REPÜLÉSTUDOMÁNYI KÖZLEMÉNYEK
On-Line tudományos folyóirat
XXIV. évfolyam 2012. 1. szám

Bob STRUIJK[1]

NEW DESIGN PHILOSOPHY IN MILITARY ROBOTICS[2,3]

The use of robots by the military started in the second world war and has grown exponential over the last decade. To understand the trends and how current robotics for the various military applications will develop and what its effects are on society, a large number of factors can be investigated:

- *The history of military robotics*
- *The desired objectives of using robotics in the war theatre.*
- *The obtained results in current war zones*
- *The constraints that exist surrounding the use of military robots*
- *The geopolitical economic interests driving new developments*

The combined analysis will highlight the upcoming trends of military robotics in general and UAV's in specific.

ÚJ TERVEZÉSI FILOZÓFIÁK A KATONAI ROBOTIKÁBAN

A robotok katonai alkalmazása a II. Világháborúban kezdődött, és az elmúlt évtizedek során exponenciálisan növekedett. A katonai robotika fejlődésének megértéséhez, valamint a robotalkalmazások társadalomra gyakorolt hatásának vizsgálatához az alábbi tényezők vizsgálata szükséges:

- *A katonai robotika története;*
- *A robotika műveleti területi alkalmazásának fő célja;*
- *A műveleti területi alkalmazások tapasztalatai;*
- *A katonai robotok alkalmazásának korlátai;*
- *A robotfejlesztések geopolitikai-gazdasági okai.*

A cikk a katonai robotika általános, és az UAVk, mint speciális robotok fejlődésével foglalkozik.

I. RELATED WORKS

Tools to gain military advantage have been around since mankind. The use of military robots as an industry is growing fast. In [1] a roadmap by the US Defense Department is given. Bartoli in [2] studied the works of Leonardo da Vinci, the first recorded theoretical war tools. Tesla in [3] proposed solutions for a various range of new weaponry among which remote controlled vessels.

Jaugitz in [4] analyzed the use of battle field robots deployed by the Nazi's in World War II, while in [5] a description of the red army's teletank is given. Examples of modern day military robots are given in [6] in the form of r/c helicopters and the logistics robot BigDog in [7]. Davor et al investigated the requirements and constraints of de-mining robots in [8].

---

[1] PhD Student, National University of Public Service, bob.struijk@fanuc.eu
[2] Lektorálta: Prof. Dr. Pokorádi László, egyetemi tanár, DE MK;
[3] Dr. Zentay Péter, egyetemi docens, ÓE BGK.

A popular report on UAV is used to demonstrate its use and growth worldwide in [9]. Heath in [10] investigates the use and restraints of unmanned military systems for the future. An update of modern systems in defense industry is used in [11] to report on armed robot vehicles. The spread and use of UAV is commented by Newsweek in [12]. DARPA, the US Defense Advanced Research Project Agency is the world's advanced institute on funding and developing tools of any kind to gain a competitive technological advantage, as reported in [13] [23] and [24]. Futurist Kurzweil in [14] discusses the point of technological singularity in [14].

A Wikipedia posting reports on captured UAV by Iran in [15], while in [16] an account of a UAV strike in Pakistan is used. Research on the role of human casualties in US Army UAV is investigated by Manning in [17]. An accident with a firing robot is given in [18]. Arkin in [19] comments on the need for ethical autonomy in unmanned systems.

While Sullins in [20] deals with Robo-Ethics. Statements by Clausewitz are used in [21]. Wallach in [22] discusses the relation between robots and ethics and moral decision making. In [25] and [26] Szabolcsi dealt with special UAV applications for non-military purposes. The basic mathematical modeling problem of the human pilot is outlined in [27] to derive main parameters of the pilot. The random gust models are described by Szabolcsi in for use in control system design purposes [28]. Identification of mathematical theoretical models and backgrounds for UAV's model identification are summarized in [29] by Szabolcsi.

II. INTRODUCTION

Since the 1970s robots have made a dramatic inroad in our factories. Today robots can be found predominantly in automotive industry, electronics manufacturing, food and beverage, metal and general industries. In total there are more than 2 million in operation today. On the other hand the field of Military Robotics is still in its early growth phase.

