privacy have been identified as the main problems that have to be addressed for the coming years to form the necessary technological background of the future manufacturing and living environments;
- Decentralised control and management are among the concepts ensuring flexibility and greater reliability of future systems.

Both to a large extent rely on the assumption that higher autonomy of the systems will bring greater performance and effectiveness within a particular application domain.

Looking back to the military domain most of the operational systems deliver weak autonomy or are completely tele-operated (especially in ground domain). This does not apply to systems being under development and research. One of the reasons why systems are slow in bringing more autonomy is due to the simple fact that in complex missions not always more autonomy means higher performance. However, elaboration of a metric for autonomy levels estimation itself is rather complex.

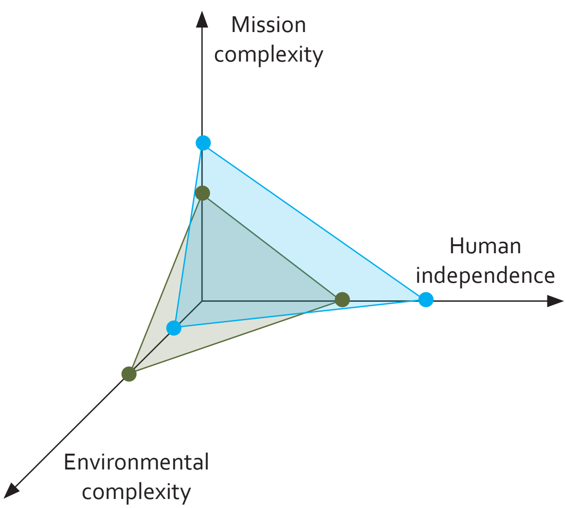
Unfortunately, there are no common standards or methods providing a comparative measure of different UMS and methods for measuring parameters of the systems itself, mission and environment. Some of the most commonly known and used tools are described in the following sections.

AUTONOMY LEVEL ASSESSMENT FRAMEWORK FOR UNMANNED SYSTEMS

While there are several reference system architectures and development methodologies for autonomous systems, the assessment of their autonomy and performance is still weakly developed. One of the most developed performance assessment models is ALFUS – Autonomy Levels for Unmanned System, which was created and presented by ALFUS workgroup in 2004 at the international Society for Optics and Photonics[4]. The model is focused on autonomous ground vehicles (UGVs) and consists of several components[5]:

1. Terms and definitions;
2. Detailed model for autonomy levels;
3. Summary model for autonomy levels;
4. Guidelines, processes and uses cases.

The ALFUS framework lays the groundwork for how an UMS's performance evaluations could be combined into a single quantitative measure of a system's autonomy.



Mission complexity:
- Commanding structure;
- Types of tasks;
- Collaboration;
- Dynamic planning and analysis;
- Situation awareness;

Environmental complexity:
- Static: terrain, soil conditions;
- Dynamic: object density, types and frequency;
- Operational: threats, decoy, mapping;

Human independence:
- Interaction time in (%);
- Planning time in (%);
- Workload and needed skills;

Figure 1. ALFUS scoring axes and parameter examples[6].

This detailed ALFUS model uses a three-axes method of Context Autonomous Capability (CAC) outlined in Figure 1. The scores for each axes are acquired through bench tests specific to particular test domain. Acquired scores are combined into a single autonomy level score. While the tests are specific to particular domain the CAC model itself is limited to these bench tests. Each of the UMS mission subtask is evaluated against the axes providing the autonomy estimation throughout the mission. The scores estimated afterwards are weighted and averaged providing a higher level task score thus providing an iterative method to calculate the score for the given UMS within the given environment and mission.

The summary model is a simpler version of the full model to be used for reference and further communication of the results to be compared with other systems. The model steps can be summarised as follows[7]:

1. Starting from the subtask autonomy scores they are summarised up to top level tasks using weighted sum;
2. For each autonomy level a human interpretable description is added;
3. Domain specific capabilities are described bringing the domain and mission context into the model.

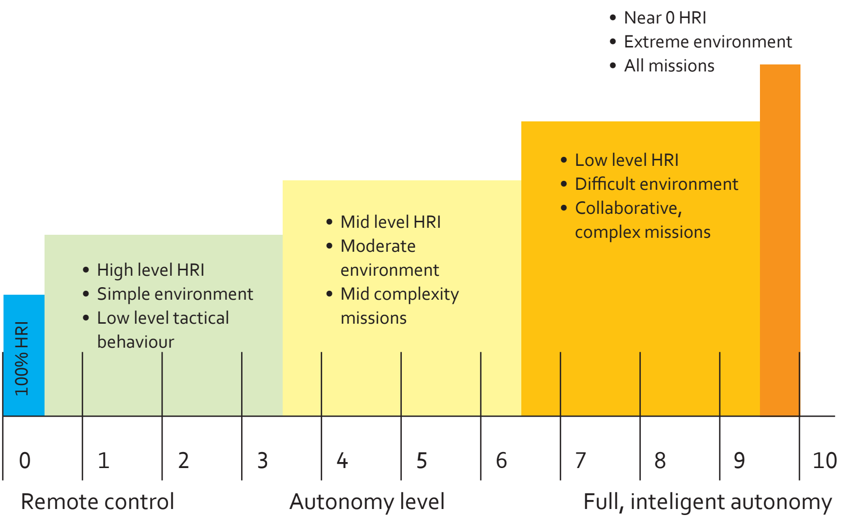


Figure 2. ALFUS summary model HRI – Human Robot Interaction[8].

As emphasised in[9] the ALFUS framework provides the capability of estimating the level of autonomy of one robot or a team of robots, but it still has some drawbacks that prevent its direct implementation:

- Lack of commonly agreed standards for task decomposition;
- Requires to conduct exhaustive tests for a given UMS;
- Lack of methods to assess the interdependency between the metrics, as some of the subtasks can apply to more than one metric;
- Uses subjective ratings instead of objective metrics decreasing potential of comparative measurements;
- Does not integrate the metrics into the final the autonomy level.

As mentioned above a fully autonomous mode of operation does not always deliver the highest performance. An example might be an inspection task of improvised explosive device, where a fully tele-operated asset would perform better due to various risk factors. Unfortunately, ALFUS suffers from the assumption that a higher level of autonomy is directly related to higher mission performance.

Other contextual-based measures of autonomy have been proposed, namely those focused on measures of human-robot interaction[10] and those designed to determine 'optimal' performance through adjustable autonomy[11]. While these methods provide the benefit of a rigid definition of UMS autonomy levels, they still suffer from many of the same drawbacks of the ALFUS. Specifically, any performance measure derived from human operator performance fails to produce a firm result that is comparable between systems and tests, especially for tests aimed at defining what sensor, hardware, and software requirements are 'optimal' for a given UMS.

NON-CONTEXTUAL PERFORMANCE ASSESSMENT

As illustrated previously context is one of the main drawback of the ALFUS approach since it brings a subjective component to the evaluation procedure. Even for the same UMS it might be difficult to re-establish the same environmental context. Therefore, a method, which could derive the performance just having parameters of the system itself would be more appropriate.

Moreover, most of the ALFUS inputs do not have commonly agreed methods or standards for their estimation, what makes it difficult to widely accept and apply in practical problems. Having these drawbacks highlighted a Non-Contextual Autonomy Potential (NCAP) has been developed, which draws the autonomy level from reference architecture model of a given UMS[12]. The NCAP provides a predictive measure of a UMS's ability to perform autonomously rather than a retrospective assessment of UMS autonomous performance. Furthermore, the UMS autonomy level is determined outside of a mission or environmental setting. The key difference is that the NCAP treats autonomy level and autonomous performance separately. A UMS that fails completely at its mission but does so autonomously still operates at the same autonomy level as another UMS that succeeds at the same mission.

The NCAP defines four Autonomy Levels (AL). The AL ranges from 0, no autonomy/fully-radio-controlled or tele-operated, to 3, fully autonomous. A UMS's AL is defined within the context of a generic UMS architecture model as follows. A UMS that only contains perception, i.e., a tele-operated Unmanned Ground Vehicle (UGV) with an onboard camera, has no autonomy. A UMS that generates some sort of world

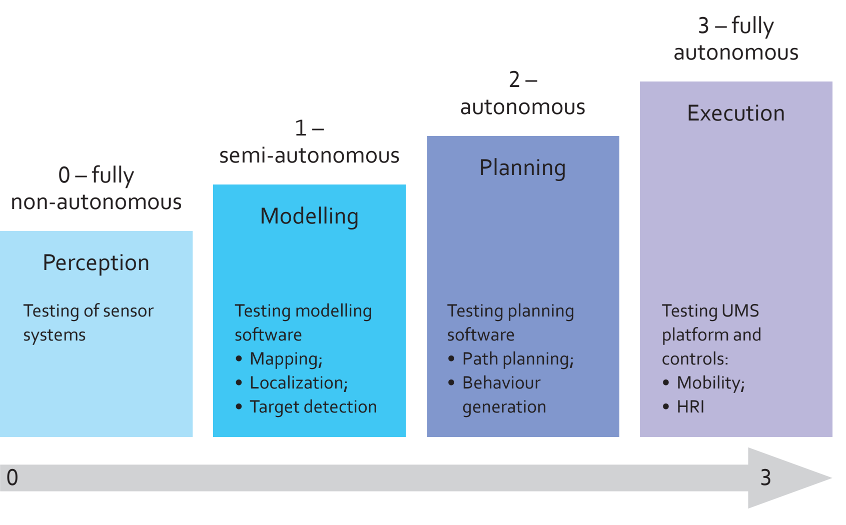


Figure 3. NCAP levels within generic UMS architecture model[13].

model or retains an internal knowledge base of its surroundings is considered semi-autonomous. At this level, the UMS is interpreting the raw sensor data on its own and has the beginnings of intelligence. A UMS that further uses its world model to form a plan of action is considered autonomous. At this level, the UMS is making a judgment based on its internal knowledge base. Finally, a UMS that chooses a best action based on its modeling and planning and performs that action without operator input is considered fully autonomous. The following figure shows the NCAP autonomy levels:

Figure 2 shows the NCAP AL along with the level of UMS architecture with which each AL is associated.

