Dear Sir

Firstly, thank you for the invitation to participate in this enquiry, which I see as very important for the nation's longer term security. Unmanned platforms, as they relate to defence applications across air, sea, land and space, have been a strong interest of mine for some time. To this end, I have been quite active as an author on these topics over recent years. My articles have recently (2012 to the present) appeared in the Australian Defence Force Journal (aerial unmanned vehicles); Journal of the Australian Naval Institute (maritime unmanned vehicles), and just this month in the Canadian Military Journal (unmanned ground vehicles). In September of this year, I have also had another article published (Sept.) in the Australian Journal of Military & Veterans Health dealing with unmanned platforms as would be employed in future battlefield medical operations.

To assist the Standing Committee in the process, I have attached these publications in .pdf version in the order as mentioned above. Please note that due to file size, I may have to send some as separate emails attachments. Although I am sure that there may be senior fulltime defence personnel with more expertise than I available to your enquiry, should you need my contribution I would be pleased to participate and assist.

Kind regards

Gary

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CONTENTS

'Drones' or 'Smart' Unmanned Aerial Vehicles?

Pilot Officer Gary Martinic, Australian Air Force Cadets

Introduction

Over the past decade or so, it has become commonplace to refer to unmanned aerial vehicles (UAVs) as 'drones', no doubt in reference to the bee-like, deep humming sound they supposedly emit as they fly endlessly along programmed routes in search of potential targets. However, the term 'drone' has a number of less favourable connotations—notably 'idling', 'monotonous' and 'non-working'[1]—which depreciate and disparage the increasing utility and cost-effectiveness of UAVs in modern warfare.

For a number of years, UAVs—characterised by the highly-effective 'Predator' (see Figure 1)—have been used in combat missions with some visually-spectacular and well-publicised results, notably in Pakistan, Afghanistan and Yemen.[2] UAVs can undertake a large range of tactical missions, often with superior strike accuracy to manned aircraft. They are also smaller, more economical and typically can fly longer without refuelling or the risk of pilot fatigue.[3] Because their operators do not need flying experience, their training is some ten-fold less expensive than pilot training for manned aircraft.

Currently, the US Air Force trains more UAV operators than both fighter and bomber pilots combined; UAVs also fly more combat mission hours than any manned aircraft.[4] Larger, more sophisticated and more lethal UAVs are continually being developed, such as Northrop Grumman's 'Global Hawk' and General Atomics' next-generation 'Avenger'.[5] A recent US Air Force report asserts that planning for the next five decades will focus on building 'total flexibility' into UAV airframes, allowing future models to be used for defensive and offensive roles, including air superiority, anti-missile defence, air-to-air refuelling, medium-to-long range bombing and even air lift.[6]

Figure 1. Predator MQ-1 unmanned aerial vehicle

(Source: US Air Force website: <http://www.af.mil/information/factsheets/factsheet.asp?fsID=122> accessed 25 October 2012)

The military application of UAVs continues to grow as many countries invest in their research and development (R&D), with future models proposed that will likely achieve 'hyper-manoeuvrability', have stealthy airframes and be more rugged, giving better battle-damage survivability.[7] Military futurists envisage multiple UAVs being operated via a single operator which, in a conflict scenario where both sides possess the same technologies, would make it seemingly plausible to fight future wars by 'remote control'. It is also highly probable that as a result of the increasing variety of roles now possible by UAVs, the role of the military pilot will become far less critical to mission requirements.

This article argues that defence planners can no longer think of UAVs only as 'drones', primarily suitable for surveillance and remote interdiction of opportunistic ground targets. Particularly in the context of the forthcoming Defence White Paper, we need to be thinking of UAVs as 'smart' capabilities, with considerable potential to provide highly cost-effective, low manpower solutions to the challenges facing Australia 'in a neighbourhood that is growing more complex and more dynamic…. [and as] we … accommodate constraints on the resources we have available to do this'.[8]

The development of robotic technologies

Modern UAVs, with the ability to identify targets and launch air-to-ground missiles with lethal accuracy, are regarded as a relatively recent phenomenon. However, their development can be traced to around 1940, when Reginald Denny, a former British pilot in World War 1, developed the first radio-controlled aircraft. He initially intended it as an aerial target for the Army but, with the outbreak of World War 2, the UK Government manufactured some 15,000 units, making them the first mass-produced UAVs in history.[9]

The earliest use of unmanned radio-controlled weaponry was arguably by Germany. In World War 1, it used electronically-controlled motorboats to patrol its coastline.[10] Germany also deployed a small unmanned tank, the 'Goliath', armed with explosives, which was detonated when it came close to enemy forces.[11] With its tradition of investing heavily in military R&D for strategic gain, Germany was a keen participant in the development of revolutionary military technologies in both World Wars, exemplified in the closing stages of World War 2 by the production of the first fighter jets (Messerschmitt 262 and 263) and the first 'cruise missiles', the V-1 and V-2 rockets.

Today, broader robotic technologies are no longer the 'stuff' of science fiction novels. A variety of systems—ranging from robotic planes (including both UAVs and miniature aerial vehicles) to all-terrain ground vehicles, ground-dwelling robotic quadrupeds and marine submersibles—are now becoming a reality, with a number already deployed for both surveillance and offensive purposes in military operations. In particular, the US military's use of unmanned air and ground robotic systems has seen a dramatic rise in their application, including in Iraq, the former Yugoslavia, Afghanistan, Pakistan and more recently in Yemen.

Armin Krishnan, in *Killer Robots: legality and ethicality of autonomous weapons*, confirms this 'explosive growth in unmanned systems as fielded in US- and NATO-led operations'.[12] His book provides a timely overview of the issues surrounding the use of autonomous weapons systems (AWS), including the legal and ethical considerations. In particular, he discusses the issues relating to 'moral disengagement' and 'automated killing', concluding rather cautionary with a range of measures for regulating emergent and future systems, including that the proliferation of AWS should be slowed and that they should be defensive in posture, limited in their firepower, and fitted with neutralising mechanisms.[13]

All the while, military scientists continue to develop these technologies, increasing their sophistication, applicability and lethality, not to mention gradually increasing their level of artificial intelligence, which one day may give them the capacity for complete autonomy from the human operator. This raises a host of critical ethical, legal and political issues, which arguably will need to be resolved before further levels of autonomy are considered.

While most of the discussion has centred thus far on 'macro' robotics, or larger machines in the scale of small aircraft and the like, it should not be forgotten that these new robotic technologies have also produced micro-sized devices, similar in size to a tennis ball or even a golf ball. Fitted with imaging and/or surveillance technology, these small sophisticated devices, some of which are designed to have the appearance of small animals, could well be beaming back images and other information to their central operating base as they perch on a window ledge or even crawl inside a house.[14]

Then there are the slightly larger airborne platforms, the size of small 'toy' helicopters, which are being successfully used as surveillance systems by some police departments, particularly in the US. Such contemporary micro-technologies illustrate the use of robotics beyond just military applications, showing that they are not only reshaping the conduct of modern war but that they also have universal applicability within other industries. As a case in point, some real estate agents in the US are today using tiny robotic helicopters fitted with miniature cameras to photograph the properties they are marketing.

The development of UAVs

While robotic technologies have advanced significantly across all three environments, they arguably have been most pronounced in the air. Militarily, the use of UAVs (or UCAVs—unmanned combat aerial vehicles—as they are sometimes called) have already been a reality for over a decade. However, further research continues not only into their form, shape and size, but into finding a range of new functions, both in warfare and the civilian arena alike.

The Boeing aircraft company, for example, is currently working on aircraft that will have the ability to take off, fly and land to pre-programmed flight paths, without human intervention via a remote joystick or control input.[15] The logical extension of this technology is its applicability to civil aviation although, because of safety and legal concerns, it seems unlikely for the near future that civil aviation authorities would be willing to allow the operation of UAVs in close proximity to airliners carrying hundreds of passengers.

Moreover, the military application of UAVs continues to grow, with the US leading the rest of the world in production and deployment by almost an eight-fold margin over China, followed closely by Israel.[16] And the current massive investment in UAV R&D looks set to continue. The US Air Force's 2009 report 'Unmanned Aircraft Systems Flight Plan 2009-2047', in addition to outlining the conventional defensive and offensive roles expected of UAVs, speculated on operations where massed UAVs would be deployed in formations or 'swarms', with the primary aim of knocking out the air defence systems of opposing forces.[17]

Looking at the US Air Force's long list of proposed functions, it is apparent that the US military is intending to employ UAVs in many areas of its force structure. Furthermore, it is also envisaged that future UAVs will have increasing levels of artificial intelligence built into their operating systems, giving them a considerable degree of operating autonomy. Hence, in the coming years, it seems likely that UAVs will have all the capabilities of today's manned aircraft, as well as the capacity to make decisions that today can only be made by those onboard a manned aircraft.

Mention has already been made that the US Air Force is currently training more UAV operators than traditional pilots. Considering that a UAV is capable of staying in the air for up to 24 hours (and sometimes more), continuously over an 'area of interest', while relaying to mission headquarters precise video footage of suspect activity, it is not surprising that UAVs have many supporters. There is also little chance that a manned aircraft could achieve the same kind of mission without the need for re-fuelling or pilot fatigue. Indeed, large UAVs, such as the 'Global Hawk', can reportedly fly between continents and then scan some 53,000 square miles of earth per day via an array of electro-optical cameras, synthetic aperture radar and/or infra-red sensors.[18]

Moreover, despite the reduction in 'traditional' military capabilities announced by the US Government in early January 2012, it was made clear by Defense Secretary Leon Panetta that such cuts would not apply to 'drones', which the Obama Administration clearly sees as being extremely effective against terrorist groups and the fight against terrorism more generally.[19]

The ADF's capability

The RAAF operates its own 'Heron' UAVs, acquired from Israeli Aerospace Industries under Project Nankeen. It is a medium-altitude, long-range aircraft with high-resolution ISR (intelligence, surveillance and reconnaissance) capability, which can fly for more than 24 hrs at a speed of 180km/h and a ceiling of 33,000 ft.[20] Weighing more than a tonne at take-off, it has a wingspan of over 16 metres and navigates using GPS.