As of October 2008, coalition unmanned aircraft systems (UAS), also known as Unmanned Aircraft Vehicle (UAV) have flown almost 500,000 flight hours in support in Iraq and Afghanistan. According to the US Dept. of Defense Roadmap 2009-2034 [1], Unmanned Ground Vehicles (UGVs) have conducted over 30,000 missions, detecting and/or neutralizing over 15,000 improvised explosive devices (IEDs) and unmanned maritime systems (UMSs) have provided security to ports.

Less than 10 years ago there were hardly any drones or unmanned vehicles in active duty. As with all new technologies, they bring new opportunities, challenge long traditions and open new debates. The future use of these robots needs to incorporate the various challenges that are brought by today's battlefield and conditions. Using a so called Military Robotics Driver Matrix an analysis is made on the types, use and objectives of military robots.

III. HISTORY OF MILITARY ROBOTICS

In order to understand the future of military robotics it serves to understand its roots, its history. Although the use of tools to gain a competitive advantage is as old as human kind, for purposes of this paper the focus is on the use of flexible automation in the battle field. Robotics itself is a recent science, industrial robots only exist since the 1970s.

However due to the development of CPU processing technology, digital technologies and mechatronics, the military versions were quick to emerge. The theoretical applications were already recognized quite early. Around 1500 it was the great Leonardo da Vinci, in his engineering role that invented many (military) machines and mechanical devices like planes, helicopters and tanks that have become reality only several hundreds of years later [2].

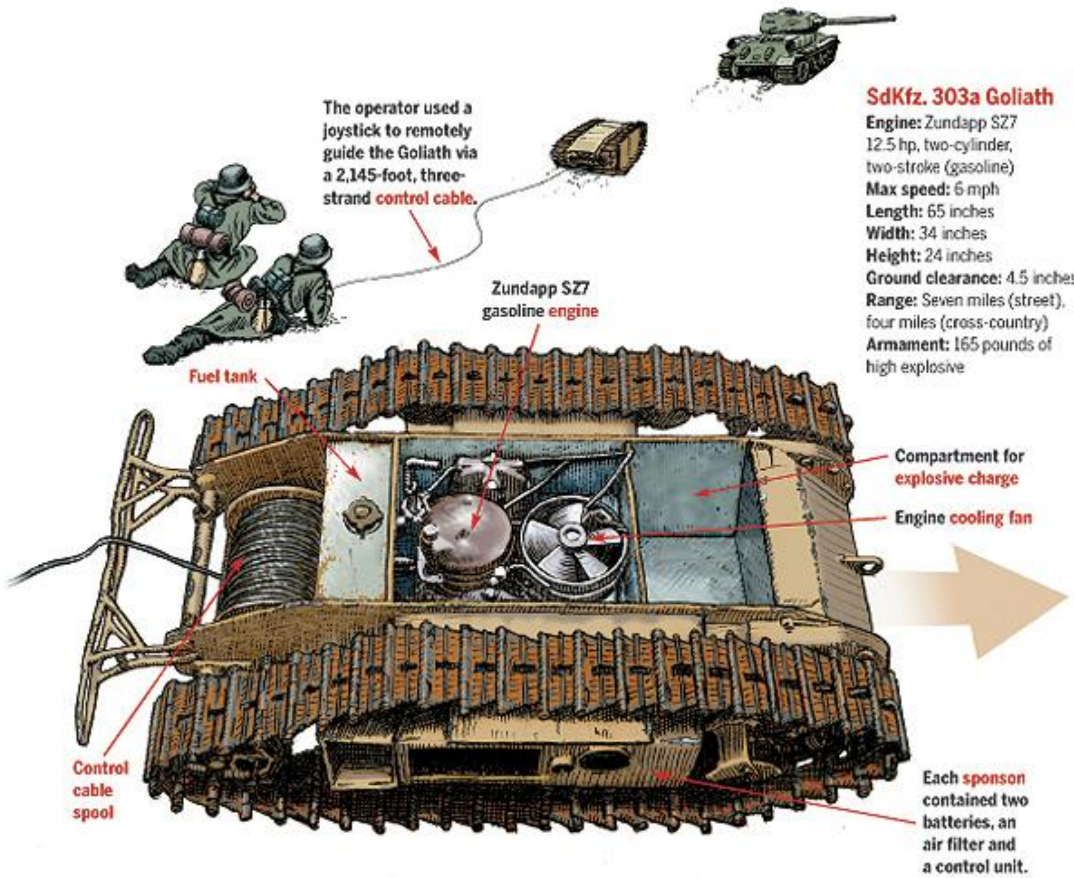
The Serbian born (1856) mechanical and electrical engineer Nikola Tesla, inventor of the induction motor, among other, has contributed highly to the development of radar and remote control of vessels. Tesla described as early as 1897 about radio controlled boats and torpedo's in what he called "teleautomaton". With his close ties to the US military and US electrical industry, his ideas and inventions laid the ground work for today's torpedo's and UAV's alike.