The NCAP is based solely on the UMS platform itself. Metrics based on component level testing of the UMS are combined to provide the final NCAP score, and the NCAP is meant to serve as a tool for predicting autonomous performance potential. According to the NCAP methodology the following table shows some examples of AL assigned by the model[14]:

Table 1. NCAP assessment examples

No.	UMS	Hardware	Software	NCAP autonomy level
1.	iRobot Roomba	caster-steered platform, IR sensor	edge detection, area coverage algorithms	3
2.	RC quad-rotor UAV	quad-rotor body	none	0
3.	NREC LAGR	wheeled platform, stereo camera, IR rangefinder, GPS, IMU, wheel encoders	obstacle detection, mapping, path planning	3
4.	CMMAD semi-autonomous counter-mine system	Talon UGV, camera, LIDAR, metal detector	obstacle detection, mapping, path planning	1

While the NCAP does offer some benefits over the ALFUS in terms of ease of implementation, it does not provide a complete solution to the problem of measuring mission performance or measuring the impact of autonomy on mission performance.

Therefore, a new metric for UMS performance is needed, i.e., one that fuses both contextual and non-contextual performance assessment methods into a single one.

MISSION PERFORMANCE POTENTIAL

The mission performance potential has been developed within NATO Research Task Group, which recommended the development of a new tool to address the lack of predictive measures of mission performance. To large extent the tool developed is a result of international cooperation among NATO alias demonstration not only a common interest but also a common commitment for future developments. Thereby the authors of this chapter are presented the work results and were only a part of the team.

As emphasised above a tool enabling predictive mission performance assessment without full scale testing would provide the critical tool missing in the UGV evaluation process. Unfortunately, for obvious reasons, without full scale testing in particular environments, or without mission context, the mission performance cannot be determined. However, if the mission context is known along with other critical data about the system and environment then it is possible to reason about performance potential that might be expected using the given asset. Specifically, a new tool should be developed that provides the following[15]:

1. A single, numeric value, comparable between UGV systems, that provides a predictive measure of UGV performance for a given mission, environment, and autonomy level;
2. A fixed UGV autonomy level and UGV performance is measured as a function of that autonomy level;
3. An input data set that can be evaluating using only the UGV system and mission description.

Thereby the MPP methodology having mission description, environment description and system description in terms of software, hardware and intelligence provides a single predictive number that describes the performance potential. Since the MPP measure is not based on retrospective tests analysis it describes the expectation level to be considered for mission planning or assets comparative analysis. The framework is presented in the following figure:

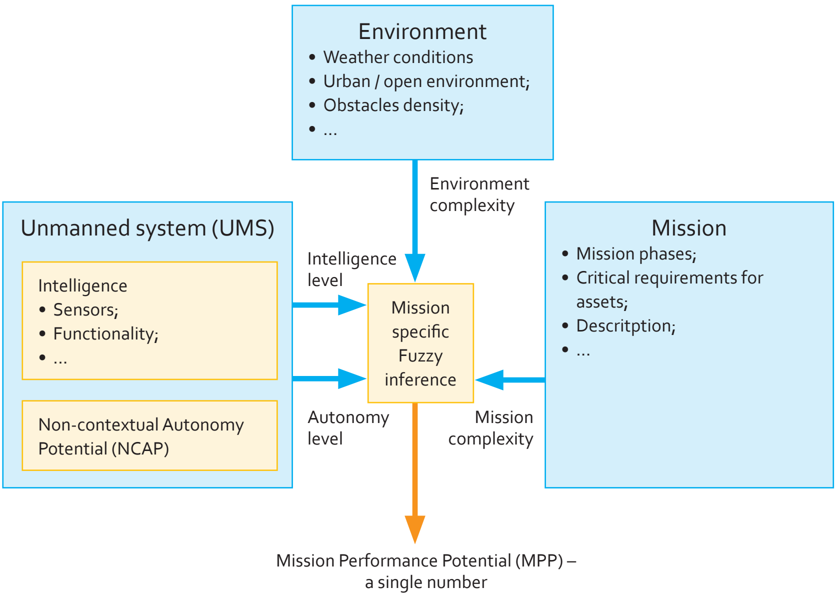


Figure 4. MPP framework – Mission specific fuzzy inference provides forms a core of the tool

MPP APPROACH

The MPP starts from an approach similar to the NCAP that fixes the UMS's autonomy level. This approach provides several benefits[16]:

- First and foremost, it fulfils the goal of assessing mission performance as a function of autonomy level enabling further comparison of the same asset under different operation modes, thereby increasing quality of mission planning;

- Second, these predefined autonomy levels provide users with a better understanding of the UMS's capabilities rather than an abstract number. Still it is and the assessment provided by the expert, but it limits the possible doubts about assignment of particular number;
- Lastly, this approach deals with the fact that for a given UMS, the autonomy level may vary between missions and environments. For example, a UMS may operate with some autonomy in urban environments but be fully tele-operated in off-road environments while having the same overall level of mission performance in each environment.

The MPP defines five levels of autonomy as follows[17]:

1. Radio-control: the operator is provided with a method of controlling the actuators of the vehicle directly. Sensory feedback is through human senses that are limited by visual range and noise.
2. Tele-operation: the operator is provided with a method of indirectly controlling the actuators on the vehicle, through control-by-wire or rates' control. He is also informed of the vehicle's status through communication subsystems and data visualisation techniques, i.e., visual animated gauges, maps, arrows, or heads-up displays.
3. Supervised Autonomy: the operator is provided with a method of controlling the vehicle's general behaviour. It is assumed the operator can maintain communications with the vehicle for task reallocation. This AL includes waypoint control, goal-based control, and scenario-based control.
4. Adaptive Autonomy: the operator is provided with a method for accepting the vehicle-initiated changes to the initial task, path, or goal. The vehicle is capable of suggesting, changing, or overriding previous operator commands, based on new situational awareness. It is up to the operator to manage the decision-making process in the UMS.
5. Higher Intelligence: the operator is provided with the vehicle's relevant information for decision making and tactical planning. The

operator does not need access to full vehicle's sensor readings or navigation sensors, and instead focuses on the mission sensitive data collection.

INPUT DATA

At its core as depicted in Figure 4, the MPP is similar to the previously proposed performance assessment frameworks. In particular, the MPP is an extended application of the basic ideas behind the NCAP that is built on the theoretical basis of the AFLUS. The MPP leverages the work already done in other efforts and reframes these ideas into a new framework that addresses mission-specific performance potential.

Similarly to the NCAP, the MPP framework ground its assessment on data provided by the field experts through answering a question about the mission and environment. The answers provide the 'filter' or 'masks' for minimum requirements to be met. If the 'mask' requirements are not met, then the MPP values are set to 0 automatically. For instance, if a given missions requires a particular positioning accuracy of the UGV and the given one cannot provide it, the MPP is 0, while all other aspect will not play any role for the MPP estimation. This is a major benefit of the MPP over previous methods.

Calculation of the MPP score requires three types of input data[18]:

1. Data about the system being estimated, i.e. the platform's physical parameters like weight, shape, dimensions, and sensing capabilities describing sensor types and their functional characteristics;
2. Data about the system's intelligence, namely the platform's decision making abilities including path planning, re-planning, obstacle avoidance, and other relevant qualities that demonstrate the system's active and reactive behaviours;
3. Data about the mission environment such as weather conditions, soil conditions, structured-ness (i.e. urban vs. cross-county), to name only a few.

Tables 2 provides a breakdown of the data as an example, including the values, ranges, and types of information needed to drive the MPP calculation. The main challenge behind the MPP calculation is the need for a reasoning procedure that allows the combination of input data that is different both in its nature and its value domains. As Tables 2 shows, data values fall within wide ranges and contain disparate types of information (binary, percentile, categorical, etc.). The only feasible solution for MPP calculation is therefore the use of fuzzy inference techniques allowing the combination of different information types into a unified inference mechanism. A full discussion of fuzzy logic and fuzzy aggregation operators is well beyond the scope of this work, and there is detailed review of these topics[19].

Using fuzzy logic, the MPP aggregates all the necessary data related to the UMS system (hardware, software, and intelligence) into a final MPP score. The rules and 'masks' mentioned above for the fuzzy aggregation are determined by the mission description. A brief description of some of the fuzzy aggregation methods used for the following example application of the MPP can be found in[20].