Figure 2. The RAAF's Heron UAV

(Source: http://www.airforce.gov.au/News/Archive/2009/December.aspx)

Allowing Australian ground troops to 'see beyond the next hill', the Herons are regarded as a valuable military asset. They are flown by remote control by a two-man team (a pilot and a payload operator), typically at a considerable distance from the front line. The operators are supported by military specialists trained in imagery and sensor capabilities. The Heron's main functions are to perform ISR, monitor enemy movements and help protect Australian forces against improvised explosive devices.

The pros and cons

One of the major advantages of UAVs is that they are considerably cheaper than manned aircraft, both in terms of acquisition and ongoing maintenance, as well as training.[21] Simple comparisons cannot easily be made—and it is not particularly meaningful to compare how many Predator-type UAVs could be acquired for the cost of a single Joint Strike Fighter. The other important issue is that the cost of UAVs is not necessarily increasing exponentially as new capabilities are developed. Again, one needs to compare 'apples with apples'. But it is interesting to note that whereas each Global Hawk UAV currently costs around US$65m, the estimated cost of the next-generation Avenger UAV, with broadly similar capabilities, is US$15m.[22]

At the tactical level, one of the benefits of UAVs is that they can carry out a broad range of tactical reconnaissance missions, including 'dirty' missions involving the monitoring and sampling of areas subjected to biological or chemical weapons attack. They can also be used in highly-dangerous or politically-sensitive situations where the loss or capture of a military pilot would further complicate offensive operations. They also can often provide more detailed targeting information than manned aircraft, giving them superior strike accuracy. And as they are smaller and without the space required for aircrew, they can fly for longer than manned aircraft and are also much more economical to operate.[23]

From a mission point of view, their use is also much more discreet, particularly for counter-insurgency operations, where their smaller profile makes them more difficult to detect. Also, unlike manned aircraft in war zones, they do not need to be rotated as often. From a cost effectiveness point of view, a very significant advantage for armed services is that UAV operators essentially require no previous flying experience, which means their training is some ten-fold less expensive than that of today's fast jet pilots.

Military scientists and engineers predict that UAV designs of the future will likely be capable of 'hyper-manoeuvrability' (or extreme lateral acceleration), achieved through advances in avionics and the use of composite materials and stealthy airframes, which would give them considerably enhanced ability to avoid detection by radar.[24] Contrarily, the extreme g-forces generated could not be withstood by a human pilot sitting at the controls. UAV designs of the future will also likely be more rugged, giving them enhanced levels of 'battle damage survivability' in situations of air-to-air combat. Even more futuristic, although technologically plausible, is the concept of multiple UAVs being operated by a single operator, fighting wars of the future by 'remote control'.

Most critics of UAVs do not believe that robotic technologies are the way of the future, for a number of reasons. The most common argument is that only a trained pilot, sitting in a cockpit, can react instantly to a threat and take appropriate evasive or defensive action. Others believe that even though the use of UAVs will increase in the future, correct decisions can only be made in a combat environment by a human being, which 'puts the pilot in the best position to make decisions about using lethal force'.[25] Along similar lines, other commentators assert that 'in a dynamic [combat] environment, where things are changing by the second, sensors [UAVs] cannot replace the judgment call of a human being'.[26]

There is another problem with UAVs, known in defence circles as 'latency'. This is the time delay between when an operator sends a signal to a UAV and the time it takes to respond. While this would usually only be a matter of seconds (or micro-seconds), it is relevant to the argument as to the responsiveness of UAVs versus the reaction time of onboard pilots. Along similar lines is the concern that a UAV is critically dependent on easily-disrupted data links. Finally, UAVs are at significant risk (and much higher than manned aircraft) of being intercepted by surface-to air missiles (SAMs), as occurred in the conflict over the former Yugoslavia, when a number of Predator UAVs were downed by ground forces using early-generation Russian-made SAMs.[27]

Proponents of UAVs see these and similar problems as easily addressed. They argue that with continuing technology developments, future UAVs will be fitted with in-built artificial intelligence systems, providing them with a significant degree of operating autonomy, including the ability to activate self-defence systems, including against ground-to-air threats. Countering the argument of data link failure, proponents argue that UAVs can continue to operate by relying on GPS guidance or even pre-loaded software, such that a data link failure is not necessarily a 'fatal' outcome. The issue of latency could also be addressed by the deployment of a series or chain of small, solar- or laser-powered ultra-long-endurance UAVS, along which satellite signals could be bounced to the primary vehicle.[28]

Despite these likely technological advances, it is evident that the primary issue remains the moral question regarding the fully autonomous use of UAVs where 'man is taken out of the loop'. It is true, as often witnessed throughout history, that the speed of technological development frequently outpaces our ethical and policy responses. As one author puts it, these advancements have always tested societal paradigms.[29] Nevertheless, these questions need to be resolved and for good reason.

The potential risks become clear when one considers that some UAVs can carry up to four highly-destructive air-to-ground missiles, being fired by an operator located in a separate continent. Whether because of malfunctioning systems onboard the UAV or simply human error, the potential exists for the operator to lose control of the UAV and its weapon systems. The added dimension is the moral perspective of being able to assess the *proportionality* of an attack, in accordance with the international Law of Armed Conflict, which is currently done by a human operator.[30]

This raises some very important issues which, among others, are the reason why countries operating UAVs have introduced legal guidelines for their employment. Most Western countries already have their own similar versions; the RAAF's is titled 'Operations Law for RAAF Commanders (AAP 1003)'.[31] However, with the increased capacity and power inherent in newer and future generation UAVs, it becomes imperative to question whether current laws are adequate. And because many will have the ability to operate 'inter-continentally', it is necessary also to apply principles of international humanitarian law; again, whether these laws have kept abreast of technological developments is doubtful.

It becomes evident that UAV operators, both now and in the future, will need a thorough understanding of the legalities of operating such weapon systems in conflict zones. That will include the need to correctly identify potential targets, decide on appropriate weapons selection and the degree of proportionality to be used in order to avoid 'collateral damage' and, lastly, to have the ability to abort attacks in the case of erroneous targeting information or a change of mind by strategic planners.

It will be interesting to see what happens when these decisions are transferred from the current generation UAV operator to the autonomous UAV of the future. In his article in a 2009 issue of the *ADF Journal*, Dale Hooper discusses the many complex legal and ethical questions, concluding his analysis by emphasising the importance of the law being consistently applied both in the planning and execution stages of UAV missions in order to reduce inadvertent civilian casualties.[32]

Hooper also highlighted the potential of software malfunctions in UAV targeting systems to result in collateral damage. He also reminds us that UAVs can potentially become an unlawful means of combat, in a scenario where there has been inability to control targeting as a result either of human operator error or systemic failures, rendering the whole process 'indiscriminate'.[33]

Conclusions

Mankind is at the cusp of a new revolution, a relatively silent 'robotic revolution' in modern warfare. These new robotic technologies, because of their sophistication and lethality, are changing the rules of warfare. How mankind further develops these technologies, while at the same time addressing the many legal and ethical implications, will remain a critical challenge for developers of these technologies and military planners alike, as well as for politicians and policy makers.

In contrast to earlier major conflicts fought on a world-wide scale, 'war is today less a matter of applying massive force across a wide front as it is of applying intelligent force at carefully selected points'.[34] It seems likely that both manned and unmanned aircraft will continue to operate concurrently in mission- and role-specific tasks over the next decade and beyond. However, over the next half-century, it is highly probable that the future battlespace will be dominated by remote-controlled unmanned weapon platforms in the air, sea and land environments.

This will require major legal and ethical hurdles to be overcome, which inevitably they will be. It also seems highly likely—and indeed inevitable—that these technologies will replace the role of many existing manned air, sea and ground weapons platforms, evidenced by the proliferating use of robotic technologies in an increasing number of armed forces around the world. This will likely result, among other things, in a rapid decline in the production of manned strike fighters. These changes will be opposed, as change always is. However, the takeover by the 'machines' will occur regardless. As history has often shown, revolutionary technological advances cannot be prevented.

Some commentators have recently questioned whether autonomous unmanned systems will control all future warfare and remove human decision-making altogether. The answer is undoubtedly 'no'. Although unmanned weapon platforms and systems will continue to evolve over time in form, function and level of intelligence, it is precisely because such advanced weapons technologies are prone to abuse that complete autonomy makes them far too dangerous. This is also the reason why a significant degree of human decision-making must remain, if only to monitor or intervene, complemented by the legal and ethical constraints written into the targeting processes.[35]

For Australia, the forthcoming Defence White Paper provides the opportunity to review our longer-term requirements for aerial platforms and to consider carefully the role and capabilities that future UAVs might provide. As the Chief of the Defence Force has indicated:

> … we need to get more capability out of each Defence dollar, which means we have to be more efficient but also, more importantly, more thoughtful in the choices that we make about the nature of the capabilities that we develop.[36]

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NOTES

1. Terms found in the definition in Bruce Moore (ed.), T*he Australian Concise Oxford Dictionary* (4th edition), Oxford University Press: South Melbourne, 2004, pp. 426-7.
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6. US Air Force, *Unmanned Aircraft Systems Flight Plan 2009-2047*, US Air Force: Washington DC, 2009.
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8. General David Hurley, 'The ADF: set for success', *ADF Journal*, Issue No. 188 (July/August 2012), p. 5.
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11. Singer, 'Interview – The rise of robotic warfare', p. 12.