According to Tesla, these automata were the first steps towards an evolution in the art of teleautomatics. He stated that the next logical improvement was the application of control beyond the limit of vision and at great distance from the center of control [3], putting humans far away from danger. He could not have been closer to today's reality. In World War II the Nazi's used their engineering skills to gain battle field advantage.

They developed a range of new weapons and systems, among which were the first (unguided) missiles V1 and V2 and jet propelled air fighters. In the automation field the Nazi's developed the robotic-like antitank weapon "Goliath". These weapons were remote controlled attack vehicles, or tracked mines.

They were the first battle field automation robotic weapons. Powered by a gasoline engine and Bosch electric motors, the Goliath was equipped with caterpillar tracks to move over rough terrain. It could deliver a 100kg explosive according to Jaugitz [4]. The Goliath robotic approach allowed the German infantry to stay effectively out of harm's way while delivering deadly charges to enemy tanks and positions.

World War II also saw deployment of large size remote radio controlled tanks, developed by the Soviets. The so-called "teletanks" were wirelessly remote controlled unmanned tanks. They were fitted with flame throwers, smoke canisters and machine guns, and reportedly could drop explosive charges [5].



Picture 1. Nazi Tracked Mine Robot “Goliath”

IV. DRIVERS OF MILITARY ROBOTICS

As we have seen in above mentioned historical examples, one of the drivers for the Nazi’s and Soviets to develop their robotic like tanks and weapons was to keep human soldiers out of harm’s way. Avoiding loss of human live or minimizing injuries - while destroying enemy’s personnel and/or hardware - leads obviously to a higher combat advantage, a lower cost of warfare and a higher morale. If we imagine an army completely made up of robots it would see no casualties or ‘killed in action’ other than destroyed machines.

If the ultimate goal of a military conflict is winning it (or not losing it) then the sub-goal would be to do so at a minimum cost to human lives and at a minimum economic expense.

Apart from the R&D and production costs, it can be argued that the cost to maintain robots are far less than to train, maintain, deploy and shelter human soldiers.

While today a full ‘robotic army’ is still far off, present day robotics for military do provide an added value to the combat soldiers and war theatre. One could list (non-exhaustive) the certain advantages of using robotics in war theatre:

- No loss of human lives by replacing dangerous human task and/or removing humans from hazardous theatre;
- Reduce possible injuries or “Casualty Aversion”;
- Subsequent effect of casualty aversion is reducing/eliminating the need for casevac and further medical intervention and/or lengthy revalidation;
- High level of delivery accuracy by robots (they do not get tired.);
- Robotics do not experience “fear” or morale issues and can hence be more effective in combat;
- Overall effectiveness due to use of technological skills vs**.** human skills;
- Less or no extensive training needed;
- Less dependence on supplies (robots do not need food, warmth, oxygen or sleep);
- Maintaining home support for operations;
- Improve battlefield intelligence;
- Increase battlefield communication speeds;
- Higher adaptive rate to terrain and conditions;
- Better resistance to NBC conditions;
- Mere economics, value for money, expendability.

Analyzing the list of mentioned advantages we can identify two scalable main drivers: Human Impact & Economic Impact. So military robots have two main objectives; cost down and keeping human’s out of harm’s way. Using these two objectives it is possible to group segments and types of military robots according to their impact on the two identified scales.