Table 2. Parameter example needed for MPP calculations: not all required are presented

Parameter	Description	Estimation approach	Comments
UMS platform parameters			
Physical parameters: Width, height, length	Size of the UMS	Numeric values	Different mission might need assets of different sizes
Locomotion schema	Categories list: skid-steered, Ackerman, Differential, ...	Single value from the list	The locomotion type can affect the MPP, for example a tracked vehicle will have a higher MPP for cross-country applications.
VTOL	Categories list: Yes/no	Single value from the list	Some of the missions might require vertical take-off and landing capabilities
Other parameters...			

Parameter	Description	Estimation approach	Comments
Control station parameters			
Command latency	Time between command input and platform response	Single numeric value	UMS with higher latency often have lower mission performance.
Portability	Is the ground station portable or not. Categories list: Yes/no	Single value from the list	Portability is an important for infantry operations.
Other parameters…			
Weather limits and environmental concerns			
Temperature	Min and max operation temperatures	Numeric values	
Wind	maximum wind speed in which the UMS can operate	Numeric values	Significant only for UAV and maritime assets
Optical visibility	Minimum operational visual range due to fog, clouds, rain, vegetation, etc.	Numeric values	Significant only for UAV and Maritime assets
Rain	Maximum rainfall in in which the UMS can operate	Numeric values	

Parameter	Description	Estimation approach	Comments
Wave height	Maximum wave height at which the UMS can operate	Numeric value	Significant only for maritime assets
Other parameters...			
Data links			
Range	max. range from control station	single numeric value	
Line of Sight	Does the UMS require LoS to operate?	Single value from the list	
Real-time configuration	does the control station allow real-time configuration of the UMS	Single value from the list	This parameter is currently qualitative and subjective.
Frequency	Transmission rate between the UMS and the control station	single numeric value	
Standards	Does the control station comply with any standards (i.e., JAUS)	Single value from the list	
Range	max. range from control station	single numeric value	
Other parameters...			

Parameter	Description	Estimation approach	Comments
Sensors			
Range (EO sensors)	Maximum range of the sensor	Single numeric value	In general, a LIDAR with a greater sensing range will provide a better overall UMS mission performance.
Resolution (EO sensors)	Maximum resolution (picture size for cameras, point spread for LIDAR, etc.)	Single numeric value	In general, a LIDAR or camera with a finer resolution range will provide a better overall UMS mission performance.
Field of view (EO sensors)	Angle of view (vertical and horizontal) for cameras and LIDAR	Numeric range	In general, a LIDAR or camera with a greater FOV will provide a better overall UMS mission performance.
Other parameters...			
Perception and intelligence			
Mapping type	Defines the map building approach used	Single value from the list	Currently this is a qualitative variable describing the general map- ping approach, i.e., SLAM, LIDAR segmentation, stereo-camera, etc.
Obstacle behaviour prediction	Can the UMS detect dynamic obstacles and predict their behaviours?	Single value from the list	Some UMS missions will require the UMS to interact with dynamic objects.

Parameter	Description	Estimation approach	Comments
Obstacle avoidance	Does the UMS react to obstacles to avoid them? Categories list: Yes/no	Single value from the list	
Path re-planning	Can the UMS re-plan its path due to changing mission parameters? Categories list: Yes/no	Single value from the list	
Other parameters (Large number)...			

Still, the main question is about the particular parameters to be estimated and how should they be combined to assess the MPP as close as possible to its true value – the actual performance. The current MPP approach is to define a set of fuzzy rules and aggregation methods for each mission or narrow enough mission class. During the practical experiments, the MPP provided by the framework and actual performance assessed by field experts on UAV showed that the MPP if properly defined is rather close (within the rage of 10%) to the actual performance. However, these are the very first experiments and the work is still ongoing.

CONCLUSIONS AND FUTURE EFFORTS

This article was to develop procedures for the assessment of system mission performance as a function of platform autonomy for unmanned land, sea, and air vehicles. To accomplish this task, a new performance assessment tool was developed to predict UMS performance for a given mission at a given autonomy level. The MPP was developed by first performing an in-depth review of many of the currently accepted metrics for UMS autonomy and performance.

The development of the MPP was necessary because the current methodologies used for autonomous performance assessment were insufficient, particularly in terms of defining a UMS' performance for its mission or range of missions. Many of the existing tools required extensive field testing to compute autonomy level or autonomous performance. Many of the existing tools also required well-defined metrics describing the UMS' environment and mission. Furthermore, while these tools measured autonomy level, they did not provide an answer for the impact of autonomy level on mission performance.

Using the fuzzy inferencing as a core mechanism the MPP combines data about UMS platform hardware, software, and intelligence, environment and mission. Through several steps of calculations, the MPP provides a single number describing the performance expectation for a given mission, environment and asset.

The key benefits of the MPP over other existing frameworks can be summarised as:

1. The MPP is predictive measure and does not depend on particular field tests. Thereby the MPP can be used off-line as a prior estimators of performance;
2. The MPP does not compute an autonomy level but rather fixes the UMS Autonomy Level (AL);
3. The MPP provides matter for comparative analysis of different systems providing a direct benefit for decision makers;
4. The MPP value is calculated using fuzzy logic, and the specific rules for the fuzzy aggregation of the MPP are defined using the mission description. This provides a possibility to use the existing field knowledge and incorporate it into the inference mechanisms. At the same time this is the main drawback because it requires an intensive use of experts, which is relatively slow;
5. The MPP allows cross-type comparisons between ground-, air-, and sea-based UMS since the mission description remains the same the other parts of the MPP framework might be combined in different ways for different platforms.

The current developments are focused on MPP application for other domains – ground and sea, which will be supported by the field experiments to validate the results and developed rule bases. Once the tool has been validated, it will serve as a key enabler for increased UMS use and increased UMS autonomy.

ENDNOTES

1 Industrie 4.0. – Smart Manufacturing for the future, German Trade and Invest Agency, 2014. (https://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Brochures/Industries/industrie4.0-smart-manufacturing-for-the-future-en.pdf Cited: 31.10.2016.)

2 Junko Nirmala, Report on the 5th basic Science and Technology Basic Plan (translation from Japanese), 2015 (http://www8.cao.go.jp/cstp/kihonkeikaku/5basicplan_en.pdf, Cited: 31.10.2016); Junko Nirmala, Super Smart Society: Society 5.0 (http://www.roboticstomorrow.com/article/2016/09/super-smart-society-society-50/8739, Cited 31.10.2016.)

3 Industrie 4.0. – Smart Manufacturing for the future, German Trade and Invest Agency, 2014 (https://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Brochures/Industries/industrie4.0-smart-manufacturing-for-the-future-en.pdf Cited: 31.10.2016.); Junko Nirmala, Report on the 5th basic Science and Technology Basic Plan (translation from Japanese), 2015 (http://www8.cao.go.jp/cstp/kihonkeikaku/5basicplan_en.pdf, Cited: 31.10.2016); Junko Nirmala, Super Smart Society: Society 5.0 (http://www.roboticstomorrow.com/article/2016/09/super-smart-society-society-50/8739, Cited 31.10.2016.)

4 H. Huang, E. Messina, J. Albus, "Toward a generic model for autonomy levels for unmanned systems (ALFUS)", National Institute of Standards and Technology, 2003.

5 H. Huang, E. Messina, J. Albus, "Toward a generic model for autonomy levels for unmanned systems (ALFUS)", National Institute of Standards and Technology, 2003; P. J. Durst, W. Gray, Levels of Autonomy and Autonomous System Performance Assessment for Intelligent Unmanned systems, 2014, US Army Engineer Research and Development Center.

6 H. Huang, E. Messina, J. Albus, "Toward a generic model for autonomy levels for unmanned systems (ALFUS)", National Institute of Standards and Technology, 2003.

7 H. Huang, E. Messina, J. Albus, "Toward a generic model for autonomy levels for unmanned systems (ALFUS)", National Institute of Standards and Technology, 2003; P. J. Durst, W. Gray, Levels of Autonomy and Autonomous System Performance Assessment for Intelligent Unmanned systems, 2014, US Army Engineer Research and Development Center.

8 H. Huang, E. Messina, J. Albus, "Toward a generic model for autonomy levels for unmanned systems (ALFUS)", National Institute of Standards and Technology, 2003.

9 Ibid.

10 Steinfeld, Aaron, et al. "Common metrics for human-robot interaction." Proceedings of the 1st ACM IGCHI/SIGART conference on Human-robot interaction. ACM, 2006.

11 Goodrich, Michael A., et al. "Experiments in adjustable autonomy." Proceedings of IJCAI Workshop on Autonomy, Delegation and Control: Interacting with Intelligent Agents, 2001; Goodrich, Michael A., et al. "Managing autonomy in robot teams: observations from four experiments." Proceedings of the ACM/IEEE international conference on Human-robot interaction. ACM, 2007.

[12] P. J. Durst, W. Gray, Levels of Autonomy and Autonomous System Performance Assessment for Intelligent Unmanned systems, 2014, US Army Engineer Research and Development Center.

[13] P. J. Durst, W. Gray, Levels of Autonomy and Autonomous System Performance Assessment for Intelligent Unmanned systems, 2014, US Army Engineer Research and Development Center.

[14] Ibid.