12. A. Krishnan, *Killer robots: legality and ethicality of autonomous weapons*, Ashgate: Farnham UK, 2009, particularly Chapter 4 (legal considerations), Chapter 5 (ethical considerations) and Chapter 6 (regulation of autonomous weapons systems).
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18. See, for example, 'RQ-4A/B Global Hawk HALE Reconnaissance UAV, United States of America', *AirForceTechnology.com*, see <http://www.airforce-technology.com/Projects/rq4-global-hawk-uav/> accessed 30 July 2012.
19. ABC News blog: see <html http://abcnews.go.com/Blotter/pentagon-fewer-soldiers-drones-save-money/story?id=15448631>.
20. McPhedran, *Air Force*.
21. Notwithstanding recent debate in the US over retaining the decades-old U-2 reconnaissance aircraft in lieu of Global Hawk UAVs, which is about the cost of 'maintenance' of a capability rather than its upgrade. See, for example, Beidel, 'U-2, Global Hawk Advocates Square Off in Budget Battle'.
22. See, for example, Beidel, 'U-2, Global Hawk Advocates Square Off in Budget Battle'.
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27. See William Arkin, 'The Score' in Andrew Bacevich and Eliot Cohen (eds.), *War over Kosovo: politics and strategy in a global age*, Columbia University Press: New York, 2001, p. 22, contending that 22 UAVs were shot down by Yugoslavian SAMs.
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Unmanned Maritime Surveillance and Weapons Systems

BY FLYING OFFICER GARY MARTINIC

The rapid evolution of military robotic technology evident today has seen the emergence and growing acceptance of unmanned vehicles (UVs) across all three operating environments, air, land and sea. This has been due to the fact that UVs have consistently demonstrated their worth across a wide spectrum of current military operations and campaigns.[1]

Developed primarily because of their strong intelligence, surveillance and reconnaissance (ISR) capabilities, lower unit costs and reduced risk to the operator, the development of UVs has continued at an unprecedented pace. Not only can they be used for ISR missions, but they can also be used to provide the delivery of effective firepower as unmanned weapons systems (UWS), and they have grown smaller, faster and more sophisticated with each passing year.

Although the most pronounced use of UWS in today's theatres of conflict have used unmanned aerial vehicles (UAVs), both unmanned surface vessels (USVs) and unmanned underwater vessels (UUVs), are fast catching up to their 'aerial' counterparts due to advances in computing and robotics, navigation, communication, power supply, and propulsion systems. UWS are gradually though consistently replacing humans in many combat missions as they take their place as frontline naval weapons systems. Their mission applications are increasing to include maritime and port security, anti-terror/force protection, ISR, naval warfare and identification and defusing of underwater mines.

Aside from military uses, maritime UVs have also been widely used in a variety of civilian offshore applications including exploration of the Antarctic Ice Shelf, inspection of underwater oil/gas pipelines and international telephone cables, investigating the impact of subsurface oil plumes (spills), UUV deep dive missions to investigate deep ocean photographic surveys, and lastly in maintaining undersea facilities where oceanographic research is carried out. Today 'state-of-the-art' USVs and UUVs are fast becoming more prevalent, and they are being incorporated into the navies by an increasing number of nations due to their utility and effectiveness. This article describes the advances, capabilities and military advantages of USVs and UUVs.

Figure 1. Spartan Scout USV

Historical Background and Classification of Naval UWS

The naval use of UVs has a long history and refers to any vehicle that operates in the marine environment without a crew. Indeed naval UVs, such as torpedoes, underwater mines and target drones, have been in use and have been tested since WWII, while ballistic missiles and cruise missiles have been employed since the days of the Cold War and continue to be in use today. The demonstrated success of UVs, particularly naval UWS in conflict zones, have highlighted their combat effectiveness across a spectrum of naval applications. This in turn has had the effect of encouraging further development and expansion of their use in future naval operations. Indeed maritime UVs are valuable for both military and non-military missions as outlined in the introduction above, but they are also significantly cheaper compared to the construction of maritime vessels and they are also more flexible than commercial-ship contributions, as can be observed via the use of 'Wave Gliders', which harness wave energy as their primary means of propulsion.[2]

With regard to the classification of naval UWS, USVs are unmanned naval vehicles which operate *above* the surface of the water. Under this category fall the unmanned patrol boats, whereas UUVs are unmanned naval vehicles which operate *below* the surface of the water. Examples of this class include various types of submersible vessels. Both of these naval UVs can be operated either completely autonomously, or alternatively via remote-control from a considerable distance away.

Unmanned Surface Vessels (USVs)

This group includes the autonomous and semi-autonomous, highly-manoeuvrable, and quick unmanned patrol boats. There are varied types of USVs available 'off-the shelf', however for the purposes of this discussion, only a few of the better known models will be discussed here.

Aside from their enhanced ISR and interception roles, one of the greatest advantages of USVs are their capabilities as low-cost 'force-levelers' against asymmetric threats, making them excellent naval assets for ship force protection.[4] In essence, this allows them to be used as the first naval line of defence by employing them to inspect certain vessels of interest by naval operators far removed from potential danger zones. Furthermore, they can be reconfigured to various mission requirements thereby further increasing their utility.

Initially developed in the United States as far back as 2001, though first tested in 2003, the *'Spartan Scout'* (Figure 1) is an unmanned surface inflatable watercraft consisting of a rigid hull, that is capable of working autonomously and remotely.[3] Originally designed for surface surveillance and force protection missions in its 7m, 2 ton and 1,360 kg version, subsequent versions of the Spartan have produced an 11m USV capable of carrying a payload of around 2,267 kg.[4]

Both initial and subsequent versions of this USV came armed with .50 calibre mission guns as well as electro-optical sensors, infrared surveillance and surface search radar.[2] It can also be modified for mine detection or anti-submarine warfare, and when equipped with Hellfire or Javelin missiles, it has the potential to attack other surface vessels and can even effect precision strikes ashore.[3]

Another effective remote-controlled and semi-autonomous USV is the 'Protector' (Figure 2) which is manufactured by the Israeli Rafael Defence Systems company.[5] Specifically developed to counter terrorist attacks on Israeli maritime assets, the Protector has the unique distinction of being the first USV to be employed in operational combat service. With a V-shaped, highly manoeuvrable 9m inflatable rigid-hull, the Protector is both fast and stealthy. Its stealth capabilities are due to the vessel's low-profile upper structure which is sealed and aerodynamic, and which also gives the vessel better stability and endurance (up to eight hrs of operation at a time).[6] Various mission requirements can be met due to the Protector's modular platform design which allows it to be easily reconfigured, and it's high speeds (92.6 km/h) are achieved via its single diesel engine which drives its water jets.[7] Furthermore, this USV is fitted with a Mini Typhoon Weapon Station, a TOPLITE electro-optic surveillance and targeting system (allowing day/night targeting capability via forward looking infrared), charge-coupled devices, laser rangefinders as well as a public address system.[5] Since 2012, the Israeli Navy has been operating a larger 11m version of the Protector, which has a greater range and a wider range of weaponry.[8]

Figure 2. The Protector USV

Another more 'basic' USV is the *UAPS20 Unmanned Autopilot System* (Figure 3) which is manufactured by the SIEL company of Italy.[9] This USV has been purposely designed as a 'low-cost' USV which can operate in fully autonomous or remote-controlled modes, usually via the use of a operator control station. It is designed as 7.5m rigid-hulled inflatable boat with a 150Hp 4 stroke outboard engine with a speed of approx. 74 km/h. Despite its basic design, this USV can carry up to 2100kg of payload for various missions which range from harbour/port protection, mine hunting/countermeasures, ISR with sonar/radar as well as UAV launch and control.

Unmanned Underwater Vessels (UUVs). This group includes the autonomous and semi-autonomous operated (controlled and powered from the surface by an operator via an umbilical or using remote-control), stealthy and long-endurance UUVs. There are a varied number of types of UUVs which are available 'off-the shelf', however for the purposes of this discussion only a few of the better known prototypes will be discussed here.

A system of classification of UUVs based on weight and diameter is in use by the U.S. Navy.[10,11] This system classifies UUVs by the following definitions; *'man-portable'* UUVs which weigh less than 45.2 kg, have less than 0.007 cubic m of payload and are between 7.6-23cm in diameter. *Lightweight* UUVs weigh up to 226 kg, can carry 0.03-0.08 cubic m of payload and are up to 32.4 cm in diameter. *Heavyweight* UUVs weigh less than

Figure 3. UAPS20 USV

Unmanned Maritime Surveillance and Weapons Systems

1,360 kg, can carry 0.11 cubic m of payload and are 0.553 m diameter (same as USN torpedoes); lastly, *Large* UUVs can weigh up to nine ton, carry 0.42-0.85 cubic m of payload (plus external stores) and are up to 0.91m in diameter.

While the very first UUV to be developed can be traced back to the pioneers of this field, such as Stan Murphy and Bob Francois of the University of Washington as far back as 1957, todays UUVs are more versatile and significantly more sophisticated.[12] This early model UUV was used to study diffusion, acoustic transmission and submarine wakes and was known as the 'SPURV', being short for 'Special Purpose Underwater Research Vehicle.'[12]

Today, more recent examples of UUVs include the *'Remus'*, the *'Pluto-Plus'* and the *'BlackGhost'* models. The Remus, manufactured by the US Woods Hole Oceanographic Institute, was designed as a low-cost UUV, which is operated via a laptop computer and therefore is completely autonomous.[13] With several aluminium-bodied, torpedo-shaped vessels within this class of UUV, the smallest in diameter is the Remus 600 (Fig.4) measuring 32.4cm. Regardless of its small size, the Remus 600 can operate to a maximum depth of 600m[13] and due to its 5.2 kilowatt-hour rechargeable lithium ion battery, it can operate for up to 70 hrs and at speeds of 9.3 km/h.[15]

The next model in order of size is the Remus 100 UUV which measures 1.60m x 0.19m x0.19m and can operate to a max. depth of 100m. The largest model is the Remus 6000 which measures 3.84m in diameter. Many Remus UUVs were employed during the 2003 campaign 'Operation Iraqi Freedom' to detect underwater mines, which proved very successful,[16] they were also successfully employed in searching for and recovering the 'black boxes' from the wreckage of Air France flight AF447.[17] These later examples confirm the capabilities of UUV platforms for hydrographic reconnaissance, seafloor mapping, and shallow water mine counter measures, which also eliminate the need for larger vessels and costly special-handling equipment.