The combination of these two main driving factors and scaling provides the “Military Robotics Driver Matrix” as shown in Figure 1.

The two axis are not mutually exclusive but complement each other depending on the military application of the robot. In other words, robots with a clear military purpose aim to either pursue an economic objective, a humanistic objective or a given scaled combination of the two factors.

Today’s military robots come in all sorts of shapes, size and application, but all fall within each of the four quadrants. Some robots combine some or all segments. The analysis does not aim to determine the Battle Effectiveness of each of the robots which can be identified within these four segments. Battle Effectiveness itself can be considered a sub-objective of the Economic Impact. Poor use leads to poor results.

Instead, the Military Robotics Driver Matrix aims to understand the driving forces of the various military robots, not its mere military effectiveness.

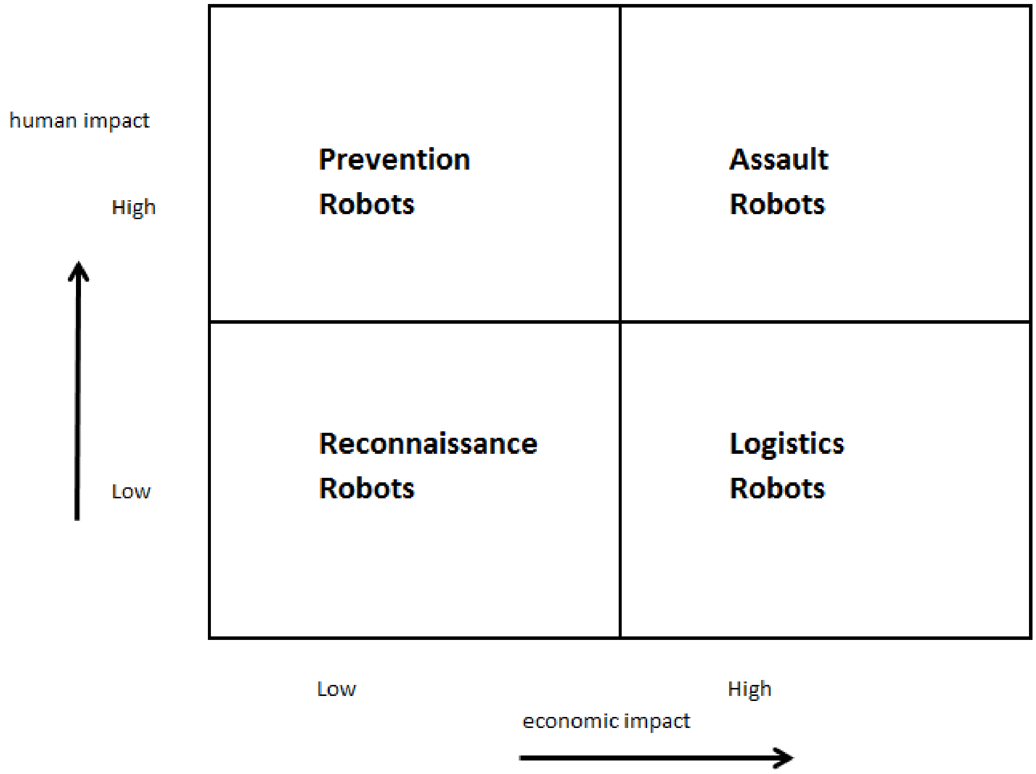


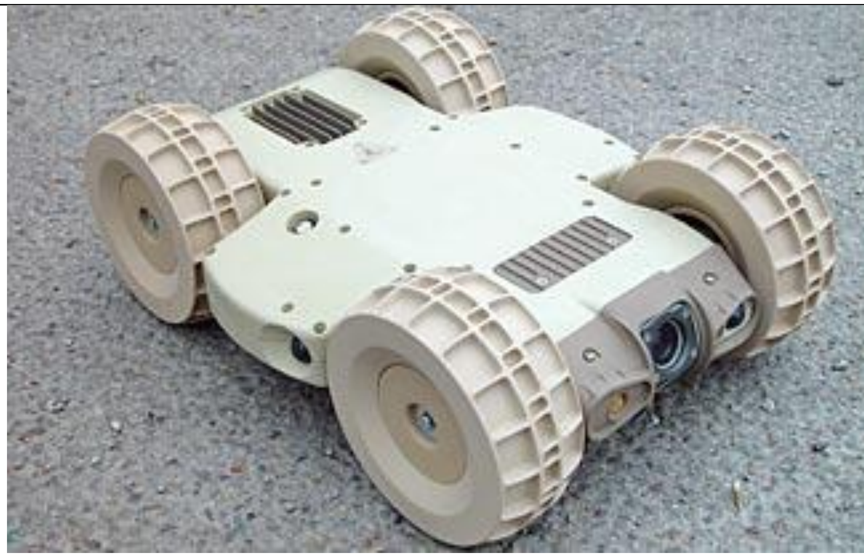
Figure 1. Military Robotics Driver Matrix