[15] J. Durst Phillip, W. Gray, A. Nikitenko, J. Caetano, M. Trentini, R. King, A framework for predicting the mission-specific performance of autonomous unmanned systems, In Proceedings of Intelligent Robots and Systems (IROS 2014), 2014, IEEE, pp. 1962–1969.

[16] Ibid.

[17] Ibid.

[18] Ibid.

[19] Zadeh, Lotfi Asker. ”Fuzzy logic.” Computer 21.4 (1988): 83–93; Gorzaczany, Marian B. ”A method of inference in approximate reasoning based on interval-valued fuzzy sets.” Fuzzy sets and systems 21.1 (1987): 1–17; Yager, Ronald R. ”On ordered weighted averaging aggregation operators in multicriteria decision making.” Systems, Man and Cybernetics, IEEE Transactions on 18.1 (1988): 183–190.

[20] J. Durst Phillip, W. Gray, A. Nikitenko, J. Caetano, M. Trentini, R. King, A framework for predicting the mission-specific performance of autonomous unmanned systems, In Proceedings of Intelligent Robots and Systems (IROS 2014), 2014, IEEE, pp. 1962–1969.

THE IMPACT OF TECHNOLOGY ON MILITARY TRANSPORT

Dr. Juris Ķiploks

Military transport is vital to the conduct of war. During the Napoleonic Wars, armies marched across Europe using technologies little changed in centuries. Horses and mules transported goods across the land and wooden sailing vessels moved cargo and people across the sea. Yet within little more than a century, thanks to the Industrial Revolution, armies could be moved at great speed and in mass using man-made power across the land, over the sea or through the air. However, the infrastructure of industrialised transport – the ports, the railways, the stations and the aerodromes – became themselves strategic targets.

Total global oil production swelled by nearly 11 percent, rising from 86.5 million barrels a day in 2008 to nearly 96 million in 2015. About 70% of the world's oil is used as transportation fuel, but only about 15% to 20% of energy released by burning fuel in internal-combustion engine does any work.[1]

The European Union (EU) is the world's largest oil-importing region. It is also the second largest oil consuming market in the world. Despite a near 20% drop in oil consumption over the last ten years, the EU's dependence on oil imports remains stubbornly high. According to latest data from Eurostat, the EU's oil import dependency rate in 2013 was 87%. Consumption has been falling, but so has production, and import dependence has grown from around 80% to nearly 90% over the last decade. Europe is therefore facing a future of dependence on oil imports from outside the region.[2]

In order to reduce Europe's dependence on oil supplies in recent years, attention is focused on reducing fuel consumption for transport. The European Commission White Paper on Transportation is a roadmap for creating a competitive and sustainable transport system by 2050.[3]

Horizon 2020, the European Commission's Framework Research Program for 2013-2020, has a budget of over €80 billion, complements and supports European program Mobility of the Future.[4]

Energy density is only one of the key factors that determine the fuel use efficacy. Energy density is the amount of energy stored in a given system or region of space per unit volume per mass, though the latter is more accurately termed specific energy. Often only the useful or extractable energy is measured, which is to say that chemically inaccessible energy such as rest mass energy is ignored.

It means that the use of fossil hydrocarbons will no longer have the primary fuel for transport by 2050. Fossil fuel sources will be replaced by renewable energy sources such as hydrogen. Today, storage of hydrogen gas is the most serious factor that limits the effectiveness and distribution of hydrogen energy systems.

URBANISATION AND OF-ROD MOBILITY

A continuing trend towards urbanization, coupled with strong population growth, suggests that by 2050 an additional 2.5 billion people will be added to cities around the world, by which point, two-thirds of the world's population will be based in urban areas.[5]

Urban population growth raises risk of potential conflicts unfold in urban areas and their immediate vicinity. Infrastructure becomes a militarily important target, especially access roads. Therefore, military operations are channeled along the main roads in order to ensure a high level of speed and mobility. This does not mean that in military operations should be abandoned from an off-road capability transport. On the contrary, off-road transport capability in this case is critical. Changing only obstacle character, from natural to man-made, which often is even more complex. The combination of natural and man-made obstacles, can create difficult overcome areas that could delay forces movements for long periods. In this context, off-road capacity is not only maintain but also improved taking into account the new urban environment challenges.

TRANSPORT PROPULSION SYSTEMS

One of the method how to reduce consumption of fuel in transportation to day is application the electric and hybrid drive technologies. The hybrid electric drive system consists of two power sources, the engine generator and the energy storage system. Hybrid electric drive systems provide energy storage in high energy density batteries to supply vehicles systems and support the main engine at peak operational (for example acceleration). Hybrid electric vehicles can be classified according to the way in which power is supplied to the drivetrain:

- In parallel hybrids the internal combustion engine (ICE) and the electric motor are both connected to the mechanical transmission and can simultaneously transmit power to drive the wheels, usually through a conventional transmission.
- In series hybrids only the electric motor drives the drivetrain. The ICE works as a generator to power the electric motor and to recharge the batteries. The battery pack can be also recharged through regenerative braking.
- Power-split hybrids have the benefits of a combination of series and parallel characteristics. As a result, they are more efficient overall, because series hybrids tend to be more efficient at lower speeds and parallel tend to be more efficient at high speeds.
- Choosing the easily integrated series hybrid drive in the ground vehicles will provide fuel efficiency and benefits in military standpoint.[6] (Figure 1) Reducing the fuel consuming in military vehicles will give an increase in range without additional supply. (Table 1)

The first time hybrid electrical drive was used in military ground vehicles was in Germany during the Second World War. This endeavour is associated with Dr. Ferdinand Porsche. The electromechanical transmission of 'Ferdinand' assault gun-tank destroyer. consist of two 'Mybach' HL120 TRM internal combustion engine with 265 horsepower (~198 kW) each that powered Siemens-Schuckert Type AGV generators. Drive realized bay two 230 kW Siemens-Schuckert D1495a alternating current (AC) electric motor on both tanks. That construction gives

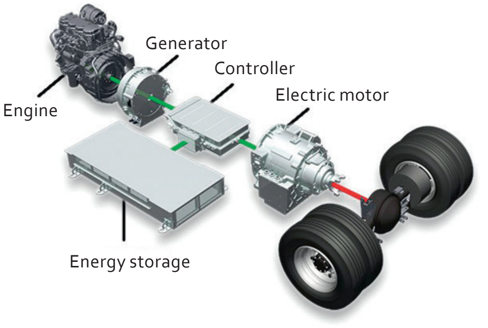


Figure 1: Integration the series hybrid into available vehicle

Table 1. Hybrid Electrical vehicles expected benefits

No.	For military vehicles	For civil vehicles
1	Vehicle Packaging Flexibility	Improved Fuel Economy (30–35%)
2	Onboard Power Generation	Reduced Emissions
3	Improved Fuel Economy (25 – 30%)	Improved Driveability
4	Stealth Potential (Silent Movement)	Improved Acceleration
5	Improved Accelerations	Reduced Maintenenc Costs
6	Reduced Maintenance	
7	Increased Silent Watch Period	

possibility to easily manoeuvre with this heavy (65 ton) machine. It was the first time when ground vehicles used hybrid electric drives.

In the last decade several studies and demonstration projects dealing with electrical and hybrid electric ground vehicles have been carried out in the USA and the EU in military areas. First time the Army integrated a fully functional hybrid-electric drive system into a combat vehicle was in the spring of 2003 in Belgium. The US Army announced (in August 2007) its first hybrid-electric propulsion system for the new fleet of Manned Ground Vehicles (MGVs), which will be tested and evaluated at the Army's Power and Energy Systems Integration Laboratory. Like the manned ground vehicle platform, the new MGV features a hybrid engine with diesel and electric-battery components. The US Marine Corps and US Army Special Operations Command are closely monitoring a new

Figure 2. Reconnaissance, Surveillance, Targeting Vehicle Shadow

deep strike, deep reconnaissance vehicle program called 'Shadow'. The Shadow is a Reconnaissance, Surveillance, Targeting Vehicle (RST-V), developed by General Dynamics Land Systems. The Shadow RST-V was developed for the Marine Corps Warfighting Laboratory, sponsored by the Defence Advanced Research Agency (DARPA) and the Office of Naval Research (ONR). It was constructed with advanced materials to reduce weight and improve protection and survivability. Hybrid-electric propulsion system and advanced suspension is utilized to improve on-road and cross-country mobility. The vehicle is equipped with an RST mission package including navigation/geolocation capability, surveillance, reconnaissance and target acquisition systems, wireless and on-the move satellite communications and advances situational awareness systems (Figure 2). The hybrid-electric drive is based on a front mounted Detroit Diesel DI-4V 2.5 litre turbocharged, intercooled engine and rated at 114 kW. The diesel powers an electrical 110 kW generator feeding individual in-hub motors at each wheel. The in-hub motors are rated 50 kW each. All electrical motors and generators are supplied by Magnet Motors. Backup power is provided by two rechargeable Li-Ion battery packs provided by SAFT. The batteries are rated at 20 kW hours output with 80 kW peak used in 'bursts'. The Shadow can travel at a maximum speed of 112 km per hour on road. At a speed of 50 km/h the vehicle will reach a range of 758 km consuming 95 litres of fuel. Up to 32 km can be travelled on battery power only.[7]

SPECIFIC MILITARY VEHICLES REQUIREMENTS

For military vehicles from all advantages hybrid electric vehicles, which are summarized in Table 1, following are the most important:

- Vehicle Packing Flexibility. Military vehicles have several platforms, namely Light Armoured Vehicles (LAV), High Mobility Multipurpose Wheeled Vehicle (HMMWV), Family of Medium Tactical Vehicles (FMTV), various heavy duty tanks, Unmanned Ground Vehicles (UGV), and various robots. An electric drives system consists of modular components connected by cables thus giving the vehicle designers more packaging freedom as shown in Figure 3.
- This avoids the constraints of conventional mechanical drive systems, which require the engine to be connected to the wheels via gearboxes and rigid shafts. This means that the components can be arranged and integrated in the vehicle for the optimum utilization of the available space.