Figure 4.
REMUS-600 UUV

Purpose-built and designed by the Gaymarine Electronics company of Italy as a reconnaissance and mine counter measures UUV, the Pluto Plus (Fig.5) can be operated by a fibre-optic cable or a wireless link, making it suitable for hull inspections and for counter-terrorism operations.[18] This UUV weighs approx. 315 kg, has a payload weight (in air) of 100kg) and can dive to a depth of 300m+.[19] It is a battery-operated underwater vehicle with an operational endurance ranging from 2-6 hrs. Sensors include three separate sonars and TV camera, and its propulsion is supplied via two horizontal and one lateral thrusters giving it a speed of around 11 km/h.[19]

Originally built by an engineering team at Cambridge University in 2008, the torpedo-shaped 'Blackghost' UUV was designed to autonomously undertake underwater assault courses and to be able to be deployed through an ice bore hole for scientific research missions.[20] Since then this UUV has undergone many improvements including improved software architecture, a new battery module and enhanced thrusters. This lightweight UUV weighs 7kg and is 1200mm long, yet cameras, a battery and a 1GHz computer are stored within its small (100mm diameter) hull.[21] Propulsion is achieved via a 100W main motor. It has a rear propeller to drive it forwards and four internal vector thrusters for manoeuvring, arranged front and back, as two sets, one vertical and one horizontal. Computer processing power is supplied via a very small (100x72mm footprint) PICO-itx, containing a motherboard with a 1GHz processor which can provide up to 1GB of RAM and which controls accelerometers, gyros and pressure sensors, while a second 16-bit microcontroller controls the motors, autopilots and the ability to perform low-level control loops.[21]

What are the advantages of naval UWS for the ADF?

As a nation at the forefront of UWS R&D, the US clearly sees a 'big future' in the considerable warfighting benefits of these unmanned platforms, and as such the US continues to invest heavily in their development and enhancement. In fact, as far back as 2002, the Chief of Naval Operations of the US Navy requested that the Naval

Figure 5.
Pluto Plus UUV

Studies Board establish a committee to review the status of, experience with, technology challenges related to, and plans for development and concepts for UVs to be used in support of naval operations. Such was, and increasingly has been, the level of interest and enthusiasm across all service branches for these platforms, which the U.S. (and many other nations) see as holding great promise for increasing roles in future military operations, encompassing air, land, sea, and potentially, space.[22]

With respect to the advantages that these naval UWS can provide for the ADF, it is the powerful combination of the protection of the operator from direct enemy action, strong ISR capabilities as well as the ability to provide the delivery of effective firepower, along with characteristics such as high manoeuvrability, flexibility and speed (USVs), and stealth and endurance (UUVs), which are undoubtedly the main advantages of these naval UV platforms.

Underwater mines are considered the most serious threat to many critical waterways of the world. Although not considered sophisticated weaponry, they are effective and can destroy key underwater infrastructure assets including important oil and gas pipelines, international telecommunications cabling and surface and subsurface ships. The US Navy estimates that some 250,000 maritime mines are stocked by 50 various countries that could be rapidly deployed in any part of the world's oceans at any time.[23]

With such an insidious arsenal lurking in many waterways, many navies are constantly employing naval divers and dedicated ships to clear these dangerous mines and other obstructive debris from key seaways, so that ships can travel safely and dock at key ports unhindered. Although divers are traditionally the main 'protection' in this regard, by virtue of the fact that they are trained to locate, identify and defuse mines, UUVs, equipped with both sensors and cameras, have made this important job exceedingly easier and quicker.

UUVs such as 'Knifefish' (a variation of the Remus class) can scan both deep seas and comb shallow harbours for up to 16 hrs at a time, un-piloted, and with its stronger low-frequency sound signals, it can discern a mine from a refrigerator littering the ocean floor.[24] These new technologies are not only proving their worth in the area of mine ISR and identification, but also in the areas of port surveillance/security and civilian offshore research applications.

Though UUVs today are more advanced than in the past, problems still remain, for example, underwater communication difficulties exist between UUVs and satellite and GPS systems, due to the nature of the current-shifting, water-distorting and 'obstacle-rich' maritime environment. Other issues include operational endurance and the need for stronger power sources (without need for constant re-charging) thereby potentially increasing operability from 'days to months.' Lastly, the need for more UUVs to be armed and to have 'dual application' exists, so they can destroy enemy targets when required, not just spy on them. The US Navy is currently investigating all of these key future requirements and has stated that it expects to have them solved by 2017.[25]

Armed USVs are essentially *'lethal, unmanned patrol boats.'* With regards to patrolling the littoral environment, USVs are perfectly suited for this role. They have ideal characteristics in this task as they are quick, agile, highly manoeuvrable, have a long range and are also considered 'stealthy.' They are additionally versatile and can be easily reconfigured for a wide variety of critical missions, all the while protecting both the operator(s) and capital assets from potential risk of harm. According to the Rafael Defence Systems company, the 'Protector' can be fitted to work with UAVs, hence USVs could be considered as 'mini' integrated naval combat systems.[26]

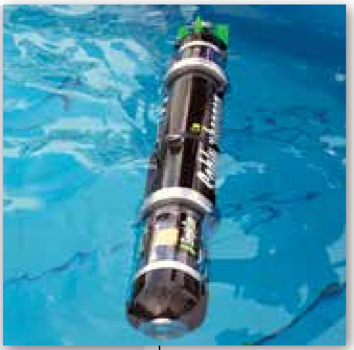

Figure 6. BlackGhost UUV

Israel, Singapore and a few countries in South America, currently operate the Protector USV for both naval operations and to protect their undersea natural resources. Of these, it is believed that only Israel has so far put their USVs to work in actual conflict zones, thus acquiring valuable 'unmanned' combat experience. Being a country that is surrounded by many hostile neighbours, and as such being involved in many continuous conflicts over a long time, Israel has obtained valuable operational experience with the use of many unmanned systems. This has allowed their defence personnel the opportunity to continually and innovatively develop, produce and perfect such systems for their own countries protection as well as providing valuable export opportunities.[26]

In summary, as an island continent, our international trade is overwhelmingly maritime, and as such the protection of our ability to trade is the very thing that underpins our national prosperity.[28] As well as Australia's sovereign land and her island territories, the RAN is also responsible for securing the protection of critical offshore infrastructure, which in the future may extend up to 648 km from Australia's shores.[28] To do this many miles from home, the RAN has a fleet based around two main

Unmanned Maritime Surveillance and Weapons Systems

types of surface combatant vessels which include the *Adelaide* class guided missile frigates and the *Anzac* class frigates, as well as a small fleet of diesel-powered submarines.[29] These fleets are capable of patrolling offshore open ocean regions around Australia, but they are not ideal for patrolling Australia's littoral environment. It stands to reason that both USVs and UUVs are well-placed for 'dual application' patrolling missions of Australia's littoral environment, both above and below the water's surface.

Apart from their low-cost ship force protection and ISR capabilities, the other important feature of these naval UWS is their ability to decipher the tactical picture surrounding them, known as 'Situational Awareness,' which USVs and UUVs can provide above and below the water, as well as, in the near future, in the air (via use of USV/UAV integrated communication links).[30] USVs and UUVs can also complement the RAN's ability by assisting in its core mission requirements, particularly by safeguarding the state's shores and by providing littoral ISR capabilities. These technologies also have a lot to offer the nation in terms of low intensity patrolling operations such as illegal fishing, drug trafficking and smuggling, potential offshore terrorist activities, and as has been more evident of late, illegal 'people smuggling.'

Because of the success of UVs in recent operations, this has led to recognition of their broader utility and to calls for more UWS, and coupled with their low production costs and low-level of risk to the human operator, the future naval battlespace is likely to be dominated by completely autonomous UWS, comprising USVs and UUVs.[31] Once questions regarding the human-robot interface are solved, the effectiveness of naval UWS will be significantly increased, as will their military capabilities. However, as with other UVs, and due to associated ethical and legal questions surrounding their use, it seems very likely that USV/UUV operators will need to be trained and skilled in strategic thinking and planning because their duties will be to plan autonomous missions which may not necessarily mean that they are controlling the USV or UUV in real time.[32] As changes in technology have always affected the characteristics of the men behind the machines,[32] it may be necessary in the future to survey the characteristics of the new naval officer who will operate these 'non-traditional' naval platforms, which are often heavily armed. This is because they will require a broader range of skills to do the job effectively including one, critical-thinking and rapid decision making skills which are semi-independent of higher chain-of-command structures, and two, and in-depth knowledge of the workings of and the maintenance and repair of these advanced technologies under their control, both being due to the rapid nature of UWS battlefield conditions. ✒

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The Proliferation, Diversity and Utility of Ground-based Robotic Technologies

by Gary Martinic

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Introduction

By contrast to weapons development, which has occurred progressively over thousands of years, the pace of development of information technology and electronics has been staggering. It has led to the 'age of the machines,' where robotic warfare and lethality via remote-control are no longer the preserve of science fiction novels.

These new 'machines' include unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), robotic ground platforms (RGPs), unmanned surface vessels (USVs), and unmanned underwater vessels (UUVs), as well as unmanned weapons and surveillance systems (UWS), all of which have already been deployed in military operations.

With each passing year, the technologies involved have grown smaller, faster, and more sophisticated, mirroring developments in the 'smart-phone' industry, which essentially uses the same electronic components, namely optics, embedded micro-processors, sensors, and batteries. And while robotic technologies to date have featured most prominently in the air environment, state-of-the-art robotic ground vehicles and platforms are proliferating, and they are being incorporated militarily by an increasing number of nations.