Battlefield automation with a low impact on the human side, and a low economical gain can be labeled as Reconnaissance Robots. Autonomous battle field sensors that report theatre intelligence on troop movements, presence etc. can be named in this respect. The segment Reconnaissance Robots distinguishes itself by the passive nature of the robots in question.

These robots are designed to gather intelligence, by means of sensors and /or vision systems. They do not actively deliver ordinance. The main purpose of the wide range of reconnaissance robots is to provide remote intelligence.

The Dragon Runner robot – used widely in Iraq - is a good example of this segment. Designed to be carried in a bag pack for Marines and infantry troop, these do-it-all reconnaissance robot are used in urban terrain operations. The robots have a rugged design and are equipped with one or more digital cameras so they can relay images of operational theatre back to an operational unit.

These robots can be tossed around, climb stairs, dropped from cars, move in houses and bunkers. In addition these robots can move through tunnels with water, scan for snipers, search buildings, screen people for traces of explosives etc. Characteristic is the relatively easy and cheap manufacturing process and their ease to use.



Picture 2. Dragon Runner, Reconnaissance war-bot.

If we extend the scale of the economic impact on the Military Robotics Driver Matrix we end up in the Logistics Robots quadrant. The Logistics Robotics segment discriminates itself from mere reconnaissance tasks through the larger economic effects realized while keeping the human impact objective low. Unmanned cargo helicopters like the K-Max [6], developed by Lockheed Martin and Kaman Aerospace, to (re)supply outposts in dangerous or difficult penetrable terrain can be named in this effect.

Also the various MULE robots are a typical example of military applications of Logistics Robots. The 'BigDog' robot by Boston Dynamics features a 4-legged animal like mechanical design, able to carry approx. 170kg of payload. According to its manufacturer Boston Dynamics, BigDog's control system keeps it balanced, navigates, and regulates its energetics as conditions vary. The robot has various sensors like joint position, joint force, ground contact, ground load, a gyroscope, LIDAR and a stereo vision system.

Other sensors focus on the internal state of BigDog, monitoring the hydraulic pressure, oil temperature, engine functions, battery charge and others [7]. Logistics robots equivalents can be found manifold in general industry where robots manage heavy payloads to relieve human workers. The benefit works in two ways because these robots can supply more cargo like ammunition and food to the various hot spots relieving the human soldiers from carrying this load, in turn making them in theory more effective (less fatigue, higher level of concentration).

The supply of troops in general is a dangerous operation due to the various ambush opportunities as supply troop typically moves slower than combat troop. The Logistics Robot carry a relative high economic impact as the effect of bulk transport without use of human intervention implies less human expenditure. Neither driver nor pilots are necessary. Also that implies less or no need for protection or lifesaving equipment of humans so lighter, flexible vehicles with larger range of autonomy.

Picture 3. 'Big Dog' by Boston Dynamics, Logistics Robot.

The Military Robotics Driver Matrix shows the Prevention Robots segment. This group of robots contains automation designed to typically keep humans out of harm's way while the economic impact of these robots is minimal.

Prevention Robots contain the large group of de-mining robots, IOD removal and similar robots can be mentioned here. The human effects in case of bad outcome while demining, is often a life or death equation, according to Davor et al [8]. It has little impact on war as a total neither does it have large economic impacts so casualty aversion is the main objective.

The implied human costs are high. Injuries are often grotesque and need extensive revalidation. Its impact on society is large as soldiers come back from the battlefield mutilated for life. Military Prevention Robots also are used in civilian life.