Available power on board some electrical system specifications for these vehicles include the following:

- LAV – Alternator 28 volts direct current (DC), 245/280 (~ 7.5 kW)
- HMMWV – Alternator, 28-volt DC, app. 100A in a particular variant (~ 2.8 kW)
- FMTV – Alternator, 14/28 dual volt DC, app. 100 A in a particular variant (200 A option; ~ 2.8 kW)
- Abrams Tank – 28-volt DC, 650 A (~ 18 kW)

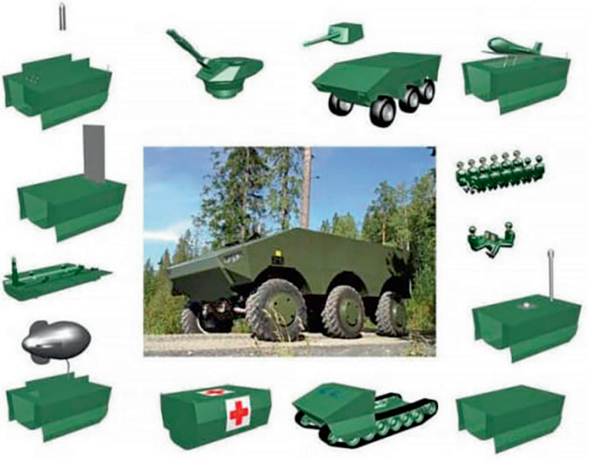


Figure 3. Hybrid electric vehicles modular components

- UGV – Similar to above depending on the platform chosen
- Robots – As low as 30 watts to 1500 watts at 12 or 24 volts, Current: about 3 A to 100 A, depending on operating the voltage.

The main power management and distribution system can be designed and sized to meet the demand of all electrical power users in the vehicle. This is extremely beneficial due to the increasing demand for electrical power for future military systems on board a ground vehicle. The power management and distribution system can supply continuous power for such loads as propulsion, thermal management and other small power users and can also be used to supply the intermittent power to drive/charge a pulsed power system for electric weapons and armour: Electro-thermal Chemical – ETC gun, Directed Energy Weapons – DEW, Laser weapons, EM (Electromagnetic) armour etc. Use of this type of military applications provides necessitate use Electrical Pulsed Power Supplies. Furthermore, the availability of these high levels of electrical power on board may be used to reduce the logistical burden to provide electric power in the field.

Fuel Economy: In military action the fuel is a one of major budget item. The fuel economy is a direct result of the engine being programmed to operate along the optimum fuel economy region in its fuel map as shown in Figure 4. This is possible because the engine speed is not dictated

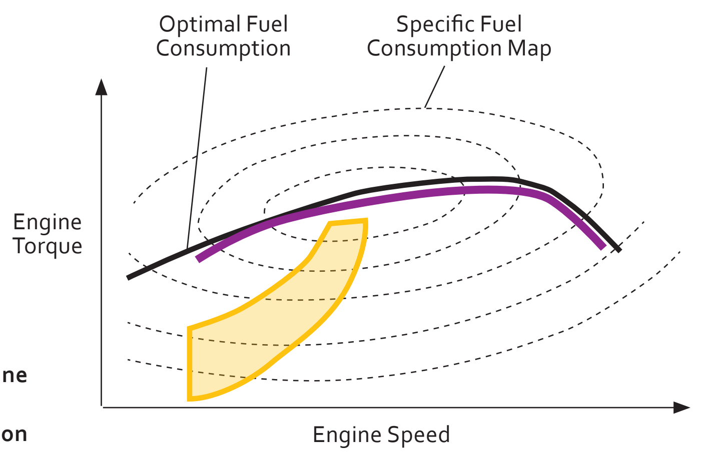


Figure 4. Engine optimum fuel economy region

by the road speed of the vehicle. The engine drives an AC generator at almost constant speed and the electric power from the generator is delivered to the wheels or tracks through the power conditioning units to match the requirements of the traction motors. In the case of hybrid electric drive where the engine power is supplemented by energy storage (batteries, flywheels, capacitors, etc.), there is another reason for the fuel economy – the engine power is mainly used during steady state driving where the least amount of fuel is consumed for mobility. Hybrid-electric drives achieve greater efficiency is in stop-and-go mission profiles than they do in long-haul commercial duty cycles. The regenerative braking that recovers and stores power as electrical energy make more fuel economy and the electric motors can generate instantaneous power for better off-road manoeuvring. The transient conditions make the main power consumption from the energy store, which is topped up by regenerating the energy from braking as well as from the generator. This feature results the significant savings of fuel and reduces exhaust emissions and thermal signature. The fuel economy improvement that has been demonstrated through preliminary testing on the US HMMWV program was the order of 25 to 30%.

Silent Watch and Silent Mobility: The significant on board energy storage system can be used to meet silent watch requirements for extended periods of time for various missions. Depending on the power requirements of the silent watch, a mission can be extended over a few hours; far exceeding the silent watch capability of the current fleets. Silent mobility over a limited distance is also achievable where the vehicle can move in or out of a hostile territory with a reduced chance of being detected.

Enhanced Prognostics and Diagnostics: In the hybrid electric vehicles every operation is controlled by microprocessors which lend itself to the provision of a Health and Usage Monitoring System (HUMS). This HUMS would be capable of identifying many impending failure before it happens and provide the data about fault so that reliability centred maintenance can be implemented. This should help to reduce the operation and maintenance costs over the life of the vehicle and help offset the acquisition costs to of the hybrid electric vehicles.

TECHNICAL DEVELOPMENT AND CHALLENGES

These important technical challenges are undergoing research but they are not expected to be resolved before some years from now. The technical challenges are: high operating temperature for power electronics, high energy density storage devices, high torque and power density traction motors.

Vehicles Electrical Power System: Electro-magnetic compatibility requirements to military vehicles apply specifications MIL-STD-461E, DEF-STAN 59-41 and STANAG 4134 (Electrical Characteristics of Rotating 28 Volt DC Generating Sets). The military vehicles presently use mostly 28 V voltage system (24 volts at load) architecture. Switching to 42 volts DC will reduce to some extent the wiring harness size and weight in the military vehicles. The application of 42-volt DC presents a number of issues and challenges such as arcing, load dump spikes, ignition system design , battery, and alternator, all of which need to be addressed. It can be inferred from the literature[8] that at 42 volts the motor size will reduce by a factor of about 8% in military vehicles (24% total copper savings). 42-volt system application for civil vehicle has been well discussed in the existing literature. Currently a reasonably mature technology exists in power electronics, which is applicable to military applications as well, and is essential for the 42 volts DC system architecture.[9] Power electronics is important for the conversion of variable speed generator voltage through rectification and dc-to-dc conversions. In addition, the existing technology of the 42-volt alternator designs can be readily used. Various architectures have been proposed for the 42-volt automotive systems (military and commercial) and dual-voltage architecture (28/42-volt) was more reliable. 42/28-volt dual voltage system architecture electrical systems in military vehicles are normally required to meet stringent transient requirements. Typical of these specifications are MIL-STD-1275B in the US and DEF-STAN 61-5 in the UK.[10]

Power Electronics: The currently available power semi-conductors have a relatively low operating temperature. The Silicon based IGBT (Insulated-gate bipolar transistor) switch for instance has a maximum operating temperature of 125°c on the junction. To maintain that temperature, the coolant into the base plate of the switch must be maintained at 65°c leaving a very small margin with the ambient temperature. Consequently, the cooling system and its power demand are too large to be integrated into the vehicle. Repackaged IGBT switches have improved the thermal limits by 50% raising the coolant temperature from 65°c to 90°c. This improvement are already available but requires further development. The ultimate solution for power electronics is the Silicon Carbide device, where the operating junction temperature can be as high as 500°c and therefore the coolant temperature can be easily maintained at 200°c–250°c. This type of device would allow the cooling system to be much smaller due to their high efficiency and operating temperature.

Energy Storage: Energy storage is an essential part of the hybrid electric drive application. Most commonly used battery (lead-acid) has low energy density, limited cycle life, cannot be stored in a discharged conditions as the cell voltage must not drop below 2.1 v, is 30 environmentally unfriendly because it has a toxic electrolyte that must be disposed in safely. In addition, battery thermal management is required as the battery loses power at low temperature and requires preheating and will start deteriorating at elevated temperatures. Although the lead acid battery does not have a serious shelf discharge problem like the NiMH battery, its shelf life is limited.