In recent years, for example, the US Army and the US Marine Corps have reportedly deployed at least 6000 UGVs in Iraq and Afghanistan, primarily on intelligence, surveillance and reconnaissance (ISR) tasks, as well as for the detection of improvised explosive devices.[1] And while details are somewhat sketchy, South Korea has reportedly deployed stationary armed surveillance 'robots' in the demilitarised zone along its border with North Korea since 2010, and they are capable of detecting movement over a distance of three kilometres.[2]

This article will briefly describe the advances in ground-based unmanned weapons and surveillance platforms and systems, and outline their broad capabilities and military advantages. It will also address their potential use to the CAF, especially as this applies to currently available 'off-the-shelf' acquisitions. It purposely does not address UAVs, which have been reasonably covered in past issues of the Australian Defence Force Journal.[3]

The Development of Unmanned Systems

Germany was one of the earliest users of unmanned radio-controlled weaponry. Most people are familiar with the V-series rockets of the Second World War. However, as early as the First World War, Germany had deployed the FL-7, a wire-guided motorboat carrying 300 pounds of explosives, designed to be rammed into enemy ships.[4] It demonstrated its effectiveness when it struck and damaged HMS *Erebus* off the coast of German-occupied Belgium in October 1917. But early guided weapons were also developed for use on the ground. A rather crude example was the 'land torpedo,' an armoured tractor packed with about 400 kilograms of explosives, intended to be detonated after it reached enemy trenches.[5]

Today, unmanned ground vehicles are generally known as UGVs, although there is a sub-class of robotic ground platforms (RGPs), such as 'quadrupeds' and 'bipeds,' which use robotic limbs to achieve movement, rather than a wheeled-or-tracked chassis. Initially, most UGVs were designed specifically for particularly dangerous tasks, such as explosive ordnance disposal. They generally are fitted with on-board sensors to scan and monitor their environment, and they operate either via a human controller, or autonomously.

Remotely-operated UGVs (ro-UGVs)

The remotely-operated vehicles work on the same principle as a remote-controlled toy car in that their movement is controlled by a human operator, either via the use of sensors (such as digital video cameras), or by direct visual observation. Most have been developed to inspect and disable explosive devices, providing a safer alternative to human operators in high-risk situations. But increasingly, their use has been extended to include ground surveillance missions, urban 'strike' operations in law enforcement and military operations, military checkpoint monitoring, and even for some peacekeeping tasks. Currently, there are more than 20 types of ro-UGVs available 'off-the-shelf.'

DVIDS image 92713 by Sergeant Giancarlo Casem

A *Talon* robot goes in for a closer look at a suspected improvised explosive device.

SWAT BOT robot by Chris Rogers at Coroflot

Mil-Sim A5 Robotic Weapon UGV.

Other ro-UGVs include the 'I-Robot 110,' which is a lightweight, remotely-controlled UGV designed to provide a quick assessment of 'situational awareness' and persistent observation in confined spaces.[6] Weighing only 13 kilograms, and fitted with four cameras and night vision optics, it can be deployed into buildings in search of insurgents or snipers. Another is the 'Mil-Sim A5 Robotic Weapon,' an all-weather/all-terrain UGV weighing 90 kilograms, which can be operated remotely by day or night from up to half a kilometre away via wireless control.[7] It can be armed with lethal or non-lethal munitions, depending upon mission requirements. [Of note, the version illustrated is the 'crowd control' variant, capable of firing 1100 hardened rubber-ball rounds at up to 20 rounds per second, and this is possible while the UGV is moving].

Another is the Modular Advanced Armed Robotic System (MAARS) UGV.[8] It weighs around 100 kilograms, has a speed of 10km/hr, and can be equipped

US Army photo http://www.army.mil.media/316424 by Patrick A. Albright

MAARS ro-UGV.

with an array of weaponry, including a machine gun and grenade launchers. It is operated remotely from a lightweight control unit, and its surveillance capabilities include day and night cameras, motion detectors, an acoustic microphone, and a hostile fire detection system. The MAARS UGV enables its operating force to project firepower while remaining under cover; the obvious weakness is its vulnerability to enemy direct fire.

Yet another ro-UGV, reportedly at an advanced stage of testing, is BAE Systems *Black Night*, which is similar in size and appearance to a traditional tank, complete with a turret-mounted 30 mm cannon.[9] While it is operated remotely, it reportedly has the capacity for a number of autonomous functions, including route planning and obstacle avoidance. A prototype has been under evaluation by the US Army since 2010.[10] The obvious advantage of a remotely-controlled tank—or indeed, any remotely-controlled fighting vehicle—is that it enables the engagement of targets and the projection of firepower without direct risk to human operators.

Autonomous UGVs (a-UGVs)

As their name implies, a-UGVs operate without direct human control. They have in-built sensors which scan and monitor their immediate environment, with sequential activities determined by the use of pre-assigned control algorithms. They typically have the capacity to traverse long distances and to operate for long mission hours without operator intervention, while some also have limited self-repair capabilities. There currently are more than 25 types of a-UGVs available 'off-the-shelf.'

One of the most successful and well-known is the Mobile Detection Assessment and Response System (MDARS), a-UGV developed jointly by the US Army and US Navy for patrolling and guarding military warehouses, airfields, and port facilities.[11] It provides an automated intrusion detection capability, as well as an ongoing assessment of the status of inventoried items, through the use of transponder tags, as it patrols warehouses and storage sites in shifts of up to 12 hours without the need to refuel. It requires operator input only in assessing the severity of an intrusion. According to its developers, the MDARS a-UGV has been so successful that it has been the first 'robot' to be employed in guarding sensitive US nuclear sites. It reportedly is also saving the US Department of Defense millions of dollars annually in labour and security-related costs.[12]

Another innovative a-UGV is the US Army's *Big Dog*, which is a robotic quadruped, designed to carry equipment for ground troops over difficult or rough terrain.[13] It is also known within the US Army as the 'Multifunctional Utility/Logistics and Equipment' robot, or 'MULE,' for short. Weighing 110 kilograms and standing 76 centimetres, it can carry 154 kilograms of explosives at an average speed of six km/hr, and climb hills at an incline of up to 35 degrees. *Big Dog* has the capability to jump over low obstructions, climb over low vertical obstacles, and to walk on ice. Importantly, 'it never falls off its feet.'

Another important semi-autonomous RGP, which was designed to locate, lift, and rescue people out of harm's way, is the 'Battlefield Extraction Assist Robot,' or BEAR.[14] Developed with funding from the US Army Medical Research and Materiel Command, it has the capability to lift up to 200 kilograms, a top speed of 10 km/hr, and can negotiate difficult battlefield terrain. One can easily deduce that this prototype RGP would also have useful application in the civilian area of emergency medicine, such as the retrieval of victims from hazardous road accident environments, or from damaged buildings following an earthquake.

Current Limitations

While some of the autonomous functions of UGVs are well advanced, such as mobility, endurance, communications, and navigation, the development of behavioural functions relating to their adaptability and employment in complex tactical scenarios is still at an early stage. One particular issue is whether to limit UGVs (and other robotic technologies) to adaptive control solutions, or whether to incorporate artificial intelligence, ultimately seeking UGVs capable of complete and 'responsible' autonomous operation.[15]

Advantages of Ground-Based Robotic Technologies for the CAF

Undoubtedly, the most valuable advantages of UGVs are their ability to perform ISR tasks, to aid and complement the mobility of soldiers on the battlefield, and, when armed, to project firepower while protecting the operator

USMC 14026-M-NS272-686 by Corporal D.J. Wu

MDARS a-UGV.

DVIDS image 1445401 by Sergeant William L. Holdaway

The Legged Squad Support System *Big Dog*, a load-carrying robotic quadruped being tested during Exercise RIMPAC.

Moreover, as the development and proliferation of UGVs continues, their acquisition cost will continue to decline, making them even more cost effective for militaries around the world, particularly where their employment can reduce overall manpower requirements, or minimize the risk of death or injury to service personnel. These attributes have been recognised by the US Congress, which mandated in 2000 that one in every three future US combat systems should be unmanned.[16]

For the CAF, the potential utility of these technologies—and ultimately, their effectiveness and reliability on the future battlefield—will need to be weighed against specific mission requirements and detailed cost benefit analyses. On one hand, it is relatively easy to justify the acquisition of a particular UGV to meet a specific, existing capability, particularly one involving highly-dangerous tasks, such as explosive ordnance disposal. The considerably more difficult exercise is to contemplate the required force structure for a future battlefield involving a combination of manned and unmanned platforms and systems, operating as an integrated battlefield network.

The other challenge, which has been addressed by a number of commentators—including in earlier issues of the *Australia Defence Force Journal*—is the complex question of the ethical, legal, and political implications of employing increasingly- autonomous robotic technologies in offensive operations.[17] While some might argue that this issue is overblown and the stuff of science fiction novels, it seems inevitable that future unmanned systems will progressively incorporate artificial intelligence systems, giving them *increased* if not *eventual complete autonomy* from a human operator.

from direct enemy action. These features have made them particularly attractive to armed forces and law-enforcement agencies worldwide, including in unconventional warfare and counter-terrorism operations.

UGVs are versatile, agile, and relatively rugged. Moreover, with the ability to perform repetitive tasks with speed and precision—and being devoid of human emotion—UGVs are tenacious, tireless, and fearless. This makes them extremely useful for a range of the more mundane, tedious, and dangerous tasks on the modern battlefield, especially ones that would otherwise expose combatants or human operators to higher-than-normal risk of injury or death.

Conclusion

The possibility of using robotics on the battlefield has long been envisaged by military planners. Just as UAVs have made a revolutionary impact in the air, it seems certain that UGVs and RGPs will continue to proliferate in ground operations, where they have the potential to greatly enhance combat effectiveness while reducing human casualties on the battlefield.