After a war, a 100% de-mining effort is executed to minimize the effect of left-over mines on the civilian population, using before mentioned de-mining robots. De mining robots have been around for many years, and due to their technical simplicity are being built by countries worldwide. Today these robots are fully or semi-autonomous in detection and defusing.

Picture 4. 'De-mining' robot deployed, Prevention Robot.

Within the Military Robotics Driver Matrix the Assault Robots are clearly the top notch, most visible group of the matrix. These robots combine maximum impact on (saving) human life while maximizing the economic benefits of using robots for the designed operational task. The whole range of Unmanned Aerial Vehicles (UAV) fits this segment.

Although the early UAV's were mere drones or radio remote controlled aerial vehicles by human operators, the latest generations UAV include built-in guidance and control systems and advanced vision and weaponry systems. Its role in fighting international terrorism in countries like Afghanistan, Yemen etc. have not gone unnoticed, only in 2007 alone 2.2 billion US$ was invested in these unmanned systems world-wide [9].

To fly a UAV requires far less training than a real fighter pilot while of course it is riskless for the operator. As Heath states in [10], operating a UAV reduces manpower. In addition the operational cost of flying manned fighter jets in war theatre versus unmanned is much higher. When a UAV gets shot down, there is a certain risk of loss of technology ownership. When a fighter gets downed there is the additional impact of capture of its pilots that end up as prisoner of war.

So from both a human and an economic viewpoint the rewards to employ robots is high. Not only UAVs are found in this quadrant. Land and sea based systems exist as well. Robotic battle tanks, like the before mentioned Goliath example, are to be found in the Assault Robot segment. These infantry robots are designed to keep humans (soldiers, pilots) out of harm's way while being on the forefront of the battle.

Assault robots or Armed Robotic Vehicles (ARV) are designed to overcome human limitations like fear, exhaustion, exposure to climate, terrain and battle field conditions, while maximizing their lethal potential. These ARV can be made part of an organization of vehicles and sensors.

Equipped with C2 software /hardware and various communications systems. They have semi-autonomous navigation and mission equipment operations. Fire authorization is handled via C4ISR network where humans are in control [11].

Picture 5. Predator UAV firing Hellfire missile. Assault robot.

These four segments can be further sub-segmented into land/sea/air robots but it doesn't offer a different function or benefit. The growth and use of robotics in the military is an irreversible trend.

The adaption rate for Assault robots like UAV is high as they have proven their value in the past decade. According to Newsweek more than 40 countries are developing their own UAV [12]. Even that other interest groups are adopting these technologies. In the US certain Police departments are experimenting with drones for surveillance [25] while in the US the spy agency CIA is said to operate their own drones, disconnected from the military.

One can only speculate their tasks, apart from the obvious surveillance. Usage of ground operated unmanned assault robots is still low due to the technical constraints. The opposite is true for Reconnaissance and Protection Robots. These two groups enjoy wide interest. Their technical threshold level is low while output is high.

V. NEW CHALLENGES AND APPLICATIONS IN MILITARY ROBOT DESIGN

As with all new technology, they have their upside and their downside. The recent experiences of the various robot types deployed in the Afghanistan and Iraqi wars prove their benefit and hence existence. DARPA, the US Defense Advanced Research Project Agency operates with a staggering budget of well over US$ 3.1 billion. DARPA finances projects in Aerospace and Space systems, advanced electronics and technologies, C3 systems, network-centric warfare technology, sensor technology and guidance technology, amongst others.

The above mentioned BigDog is i.e. a DARPA sponsored project. An analysis of the projects that DARPA is working on learns that artificial intelligence is high on their agenda. DARPA's Foundational Machine Intelligence program is supporting research on the foundations of artificial intelligence and machine learning and reasoning.

One focus is on techniques that can efficiently process and "understand" massive data streams. Deeply layered machine learning engines will be created that use a single set of methods in multiple layers (at least three internally) to generate progressively more sophisticated representations of patterns, invariants, and correlations from data inputs.