Other advanced types of batteries are being considered for hybrid vehicle applications. The most important candidates at this time are: Nickel-Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lithium-metal polymer (LMP), Lithium-ion (Li-Ion). All these batteries have higher energy densities than the lead acid batteries but they all are in the development stage and at present some challenges must be resolved before they can be considered suitable for military use. The Li-Ion is very sensitive and can be dangerous if it is not designed and manufactured with over current and/or shock protection as well as a thermal management system.

The US Army Tank-Automotive Research Development Engineering Command (TARDEC) has selected SAFT Company, a world specialist in the design and manufacture of high-tech batteries, to enhance the efficiency of military vehicle operations. The US$1.2 million contract will focus on the design and demonstration of SAFT's high-power lithium-ion (Li-ion) batteries, to address the requirements for next-generation hybrid electric military-vehicles. In November 2008 SAFT's completed the first phase in development of a new ultra-high power Li-ion cell touted as the world's most powerful electro chemical cell- and has delivered the first 5 prototype VL-U cells to the US Army TARDEC. The VL-U cell produces 10 kW/kg of continuous and 30 kW/kg of pulse power.

The NiMH has a self-discharge problem that will drain the battery in a short time. Never the less it is used in a number of commercial hybrid electric vehicles now.

LMP batteries are relatively new but seem to be ideal for military applications if their predicted performance can be realized the cost of any of these batteries is currently high because they are still in development and limited production.

Supercapacitors can withstand more than 500,000 charge-discharge cycles, and consequently exhibit a much more linear performance than batteries. Combinations of Supercapacitors and Batteries can be passive,

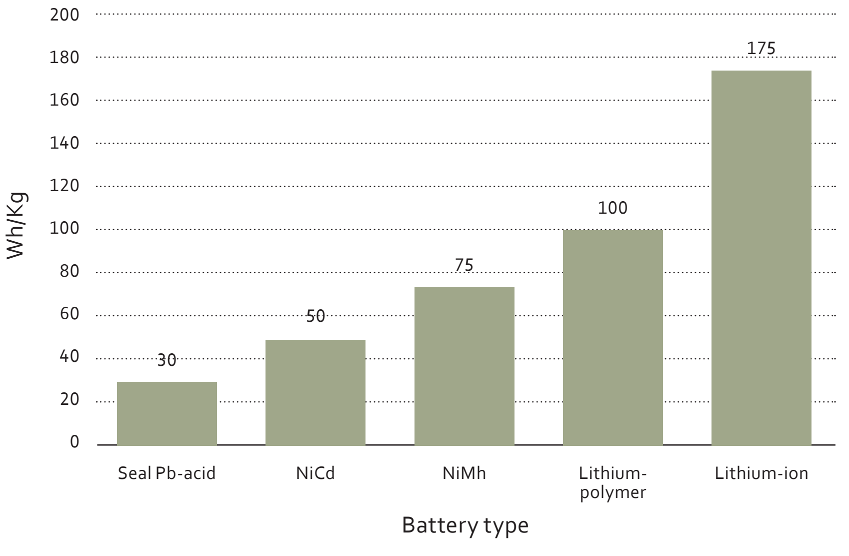


Figure 5. Battery energy density comparison

when the Supercapacitors are connected in parallel to the battery; as such, the battery will not be exposed to high-frequency pulses, thereby increasing the life of the battery. Alternatively, the Supercapacitors can be connected to the battery via a DC/DC converter, in which case the power flow to the Supercapacitors can be controlled. This offers the opportunity to implement a control strategy focused on the system efficiency, or the lowest lifecycle costs. Inclusion of the DC/DC converter considerably increases the cost and the weight of the system.

Traction Motors: For purpose of traction the military vehicles use generally three types of motors suitable to meet new requirements: Permanent magnet brushless motors; Induction motors; Switched reluctance motors. The first two are currently receiving the most attention, however the traction motor cannot be considered in isolation and it is necessary to consider the way they are to be integrated into the vehicle platform.

For a tracked vehicle the choice is between the 'two-line' approach where one traction motor is used to drive each track or the 'single-line' approach where one traction motor and one steer motor is used. The former approach would offer the maximum flexibility in design of the vehicle if the traction motors associated control systems can be reduced in size significantly. The problem is due to steering of a high-speed tracklayer, which requires the power to be transferred across the vehicle to maintain efficiency as the vehicle steers. If this is done electrically, it is necessary to transfer in the order of 2.5 times the power of the main engine from one track to the other (the two-line approach). The utilisation of the mechanical cross shaft to transfer this power (the single-line approach) means that the electrical motors need only be rated at the main engine power, but clearly some packaging freedom is given up.

With wheeled vehicles the basic choice is between mounting the traction motors in the chassis, where disadvantage is that drive shafts are still needed to transfer the power to the wheels or in the hubs and hence the design freedom is lost. The in-hub approach offers the optimal development; however, the challenge is to keep the mass as low as possible as, ideally not greater than a conventional vehicle, in order not to compromise the mobility of the vehicle at high speeds, particularly in cross-country. Two approaches are being offered: a single speed reduction gear or a two-speed gear arrangement where the low range is only needed for high torque/low speed operation.

The latter approach enables the motor size to be reduced, thus reducing the whole mass. Most of the current traction motors have some design limitations, which if overcome them, would enable better overall designs: their size and weight limit and their packaging. They require cooling and they are expensive. It should be noted that despite the challenges mentioned above, the state-of-art for the traction motors have been successfully integrated and demonstrated in electric vehicles. The challenges described above are intended to point out that improvements to the traction motors are needed and this will enhance their packaging and integration in ground military vehicles.

CONCLUSION

Historically, military transport has developed alongside with civilian transport systems. Transporting of any system has a military dimension and it can be used for military operations. Currently, civilian transport system are devoted Instruments in large, thus it is inevitable that these innovations will pass well to the military. Fuel is a cost-driver for both the Army and the commercial truckers.

Hybrid-electric drive technology as applied to military vehicles is the most advanced system and now is in its development and experimentation phase. Almost every component now is designed for specific application in a very limited quantity. Currently, there are few, if any, situations where systems designed for the civil environment can be directly applied to the military applications. This is particularly true for the technologies that are needed to enhance the state of the art such as advanced batteries, traction motors and power electronics. It is prospective that the cost will drop for new electric drive components and they become more available commercially with the growing demand for hybrid-electric cars and trucks. Unmanned ground vehicle (UGV) projects accelerate the process of electric drive technology implementation in civil and especially in military field. UGV conducting process is very difficult problem and electric drive can solve particular moment ad engine control section.

At the current level of maturity, the acquisition cost is likely to exceed that of a mechanical system. Emerging technologies such as Silicon Carbide and Lithium Ion Batteries will greatly enhance the packaging and integration of the hybrid electric drive systems for both continuous and pulsed power in a combat vehicle. Life Cycle Cost studies are based on models with existing systems as baselines and cannot be totally substantiated without extensive field testing. The results available today show that a development cost for hybrid electric drives are currently excessive. However, most of these costs are likely to be offset in the long run by the fuel and maintenance savings. Pulsed power technology particularly for ETC gun applications is achievable and can be integrated in combat vehicles depending on gun's size and repetition rate requirements.

ENDNOTES

1 Ķiploks, J., Raņķis, I. Hybrid Electrical Drive for Military Vehicles. No: Baltic Defence Research and Technology Conference 2009, Latvia, Riga, September 10–11, 2009. Rīga: Latvijas ZA Ekonomikas Institūts, 2009, 22.–33. lpp.

2 Peter Kiernan, Europes Oil Import Dilemma, http://energyfuse.org/europes-oil-import-dilemma/

3 European Commission White Paper on Transportation, http://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm

4 Horizon 2020, http://ec.europa.eu/programmes/horizon2020/en

5 United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2014 Revision, 2014

6 Zaļeskis, G., Ķiploks, J., Bražis, V. Hybrid Vehicle for Military Operations. No: 11th International Symposium 'Topical Problems in the Field of Electrical and Power Engineering. Doctoral School of Energy and Geotechnology II', Estonia, Pärnu, 2012. Tallinn: Elektriajam, 2012, p. 84.–87. ISBN 978-9985-69-051-2

7 Shadow-Reconnaissance, Surveillance and Targeting Vehicle (RST-V); http://defense-update.com/products/s/Shadow-afv.htm

8 G. William and M. J. Holt, 'Vehicle Electrical Power Supply Systems and Their Impact on System Design', Proc. I. Mech. Engr (UK), Vol 206, pp. 149–159, 1992.

9 P. Nicastri and H. Huang, '42 V Power Net: Providing the Vehicle Electrical Power for the 21st Century', SAE 2000 paper # 2000-01-3050.