In the longer-term, it seems inevitable that the battlefield of the future will be dominated by increasingly-autonomous unmanned weapons platforms and systems, operating across the environments of air, sea, land, and space. How those platforms and systems are integrated into future force structures—including for the CAF—is a complex issue, requiring considerable analysis and planning, as will the associated ethical and legal questions surrounding their employment.

This article has attempted to provide some vision of what future ground warfare and surveillance using 'weaponized' UGVs, may look like. In some ways, these UGVs are perhaps the 'perfect soldier' in the sense that they are dangerous, mission-driven, highly-survivable, easily-repairable, and, if required, disposable. Their effectiveness will only be enhanced further when questions regarding the human-robot interface are solved, as will be their repertoire of military uses, as increasing levels of operating autonomy are achieved.

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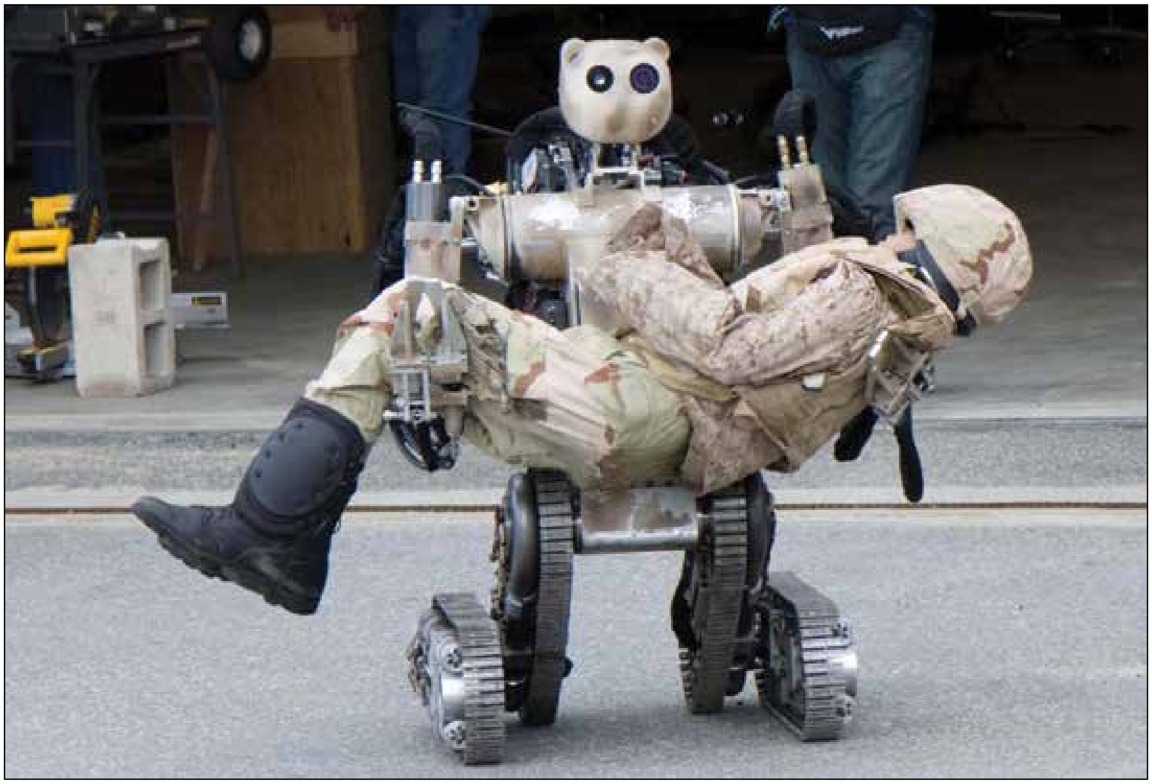

A Battlefield Extraction Assist Robot (BEAR).

NOTES

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- Glimpses of future battlefield medicine
- Trial of iron supplementation attenuates fatigue and declining iron stores for female officers-in-training
- A study of alcohol consumption in a cohort of military nurses

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Original Articles

Glimpses of future battlefield medicine - the proliferation of robotic surgeons and unmanned vehicles and technologies

Flying Officer Gary Martinic, Australian Air Force Cadets

Introduction

The rescue of severely wounded soldiers, while under fire, is itself a major cause of military death and traumatic injury.[1] Some sources estimate that up to 86% of battlefield deaths occur after the first 30 minutes post-injury.[1,2] Hence life saving training techniques[3] and treatments, and more recently, the application of robotic surgical systems (RSS; Fig. 1), technologies and unmanned vehicles (UVs), have been developed to provide battlefield casualty extraction, critical life-saving interventions, and physiological monitoring, in order to reduce this incidence. Although not invincible themselves, when it comes to enemy small arms fire, UVs and RGPs can sustain a lot more direct fire than can the average human soldier, hence their utility in combat first responder scenario's.

Just as unmanned aerial vehicles (UAVs)[4] have continued to provide grounds troops with timely intelligence, surveillance and reconnaissance capabilities, and when armed, with the ability to bomb enemy targets using precision-guided bombs, today, unmanned ground vehicles (UGVs) and robotic ground platforms (RGPs), are increasingly being developed. Not only to search for improvised explosive devices, but also as important battlefield life-saving technologies. With today's battlespace domination by various 'life-taking' weaponised robots, which can achieve 'lethality via remote-control', it has been encouraging to see the recent proliferation and availability of new 'life-preserving' technologies and unmanned platforms.

Over recent years, these technologies have grown smaller, lighter, faster, more agile and sophisticated. While UAVs to date have featured most prominently in the air, state-of-the-art RSS, UGVs and RGPs are proliferating, and are being increasingly used. Such technologies include surgical robots, 'porter' or load-carrying UVs and battlefield casualty extraction devices (both air and ground). The latter include the development of UAVs specifically designed for casualty air-lift evacuation (though these are not covered here). This article describes the advances, variety and utility of some RSS, UGVs and RGPs that have potential application for use in battlefield medicine, and outlines some current systems and prototype models in the testing phases.

Figure 1. Diagramatic representation of RSS. Sourced from: www.economist.com-Jan192012

On-site Robotic Surgical Systems

The idea of RSS, or technologies that use robotic systems to aid in surgical procedures on-site, have been around for over three decades. In 1992, Dr. Senthil Nathan of Guy's and St. Thomas hospital in London successfully carried out the first robotic surgical procedure (prostatectomy) in the world, using 'Probot', developed at Imperial College London. Since then, RSS development was advanced further by two companies working together, SRI International and Intuitive Surgical, who had introduced the 'da Vinci' surgical system as well as 'Computer Motion' with the 'AESOP' and 'ZEUS' RSS.[5] The ZEUS was later used to perform a Fallopian tube reconnection (July 1998), a beating heart coronary artery bypass graft (Oct. 1999), a closed-chest beating heart cardiac hybrid revascularisation (Nov. 1999) and the 'Lindbergh (cholecystectomy)operation which was performed remotely (Sept. 2001).[6]

With grant support from both NASA and DARPA (US Defence Advanced Research Projects Agency), and thanks to the years of pioneering work of Dr. Robert M. Satava, the original telesurgery robotic system was developed, based on the da Vinci design.[7] It turned out to be more useful for on-site minimally invasive surgery (MIS), than remotely-performed surgery on the battlefield and other environments. Today, both on-site and remotely-operated RSS have been developed in various shapes and sizes to overcome the limitations of MIS and to enhance the capabilities of surgeons performing open surgery.[8] This has also provided the ability to perform 'remote surgery' or 'unmanned surgery', though at this point in time, this still requires a human operator assisting at the robot end. Of course, this may provide useful applications in settings where highly skilled medical resources are not available such as the battlefield, isolated enclaves, and even space travel.

Robotic surgery is a method to perform surgery using small surgical instruments attached to robotic arms. RSS can be divided into three separate categories contingent upon the level of surgeon interaction during the procedure; these include Supervisory-Controlled, Telesurgical and Shared-Control methods.[8] The Supervisory controlled method exclusively employs a robot to perform the entire procedure, which it does in accordance with the computer program loaded into it by the surgeon pre-operatively. The disadvantage of this system is that it must be individually programmed, making it expensive as several images and data for patients are often required. Also known as 'remote surgery' the telesurgical method is where a (human) surgeon directly manipulates the robotic arms during a procedure, as opposed to the robotic arms working themselves from pre-loaded software. Using telesurgery, the surgeon can operate from a remote location using sensor data, and real-time image feedback from the robot.[8] As an example of this, in 2001, using Computer Motion, the first transatlantic remote surgical intervention was performed by a doctor in New York, who had removed the gallbladder from a patient located in Strasbourg, France.[9] This operation demonstrated that surgery over long distances was indeed possible. The shared-control RSS allows for jointly performed tasks to be undertaken. For example, the robot steadies manipulation of the fine instruments while the surgeon carries out the procedure.[8]

The da Vinci RSS comprises three components; a surgeon's console, a patient-side robotic cart with 4 arms (one to control the camera and the other three to manipulate the instruments) and a high definition 3D vision system. Da Vinci senses the hand movements of the surgeon and electronically translates them into scaled-down micro-movements so it can manipulate miniature surgical instruments. Any tremors of the surgeon's hand movements are also easily detected and filtered out so they are not reproduced by the unit. The beauty of da Vinci, is that the surgeon's console is provided with a realtime stereoscopic image beamed to it from the camera built into da Vinci. Proponents assert that the advantages of RSS, are that they result in less blood loss and pain and faster recovery times, as any incisions made are smaller and are more precise.[8] Other users also report that RSS result in shorter hospital stays, less need for transfusions, and pain relievers post-operatively.[10]