These will have far-reaching military implications with potential applications such as anomaly detection, object recognition, language understanding, information retrieval, pattern recognition, robotic task learning and automatic metadata extraction from video streams, sensor data, and multi-media objects. [13] These algorithms must allow robots or unmanned vehicles to generate and manage their own goals within human-described mission constraints.

Research of publicly accessible sources show that today's military robots are still (far) away from the by Hollywood presented 1984 Terminator do-it-all fighter robot. To understand the future trends and new applications of military robotics one must understand what are their limiting factors today.

Can robots eventually outperform humans?! It was futurist Ray Kurzweil (2005) that investigated the concept of Technological Singularity, a hypothetical future emergence of an artificial intelligence larger than those of humans [14]. Although it is an irrefutable fact that powers of computers and other technologies is doubling every two years (Moore's Law), it does not mean that we will reach the point of technological singularity with regards to military robotics. Yet.

Apart from the various complex technical obstacles preventing humanity from developing robots on the Terminator level, we can easily identify ethical and legal questions as well as economical ones surrounding the deployment of military robots. Also technical issues are constraining the deployment of full autonomous assault robots today.

VI. MILITARY ROBOTS AND ETHICS

From a political point of view, deployment of robot soldiers, or unmanned weapon systems like UAV make sense. The presence of a UAV flying over non-friendly airspace is seen as less of an infraction of sovereignty than with physical troops deployed on somebody else's territory. Also the capture of a robot, as done by Iran that captured a US drone in Feb 2012 [15] does not provoke the same emotional reactions as if a spy plane was downed and a pilot was captured by Iran. Neither the response of the US is that impacting, as they down-played the incident. The Black-Hawk incident in Somalia provoked a costly rescue mission.

The failure resulted in the withdrawal of the US troops of Somalia. Now UAV patrol the area. So it makes a great difference if a robot is captured or a human. It is very doubtful that Israel would trade a captured robot for 1200 prisoners. Then again there is the question of advanced technology ending up in the wrong hands. So the employment of military robots have clear objectives and its successes are proven on the battle field. So what is holding us back from converting the traditional army into a robot army?

One function that robots do not possess is "moral" or ethics, driven by a conscious. Ethics are built on values, tradition, religion, rules. Human soldiers are accountable and protected for their actions under various war conventions, like the Rules of Engagement written in the Geneva and The Hague conventions.

It governs what is acceptable and what not in warfare. Ethics and conventions alike describe the concept of a "Just War". The following question arise: do or should autonomous robot follow those same rules? Subsequent question is can we program the robots according to these rules of war and morality? If we assume that an Assault Robots can operate autonomous then inherently it can make autonomous call on the use of force, the decision to kill. Small errors in perception (by the robot) can kill innocent civilians or can cause unwanted collateral damage. So guidelines and fail safe systems are needed.

On November 26th 2011 the US launched a drone strike in Pakistan, killing 24 Pakistani soldiers, allies of the US. [16]. A typical real life example of the risks involved in using unmanned technology, where decisions are made far away from the real theatre. It (only) stopped the US for 6 weeks before another Taliban leader was killed by a drone strike. A 2004 study showed that that human-error plays as significant a role in UAV accidents, approximately 33% in all cases investigated. [17]. Apart from people using unmanned machines making mistakes, from an ethical point of view, and legally as well, it is important to establish the chain of responsibility in case the machine makes a mistake. If a civilian looks like a terrorist, who determines the order to fire? And, who is eventually responsible?

In 2007 an automated unmanned anti-aircraft gun killed 9 soldiers in South Africa when some malfunction occurred during a live training exercise [18]. Ronald Arkin in [19] advocates for military robots to have a moral; they should not always follow orders. It must be possible for the robot to refuse an order, if it is deemed to be unethical. Consequently would commanders than also allow for their soldiers to refuse an order based on personal moral?

Basically, it means that robots should operate following some ethical software. John Sullins in [20] argues that future unmanned Assault Robots should be designed in such a way that human targets should be identified as such and that a moral agent, (human or non-human) is in full control. If no human can be in the loop these weapons should not be used. In addition he argues for operators to receive training in "just war". Would a robot identify a wounded enemy soldier as being wounded and would it refrain from terminating him?