10 A. Jordan, Meeting transient specifications For electrical systems in military vehicles 2004 APPNOTE Mil VTS, p.8; www.vicorpower.com

DIGITAL INFANTRY SQUAD CONCEPT OF OPERATIONS

Uģis Romanovs

There is inevitable evidence that the future of the land operations will heavily rely on the ground robotic systems. This assumption is based on two key factors – firstly, modern battlefield represents extremely high threat environment requiring new methods and tools to protect our soldiers, secondly, advances in modern technology enables soldiers to be augmented or replaced by unmanned ground systems in the battlefield. With the help of unmanned systems, combat capabilities and survivability of the ground troops will increase significantly. Robotic systems will allow to reduce number of personnel in the military and will decrease training costs, thus relieving the funds to be available for further investments into technologies. Furthermore, unmanned ground systems offer 'improved performance where automated systems either perform better than humans or eliminate the system compromises required by human physiological limits (comfort, fear, fatigue, vibration, etc.)'.[1] However, the introducing unmanned systems will take many years. And most likely integration of the land systems will not be slowed down by the technological or financial limitations, as much due lack of institutional agility to adapt radically new doctrines, change the tactics, education and training. The purpose of this article is to bring the domain of unmanned ground systems one small step closer to military doctrine by offering very simple concept of operation for Digital Infantry Formation – an infantry unit which is force multiplied by unmanned ground vehicles. The concept describes structure, characteristics and basic capabilities of the digital unit. This article is meant to trigger discussion among military professionals on the future role of the unmanned ground systems; and to be used a source of inspiration when current army doctrines will be aligned to fit modern military challenges and solutions. To keep the concept simple – infantry squad[2] – one of the smallest formations in army will be used as a framework around which the operational concept will be designed.

1. HOW THE UNIT IS ORGANISED?

a. General. Digital Infantry Squad is a man/unmanned fighting team. This is approximately nine men team force multiplied by various types of unmanned ground systems. Squad has three fire teams, leadership and service support element. The task of the fire teams is to execute various combat actions; leadership and service support elements are responsible for allocations of tasks and resources and ensuring tactical level computer network and communication security measures. Unmanned systems work under human supervision; however, some functions are performed fully autonomously. These include tasks such as navigation to the area of destination, self-concealment, surveillance and target acquisition, air defence, cyber security or electronic warfare attacks, self-recovery. Due various ethical and legal reasons UGVs in autonomous mode is not used for lethal operations.

   The combat capabilities of squad reach and exceeds capabilities of mechanised infantry platoon. Fighting team can operate independently, in concert with other Digital Infantry Formations or regular infantry units. Unit has a definite structure, formalised training and maintenance procedures. Operators are receiving specialised training, which includes computer assisted battlespace analysis, decision making, targeting and other critical skills required to operate in digital formation. Squad has a high level of cross-domain interoperability allowing time sensitive decision making and instant delivery of desired effects to the battlefield. Single fighter-operator conducts 'real-time analysis of multiple situations'[3] controls multiple vehicles of the fighting team; unmanned systems 'shares, information, responsibilities and tasks'[4]. The force protection of personnel is achieved through the distance and continuous real time situational awareness.

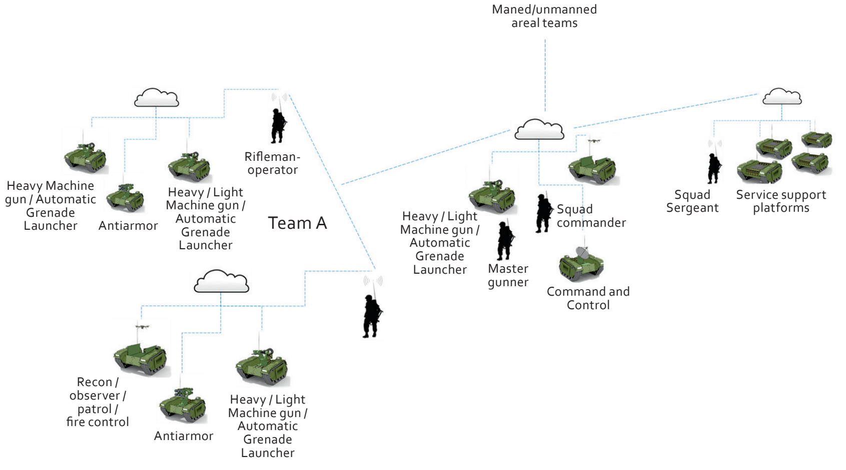


Figure 1. Structure of Digital Infantry Squad

b. Command and control. The decision making and response to the changes in the operational environment of the unit is very high comparing to the regular infantry unit. It is achieved by enabling 'seamless integration of human and machine decision making'[5]. It means that most of the processes related with operational planning and management, including assessment of the battlespace, surveillance, target acquisition, dissemination of the information, and battle damage assessment is automated; human operators are exercising positive control of the process. Another factor enabling agility of the command and control system is adaptive distribution of decision making authority. In other words, shared real-time situational awareness enables mission command to its full extent. Command of the unit is enabled through Military Cloud technologies. Cloud computing is a 'model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction'.[6] The constancy and currency of flow of computing activities is enabled by liquid computing technologies[6]. Soldiers are using 'a single smart-phone-like cloud portal'[8] to control multiple unmanned systems, share, view and exchange data. Security of the data is ensured through homomorphic encryption (HE) which allows 'software to analyse and modify encrypted data without decrypting it into plaintext first. The information stays encrypted while operations are performed on it'.[9]

c. Equipment. The unit is equipped with various types of UGVs designed to serve as a force multiplier for different combat functions. Small, man-portable systems are designed to conduct area surveillance, reconnaissance, target acquisition and attack IEDs and primary supporting functions of Intelligence, Force Protection and Mobility. There are number of small unmanned ground systems in the inventory of DIS which are designed for micro-targeting missions This implies surgical engagement of specific individuals with lethal and non-lethal means. Micro-targeting is enabled by the capability to locate selected targets with high precision through a capability to acquire and analyse enormous amounts of information.[10] Some of these unmanned portable systems can be used as 'intelligent, single used ammunitions and can be utilised as fire-and-forget missiles and ground-crawling intelligent mines'[11]. Small robots can be deployed and dropped by operators or larger unmanned ground systems.

   Most of the vehicle-transportable/self-transportable medium size platforms have a 'plug-and-play' design. This allows quickly and easy to change the payload based on the upcoming mission. These systems carry remote weapon platforms, communication and surveillance systems. Remote weapon stations are supporting various types of interchangeable weapons, including light and heavy machineguns, automatic grenade launchers, anti-tank weapons, air defence systems and non-lethal weapon systems. Some of UGVs are coupled with rotary wing Unmanned Aerial Vehicles and can conduct extended surveillance tasks.

   Each DIS include number of service support platforms intended to carry unit equipment or evacuate casualties from the battlefield. Vehicle -transportable/self-transportable unmanned systems are supporting broad spectrum of functions including Intelligence, Sustainment, Command, Fire and Manoeuvre.

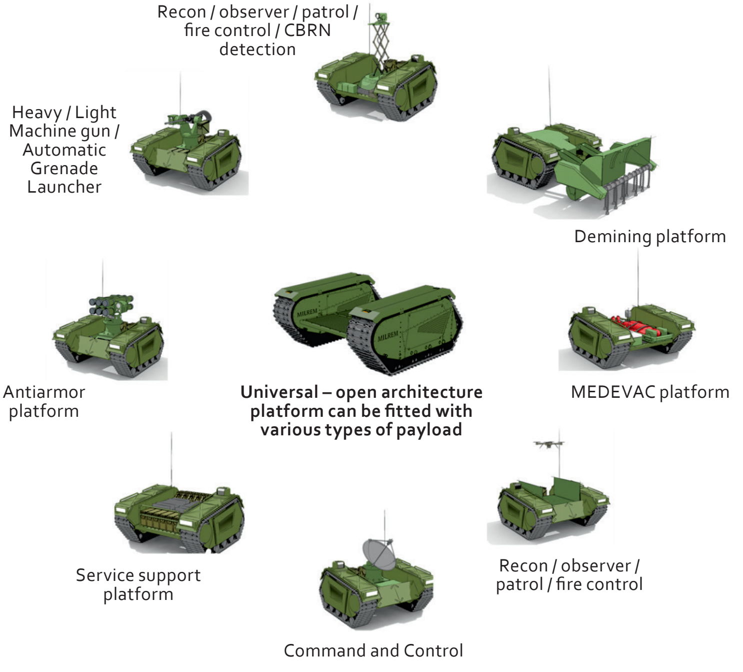


Figure 2. Inventory of vehicle -transportable/self-transportable unmanned systems

2. WHAT ARE THE MAIN CHARACTERISTICS OF DIGITAL INFANTRY SQUAD?

The formation has six key characteristics:

a. Situational awareness – unmanned ground systems being capable to conduct continuous reconnaissance tasks and to share the information with unmanned and manned areal sensors change the way the situational awareness is obtained, maintained and shared. Effective situational awareness is one of the key factors enabling DIS to achieve the 'competitive advantage over an adversary'[12]. Furthermore, awareness contributes to the risk management quality thus raising the security of friendly troops. Shared situational awareness enables decentralised execution of the mission as it requires less planning to deconflict fire and manoeuvre of units.

b. Tactical agility – agility is achieved through close-to-real time situational awareness, rapid decision-action cycle, low sustainment requirements and manoeuvrability around the battlefield in restricted terrain and constantly changing weather conditions. This characteristic enables DIS respond quickly to the changes in the operational environment and keep adversity of the balance by engaging before it can attack. Another characteristic of the team enabling agility is computer assisted decision making or 'cognitive teaming' – 'human-machine collaboration is allowing a machine to help humans make better decisions faster'.[13]

c. Durability – DIS possess long mission endurance which is measured in days and weeks. 'This is a key desirable attribute as manned tasks are always constrained by the human body's need for food and sleep'.[14] Selected elements of the DIS could be infiltrated or left behind the enemy lines for prolonged time periods and activated as required for fire control, surveillance or other type of missions.