According to critics of RSS, there are a lack of studies that indicate that long term results are superior, there is often a steep learning curve, requiring additional surgical training to operate the system.[11] Whether the purchase of RSS are cost effective (between $1.75-1.8M), surgeon's opinions vary widely, mostly because some surgeons consider the learning phase too intensive, as they need to complete at least 12-18 procedures before they comfortably adapt to the RSS.[8] During the training phase, some surgeons suggest that MIS can be twice as long as traditional surgery, resulting in patients being kept under anaesthesia longer and ORs open longer. Though, based on patient surveys, RSS provide for lower morbidity outcomes.[10]

Regardless of the mixed opinions of surgeons, today on-site RSS have a multitude of applications which include general surgery, cardiothoracic, cardiology/ electrophysiology, gastro-intestinal (GIT) surgery, gynaecology, neurosurgery, orthopaedics, paediatrics, urology and vascular surgery.[8] Many examples can be cited where RSS have set new precedents in the field of robotic surgery, such that today they have become common tools in the field. For example in 2000, da Vinci was used to perform oesophageal and pancreatic surgery for the first time in the world.[12,13] Later a pancreatectomy and the first fully robotic Whipple surgery was performed. Later, in 2008, the world's first fully MIS liver resection for a living donor transplant was performed.[14] Since the first robotic cardiac procedure in the U.S. in 1999 at Ohio State University, the same group of doctors (Michler, Crestanello & Vesco) have gone on to perform coronary artery bypass graft, mitral valve, oesophagetomy, lung resection, tumour resection, and other procedures, and today their institution serves as a training site for other surgeons.[8] Similarly, RSS are being used today to perform three types of heart surgery, those being; atrial septal defect repair, mitral valve repair and coronary artery bypass.[15]

RSS, using 'Zeus' or 'da Vinci' have been used in GIT surgery to perform colonic resection and oesophagetomy. This has been echoed in the gynaecology field, where RSS have been used to treat fibroids, abnormal periods, endometriosis, ovarian tumours, pelvic prolapse and female cancers via the transvaginal approach for a number of years. Gynaecologists now also routinely perform hysterectomies, myomectomies and lymph node biopsies using RSS. No doubt, as surgical experience and robotic technologies develop further, it is expected that the repertoire of on-site RSS procedures may expand even further.

Most Da Vinci units are located in major centres of capital cities, and it is estimated that they are commonly used in up to 450,000 operations per year globally.[16] Though, while they currently dominate the RSS landscape, they are not without their problems. Firstly, they use proprietary software, and post-installation, each machine collects more than $100K in maintenance service agreements, plus the costs of ongoing, expensive surgical consumables.[16] They are also heavy kits of machinery, weighing more than half a tonne. This from a military point of view of course, renders them somewhat 'immobile' and limits their deployability.[19] However, from the 'base' model of da Vinci, modifications have been made to develop robots with other military applications. It should be noted that most public hospitals in Australia have not acquired the 'da Vinci' RSS, due to the high consumable costs of operation, and also to the belief that the evidence for their use is not strong. Having said that, there are currently 10 da Vinci machines in use in Australia, in both major public and some private hospitals, including three in Sydney and three in Melbourne, two in Brisbane, and one each in Adelaide and Perth. While there is an evident polarity regarding the usefulness of da Vinci among many surgeons, those that favour the machine are strong supporters of this technology, whom believe that the da Vinci RSS is an excellent tool that can produce amazing patient outcomes, but which ultimately requires its surgeons to be well trained and experienced, otherwise complications could be caused by the actions of the surgeons themselves.[17] Also, it should be taken into account that each new version of the robot incorporates several small but significant improvements to reduce risk of patient harm.

'Remote' Robotic Surgical Systems

As far as remotely-applied RSS, and although they still have some way to go, they are starting to make their way into reality.[16] This is the kind of technology that could provide remote surgical care in the field, and the military and private companies are investing in this idea, to make remote surgical interventions possible, thus providing a semi-autonomous technology that can provide attractive options for situations with limited access to medical care.

Envision a scenario of the future in which a "man down, man down" message comes across a military radio. Almost immediately, a casualty extraction UAV is despatched and collects the injured soldier from the battlefield and accommodates him in a mini-OR (inside the UAV itself) while flying away to a safe zone.[16] An assessment and diagnosis are reached after scanning the soldier's body for injuries, and surgery begins to control the injuries. Once those injuries are effectively treated, the soldier is evacuated via casualty extraction UAV to a base hospital.[16]

Although the above scenario may probably be deemed 'too futuristic' a system known as 'Trauma Pod', actually exists and it is being developed in incremental stages by DARPA.[17] 'Trauma Pod', is a project designed to develop robotic diagnosis, life support and surgical capabilities to remotely provide medical care to soldiers injured in the field, which involves the equivalent of a futuristic operating room, in which the only human present in the room is the patient.[16] The demonstration of this system, consisting of a surgical robot, robotic assistants, an integrated life support system and an intra-operative imaging system, is to perform procedures common to the battlefield, on a full-sized mannequin patient.[16] The feasibility of this project has been demonstrated by the dynamic 'choreography' of a team of robots moving around a patient while exchanging tools and supplies.[16]

Interestingly, another new RSS, called 'Raven' has recently (2012) appeared. Originally designed for the US Army as a prototype for robotic surgery on the battlefield, this RSS, unlike da Vinci, is the first surgical robot to use open-source software (Linux-based operating system which allows modification of the original code), and in stark contrast, is compact, light and significantly cheaper ($250K).[18] The Raven RSS has the disadvantage though that it is not yet approved by the US FDA for use in human surgery, so essentially, at this stage, it is still only an 'experimental' RSS, limited to perform operations on human cadavers and animals. It is expected though, that having put enough of these new RSS through their paces, and over time, they will overcome the hurdles of registration for human procedures. One significant dilemma that Raven will face is that its main competitor, Intuitive Surgical, holds the patents to these technologies, thereby risking the possibility of a legalistic issue in the future.

Another remote RSS, developed by SRI International consists of two lightweight 6-degrees-of-freedom arms, each weighing 4.5 kg, that can be carried in small rugged cases and quickly deployed in the field. Such systems are designed as smaller, portable, surgical systems that can function in rugged environments, such as SRI's 'M7' RSS.[16]

Of course there are also other robotic systems, not necessarily RSS, but rather robotic 'life support'.

One such system in this category is known as 'Life Support for Trauma & Transport System' (or LSTAT), which is a snake-like robotic arm attached to a high tech stretcher designed to medically attend to injured soldiers.[19] This 'snakebot' is wirelessly controlled by a human operator with a joystick, and using its sensors and camera, it can monitor a soldiers condition. Containing a ventilator, defibrillator and other physiological monitors (oxygen saturation rate) to perform preliminary diagnostics, the stretcher attached to snakebot is basically a small, portable intensive care unit.[19] The serpent-like flexibility of LSTAT allows this robot to easily manoeuvre over any point of a soldiers body, making it a useful tool to conduct an initial medical assessment in the field, being particularly useful where casualties cannot be easily evacuated when under fire. Using this system, a doctor can move the robot anywhere over a soldiers body to assess his injuries, until he can be evacuated.[19] One of the drawbacks of LSTAT is that casualties still need to be loaded onto the stretcher, thereby increasing the risk to medics, but once loaded, medics can use the onboard equipment to attend to injuries. Further development is continuing to fully automate the system so that sensors move to immediately work on the casualty, while the stretcher is evacuated by UGVs. Another drawback of LSTAT, as opposed to a human operator, is the lack of tactile information. Some military trauma physicians feel that there is no evidence that robots perform better than human operators with respect to medical assessments, particularly in patients with severe trauma. While opinions vary as to the effectiveness of LSTAT, it is imperitive that such systems, at the very least, do not slow the process of diagnosis, treatment and transport, when compared to human operators. Carnegie Mellon University, who initially developed the Snakebot concept, in association with the U.S. Army's Telemedicine and Advanced Technology Research Centre, who developed LSTAT are currently collaborating to address these issues.

Despite the huge strides made in the development and sophistication of RSS, particularly as they relate to both efficiency and accuracy of surgical robots, there are still many technical issues which need to be ironed out. The first relates to the delay in transmission, known as 'latency', (time taken between what happens at one end and what happens at the other). The second relates to the interrupted transmission of the electronic signal, known in the field as jitter, which can make the difference between a successful surgical procedure and an unsuccessful one.[19] Inevitably these hurdles will be overcome. Ultimately, the concept of remotely controlled medical care is moving toward one of human-supervised autonomous operations, in which robotic devices are capable of interpreting and acting on sensor data to provide better feedback to the surgeon.[16] However, mostly due to bandwidth limitations, it is likely that semi-autonomous or 'supervised' procedures may enter this field much quicker than remotely-controlled RSS. Having said that, humans will always remain behind the decision-making process.

Classification of Ground-based Unmanned Vehicles and Platforms

UGVs are by definition, UVs that operate on the ground, however when armed, they are commonly referred to as unmanned weapons systems (UWS). Under the UV category, though in a class of their own, also under the RGPs, which are either quadrupedic or bipedic 'robots', and unlike their UGV 'cousins' they use robotic limbs, rather than a wheel or tracked-chassis, to achieve movement. In general, UGVs and RGPs were designed specifically for dangerous missions, where a human operator could not be used. Similarly to UAVs, UGVs generally have onboard sensors to scan and monitor their environment, usually achieved either completely autonomously or via a human 'controller' located in another location. This distinction provides the two main categories under which UGVs and RGPs generally operate, those being; remotely-operated and autonomous.

Figure 2. Battlefield Extraction Assist Robot (Source: http://www.vecna.com/innovation/bear accessed 6 August 2013)

Battlefield Casualty Extraction Robots

An important semi-automonous (remote) RGP, designed to locate, lift (scoop) and rescue people out of harm's way, is the 'Battlefield Extraction Assist Robot' or BEAR (Figure 2). Developed by Vecna Technologies of Cambridge MA, and funded by the US Army Medical Research and Material Command, BEAR was designed as a powerful, highly agile, mobile robot.[20,21] Standing at 6ft high when extended, its upper torso has two arm actuators which are extremely strong, whereas its lower body base consists of highly manoeuvrable tank tracks, which can separate out as thighs and calves, giving BEAR extra height when required.[20,21]

Designed to negotiate rough and uneven terrain, in its kneeling position, it travels over rubble using its tracked 'legs'. The robot's sense of balance and coordination are controlled gyroscopically using Dynamic Balance Behaviour technology and computer-driven motors which enable it to stand and carry loads upright on its ankles, knees or hips for up to an hour at a time.[21] Interestingly, it can even negotiate stairs while carrying a wounded soldier, as well make its way through most standard doorways. With a top speed of approximately 10 km/hr, and a hydraulic upper body having the capability to lift up to 227kg (500lb), this robot is very well placed to carry out it's core mission of casualty extraction.[20,21]

BEAR 'sees' via use of its inbuilt cameras, and 'hears' via use of its inbuilt microphones. While the early prototype (vers. 6) essentially can carry out all of the above functions, the latest model (vers. 7) has undergone a number of improvements. One of the most significant of these has been to give BEAR a 'friendly' face, which its designers felt was important, so as to re-assure casualties and allay their fears. Other design modifications include a stronger and sleeker, 'humanoid' upper torso, Actin software integration (from NASA) for controlling and coordinating limb movement, 'finger-like' end effectors, and inbuilt detectors for chemical, biological and explosive agents, using Laser-Induced Breakdown Spectroscopy.[20] The latest efforts include implanting pressure sensors in the effectors to ensure that human casualties are handled with 'sensitivity'. One can easily deduce that this RGP would also have useful applications in the civilian area of emergency medicine, such as the retrieval of victims from hazardous road accident environments, from damaged buildings after an earthquake, or simply to move immobile patients in a hospital.

Another robotic casualty extraction system to come onto the military market recently is the 'First Responder Robot' from Hstar cRONA. The beauty of this RGP is that it provides the 'traditional' functionality of mobility, telepresence and casualty lifting capabilities, but also diagnostic capabilities including 'in-field' ultrasound.[22] According to its developers, future upgrades will include autonomous ultrasound image acquisition, 3D ultrasound imaging and visualization, infra red scanning and autonomous traumatic injury assessment and desired treatments will be possible via a medic operating the system remotely.[22] Of course, 'First Responder' has, similarly to BEAR, the same capabilities to operate in hazardous conditions including fire, biological, chemical and even radioactive environments.

Load-Carrying or 'Porter' UGVs and RGPs

In recent years the task of carrying logistic loads (medical supplies; munitions; weapons) has become an 'automated' function, and lately it has been greatly enhanced by the array of 'porter' UGVs and RGPs, which have become available. Not only having the ability to carry heavy loads (227kg) over long distances and over rough terrain, but also to act as 'escorts' to accompany small squads (3-10) soldiers on both operational and logistical missions.[23,24] This they can do quietly, for up to 72hrs without refueling, and one example is the 'REX' porter UGV (Figure 3).[23]

Essentially, the REX UGV follows the soldier or medic that operates it remotely. Alternatively REX can be programmed to trail soldiers up to 6 metres away, via use of a small remote control device.[23] The functionality of these systems has not only enhanced the performance of infantry combat units in the field (as soldiers can carry more supplies to accomplish their mission) but it has also enhanced the 'mobility' of field medical missions, particularly where the REX UGV has an RSS on board. In terms of operability, the REX UGV is hard-wired to move at the same pace as that of the soldiers or medics on patrol, to come to a stop when required, and to either reduce or increase its operating speed.[23,24]

Figure 3. 'Rex' porter UGV. (Source: http://www.w54.biz/showthread.php?391-Unmanned-Ground-Vehicles/page11 accessed 12 Dec.2013)

Currently, a series of UGVs and RGPs are in development, each being designed with a function in mind. For example, REX, and other similar prototypes (designed to accompany combat infantry units) are being armed with an array of lethal weapons, an example of one of these being the 'CaMEL' UGV.[25] The core mission of these armed UGVs is to serve two purposes, to manoeuvre with small units and conduct ISR, and secondly, to close in on and destroy the enemy.[25] Interestingly, the CaMEL UGV can carry 200kg of supplies over a 72 hr mission, while maintaining a 4km/hr steady march speed for 8 hrs, and with the ability to jump from zero to 38 km/hr bursts for up to 200 metres, and on slopes between 30-60 degrees.[25]

Some UGV and RGP models are being designed exclusively for ISR whereas others are purely as medical logistics and treatment platforms. Aside from military applications, the civilian 'Remote Package Handling System' (or RPHS) from the Provectus company, has been exclusively designed to operate at airports where its core function is to assess and quickly remove 'suspect' packages from airport terminal buildings, thus reducing risk to airport employees, as well as minimizing both loss of revenue and downtime.[26]

An innovative autonomous RGP is the US Army's 'Big Dog' (Figure 4),[27] which is a robotic quadruped, designed to carry equipment for ground troops and medics over difficult or rough terrain. Also known in the US Army as the 'Multifunctional Utility/Logistics and Equipment' robot or 'MULE'. Weighing 110kgs and standing 0.76m tall, it can carry 154kgs at an average speed of 6km/h, and climb hills at an incline of up to 35 degrees.[27] Big Dog has the capability to jump over low obstructions, climb over low vertical obstacles, walk on ice and importantly, it never falls off its feet.[27]

Figure 4. 'Big Dog', a load-carrying robotic quadruped (Source: www.boston-dynamics/BigDog.com accessed 6 August 2013)

Current limitations of UGVs and RGPs

While some of the autonomous functions of UGVs are well advanced (such as mobility, endurance, communications and navigation), the development of behavioural functions relating to their adaptability and employment in complex tactical scenarios is still at an early stage. One particular issue is whether to limit UGVs (and other robotic technologies) to adaptive control solutions or whether to incorporate artificial intelligence, ultimately seeking UGVs capable of complete and 'responsible' autonomous operation.

What are the advantages of RSS and UVs for the ADF?

Undoubtedly, the most valuable advantages of RSS is their ability to perform critical life-saving surgical interventions and physiological monitoring, whereas UVs can facilitate combat casualty extraction and evacuation. UVs can also do ISR tasks, and aid and complement the mobility of medics and doctors on the battlefield, while at the same time, protect the operator from direct fire using their own self-defence mechanisms. Such features have made both RSS and UVs attractive to armed forces and law-enforcement agencies alike, including unconventional warfare and counter-terrorism operations.

UGVs and RGPs are versatile, agile and relatively rugged. Moreover, with the ability to perform repetitive tasks with speed and precision—and being devoid of human emotion—they are tenacious, tireless and fearless. This makes them extremely useful for a range of mundane, tedious and dangerous tasks on the modern battlefield, especially ones that would otherwise expose human operators to higher-than-normal risk of injury or death. Similarly today, with the rapid pace of research and development in this area, it is hoped that small portable RSS will be able to provide the capability of remote surgical interventions, as well as advanced life support in the field, in the near future.

Moreover, as the development and proliferation of RSS, UGVs and RGPs continues, their acquisition costs will reduce, making them more affordable for militaries around the world, particularly where their employment can reduce overall manpower requirements or, it is hoped, minimise the risk of death or injury to service personnel. These attributes have been recognised by the US Congress, which mandated in 2000 that one in every three future US combat systems should be unmanned.[28]

For the ADF, the potential utility of these technologies—and ultimately their effectiveness and reliability on the future battlefield—will need to be weighed against specific mission requirements and detailed cost benefit analyses. However, the drawbacks of these technologies which include significant expense, the question of how to provide an ongoing power supply for prolonged missions, and reliable evidence for the efficacy of these technologies all need to be considered. On the one hand, it is relatively easy to justify the acquisition of a particular UV to meet a specific, existing capability. The considerably more difficult exercise is to contemplate the required force structure for a future battlefield involving a combination of manned and unmanned platforms and systems, operating as an integrated combat and medical battlefield network.

The other challenge, which has been addressed by a number of commentators— in earlier issues of the Australia Defence Force Journal as well as other scholarly publications—is the complex question of the ethical, legal and political implications of employing increasingly autonomous robotic technologies in operations.[29,30,31] While some might argue that issue is overblown and the stuff of science fiction novels, it seems inevitable that in the long term future, UGVs and RGPs will progressively incorporate artificial intelligence systems, giving them increasing levels of autonomy, but not complete autonomy from the human operator. Remote RSS however (unlike on-site RSS) are still at an experimental stage of development, hence they may provide potential future advantages in the field, though these are currently only 'experimental' at best.

Conclusion

While the possibility of using robotics on the battlefield to conduct warfare operations has long been envisaged by military planners, it has not until recently been recognised that these very same technologies can also be developed to enhance the practice of battlefield medicine and trauma care. It seems certain that RSS, UGVs and RGPs will continue to proliferate in ground medical operations, where they have the potential to greatly improve the life-saving effectiveness of medical interventions and casualty extraction, thereby reducing human fatalities on the battlefield.

In the longer-term, it seems inevitable that the battlefield of the future will be dominated by increasingly-autonomous UWS and platforms, operating across the environments of air, sea, land and space. It is now also evident that such technologies designed and purpose-built for medical applications, will also dominate the battlefield of the future. How those platforms and systems are integrated into future force structures—including for the Australian Defence Force—is a complex issue, requiring considerable analysis and planning.

This article has provided some vision of what the future battlefield medicine and associated logistics, potentially holds. Aside from RSS, in some ways, UGVs and RGPs are perhaps the 'perfect orderly' in the sense that they are mission-driven, highly-survivable, easily-repairable and, if required, disposable. Their effectiveness will only be enhanced further when questions regarding the human-robot interface are solved, as will be their repertoire of uses within the military medical organisation, as increasing levels of operating autonomy are achieved.[32,33] It seems that, as many futurists will argue, the 'age of the machines' has truly arrived.

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