a. Security – DIS allows conduct missions with less risk by separating operators from the engagement area geographically. Advanced surveillance capabilities, inbuilt terrain analysis algorithms and cloud technologies enables collection, automated analysis, storing and sharing geospatial and other type of information of the operational area which is used for planning and during the execution of operations. Communication systems of the unit have high battlefield survivability – all of them are built to have a low level of detectability, and enable timely and secure information exchange. Furthermore, all systems have self-recovery /self-destruction function thus avoiding capturing by opposing forces.

d. Fast deployment – DIS is the first choice when it comes to the requirement for rapid deployment. Multiple Digital Infantry Formations can be transported in a single transport aircraft. This factor significantly decreases the time of deployment and reduce airlift resources. Furthermore, due its high level of survivability and mobility Digital Formations can be dropped at significant distances from the objective.

e. Decision making in information-rich environment. There are two information related factors DIS is prepared to cope with. Firstly, operate in overloaded information environment. A huge amount of invalid, outdated or irrelevant information which gets into the information processing system causes a risk to information overload and lead to the situation where operators cannot make timely and relevant decisions. Secondly, detect and avoid information attacks. Ever increasing importance of the information domain has brought the role of the deception and misinformation activities to the next level. Adversary forces are constantly feeding misleading information to mask its activities, to create confusion and delay our actions.

3. WHAT PRINCIPLES SHOULD BE APPLIED WHEN PLANNING AND EXECUTING OPERATIONS WITH DIS?

a. Maintain security. Unmanned ground systems enable unit level force projection. Unmanned systems must be used to the maximum extent to enhance the security of our troops simultaneously allowing maintenance of situational awareness and tactical initiative over opposing forces.
b. Benefit from connectivity. All elements of the unit – manned and unmanned across the ground and air domains are constantly connected over secure and reliable communications and continuously exchange data, video and audio signals. Autonomous navigation capability of unmanned ground systems allows deployment of the sensors and data relays and enables extended range communications. Connectivity allows early warning, enables situational awareness and achievement of synergy of efforts.
c. Utilise expanded capabilities. Unmanned ground systems extend the range of infantry unit operations and enable achievement of desired tactical objectives across the depth and breadth of extended area of operations. Therefore, low level tactical units must have access to the wide range of capabilities to be able 'to seize, retain and exploit the initiative'[15].

d. Exercise decentralised execution. Availability of unmanned platforms allows to disperse the intelligence sensors over the wide area and conduct continuous and tireless reconnaissance operations. This factor creates one of the critical preconditions for decentralised execution of operations. Small unit commander develops improved situational awareness allowing exploitation of opportunities on short notice.
e. Exploit advantages of precise sustainment. Sustainment requirements are very low comparing to traditional infantry units. This factor enables precise and continuous sustainment operations without relying on 'bulky, vulnerable, and costly supplies moved over extended lines of communication'[16].

4. CONCEPT OF OPERATIONS – HOW DIS IS FIGHTING?

Digital Infantry Squad is suitable to conduct most types of the land actions[17]. Including:

a. Various types of offensive actions. Due unit's capability to integrate into the planning cycle continuous and close to real-time intelligence information and very quick decision-action cycle DIS is particularly suited for types of offensive actions which are related with exploitation of fleeting opportunities. This includes such actions as a spoiling and hasty attacks, different types of raids, reconnaissance missions and infiltration tasks. Considering the capabilities of the unit to mass fires, DIS is perfectly suited for different type of ambushes, blocking avenues of approach, support the movement of other units into tactical positions. Furthermore, considering high level of force protection which is achieved through increased distance between engagement area and troops operating the unmanned systems, DIS is very suitable tool to 'clear danger areas and prepare positions for mounted elements'[18].
b. Defensive actions. DIS employment during defensive operations primarily would be related with the holding key terrain or fixing opposing forces thus buying the time and space for other tactical

formations to prepare for offensive actions. Furthermore, DIS is suited to establish 'strong points to deny the enemy important terrain or flank positions'[19]. From three types of defensive operations, mobile defence, area defence and delaying action, DIS is the most fitted to contribute to the area defence operations. The reason for this limitation is related with relatively low speed of manoeuvre comparing to mechanised units. Therefore, DIS would have a limited role in mobile defence and delay actions. On contrary, DIS is perfect fit for conduct of screening and blocking tasks to slow down and canalise the enemy.

c. Enabling actions. 'Enabling actions link other tactical actions together'.[20] Reconnaissance, security operations and advance to contact[21] are three types of the missions where DIS is the best fitted formation. All these actions imply high level of risks to troops, which can be mitigated by the possession of the characteristics possessed by DIS – awareness, agility, durability, security and precision.
d. Stability operations. DIS has a wide range of applications in stability operations. The tasks are primarily related with the framework security actions, including patrolling, overwatch and secure objects and search and rescue tasks. If DIS is to be used for the incident response, public order missions or SAR functions the weapon systems of the unmanned platforms must be replaced with the equipment suited to complete this kind of mission.

CLOSING REMARKS

This paper's purpose was to trigger discussion on how UGS' could be used on the future battlefield by offering very simple concept of operation for DIS. Besides tactical application of unmanned ground systems in land warfare this paper highlights a handful of other considerations. Firstly, most of the technological solutions used in this paper to 'enable' this unit to be an effective asset on the battlefield still do not exist or are at a very early stage of development. Closing these technology gaps will require close innovation and cooperation between defence policy makers, military industry and academia, not least with regards to autonomous operations, command systems, advanced computing, and encryption technologies. Therefore, innovation and cross-domain collaboration should become more and more important aspects of the defence system.

Secondly, the introduction of Digital Infantry Formations will challenge almost every aspect of the way that land operations are planned and conducted and consequently will render most of the current military and defence concepts obsolete. Digital Infantry Formations will be designed to neutralise regular armed forces, irregular military formations and other digital units, while regular military formations will face significant challenges to gain tactical initiative over Digital Infantry Formations. Thus, it is important for countries to maintain a far-reaching vision when choosing military capability development priorities, designing military education and rewriting doctrines.

ENDNOTES

1 US Department of Defence, Unmanned Ground Vehicle Master Plan, July 1992.

2 Regular infantry squad usually is composed of two five-soldier teams; the size of this unit depends on various factors; primarily on a type of the transportation and equipment unit is equipped with. Three infantry squads would normally form a formation called platoon.

3 US Department of Defence, Unmanned Systems Integrated Roadmap FY2011-2036, http://www.acq.osd.mil/sts/docs/Unmanned%20Systems%20Integrated%20Roadmap%20FY2011-2036.pdf, p. 70.

4 Steve Jameson et al, Collaborative Autonomy for Manned/Unmanned Teams, (American Helicopter Society International, Inc), June 1–3, 2005.

5 Alexander Kott et al, Visualizing the Tactical Ground Battlefield in the Year 2050: Workshop Report, US Army Research Laboratory, June 2015, p. 11.

6 Peter Mell and Timothy Grace, "The NIST Definition of Cloud Computing: Recommendations of the National Institute of Standards and Technology," NIST Special Publication 800–145, September 2011, http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf, p. 2.

7 Liquid computing is the capacity for data and applications to remain consistent and current across multiple devices definition from (http://whatis.techtarget.com/definition/liquid-computing)

8 John Antal, Leveraging the Military Cloud', Military Technology, Vol XL, Issue 4, 2016, p. 55.

9 Iain Thomson, Microsoft researchers smash homomorphic encryption speed barrier, http://www.theregister.co.uk/2016/02/09/researchers_break_homomorphic_encryption/, 9 Feb 2016.

10 Alexander Kott et al, Visualizing the Tactical Ground Battlefield in the Year 2050: Workshop Report, US Army Research Laboratory, June 2015, p. 10.

[11] Alexander Kott et al, Visualizing the Tactical Ground Battlefield in the Year 2050: Workshop Report, US Army Research Laboratory, June 2015, p. 16.

[12] Ministry of Defence, 'Army Doctrine Publication', December 2010, p. 5–14.

[13] Sydney J. Freedberg Jr., Centaur Army: Bob Work, Robotics, & The Third Offset Strategy, November 09, 2015 at http://breakingdefense.com/2015/11/centaur-army-bob-work-robotics-the-third-offset-strategy/

[14] Clapper, Young, Cartwright, Grimes, Payton, Stackley, and Popps. Unmanned Systems Integrated Roadmap FY2009-2034, p. 28.

[15] Headquarters Department of the Army, ADRP 6-0 Mission Command, 17 May 2012, p. 1–1.

[16] United States Army Training and Doctrine Command, The Army Operating Concept, 19 August 2010, p. 27.

[17] In accordance with UK Army Doctrine Publication there are four types of land action: offensive actions, defensive actions, stabilising actions and enabling actions.

[18] Headquarters Department of the Army, FM 3-21.71 Mechanized Infantry Platoon and Squad (Bradley), Washington, DC, 20 August 2002, p. 1–3.

[19] Ibid, p. 1–3.

[20] Ministry of Defence, 'Army Doctrine Publication', December 2010, p. 8–15.

[21] Other enabling actions according to UK doctrine includes retirement, march, breaching and crossing operations.

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