If we can learn from history the outlook is not promising. It was the great military philosopher Carl von Clausewitz (1780-1831) who said even far before robots were born that "the invention of gunpowder and the constant improvement of firearms are enough in themselves to show that the advance of civilization has done nothing practical to alter or deflect the impulse to destroy the enemy". Which is centrally the very idea of war [21]?!

The mean justifies always the ends when it comes to war. It is the ethics of the people behind the machines we should worry about. Finally remains the question of who defines what is ethical? In the 2009-2034 roadmap of the US Department of Defense on unmanned systems [1] the word "ethics" is not mentioned, not even once! We can invent weapons and robots to kill, but do not bother to debate on the use and responsibility of these systems. Wallach et al in [22] suggest that the development of artificial intelligence will contribute to a discipline dedicated to the understanding of how robots make successful moral judgments, which in turn free them to pursue their goals and purposes, in this case the military objectives.

VII. MILITARY ROBOTS AND TECHNICAL CONSTRAINTS

Looking from a technical point of view at the constraints using military robots some immediate elements come into focus:

Energy supply. Humans soldiers need food, sleep, water, oxygen etc. and are hence autonomous up to a certain point. It also makes human soldiers vulnerable and their deployment costly. Also humans need clothing and body armor, adding to the overall weight to carry around, reducing battle speed and ammunition supply. Re-supply for humans needs to be found locally or brought in. Robots are less demanding to that effect, but still depend on on-board energy supply to run its motion and weapon systems. Current battery capability is a limiting factor and the more robots are equipped with sensors and weapon system their energy demand will go up. In case of Prevention Robots and Reconnaissance Robots this is not a crucial factor. It does become important for Assault and Logistics Robots as described in the Military Robotics Driver Matrix. With the advancing technology in battery power and the introduction of super conductors (which use only a fraction of power) the energy supply constraints will become less. It is evident that robots do not need extensive life support or protection as humans do. So design of logistics and assault robots is substantially different than if humans were 'on-board'. It makes them lighter without these add-ons, reducing weight and hence increasing the weight/energy consumption ratio. UAVs can stay up in the air already many hours continuously without refueling, only enhancing to their functionality. DARPA is currently investigating the development of new thermoelectric materials with the objective to develop new components for use in diverse power systems that will dramatically increase overall energy efficiency. The focus is on new permanent magnetic materials with significantly higher magnetic strength and higher operating temperature for motors and generators, as well as high energy density capacitors. [23]

A second point is that of Target Discrimination. To become autonomous implies being able for the robot to act, plan and execute its tasks based on the input from its sensors, its objectives, learning capabilities and programming. Today's UAV are all flown by operators, albeit remotely. The targeting and fire control is executed by humans. So UAVs operating today in war theatre like Afghanistan are not fully autonomous, albeit technically it is deemed possible. These weapons fly over non-friendly territory, executing various tasks like reconnaissance and strike missions. The vision recognition technology needs to discriminate combatants from civilians or other. Enemy soldiers like Taliban are known for their disguise tactics as they are aware of the omnipresent danger posed by UAV. In this case can a UAV tell the difference between a village school teacher and a disguised combatant? Is having a weapon on you just reason for the machine to engage? In many third world countries civilians carry weapons. The robot – or better said the vision recognition software - should be able to read intent based on behavior, facial expressions, body temperature and other tells. Robot means autonomous function, so the real question is where to put the border where the robot can acquire targets and execute autonomously, if ever. Also even if the robot detects and 100% identifies a just target, what to do when this target is surrounded by civilians? Again, these are dilemma's which are currently overcome by the simple but effective procedure of keeping a man-in-the-loop. Again DARPA is working on new systems within their Robust Robotics Program to develop techniques for robots to perform in dynamic environments by improving robotic vision and scene understanding. These systems includes the capability to predict the future location and even the intent of moving objects in order that robots can handle both movement and clutter simultaneously and plan a collision-free course through the environment [24]. If frontline troops are going to rely on Logistics Robots they better arrive at the right place at the right time.

The last major constraint is the ever changing Complexity of the Environment. The wars fought in this decade have not been fought on a classical battlefield in the classical sense and against classical opponents. Today's battle terrain can be within dense urban area or remote mountain areas. The enemy is not the classical soldier anymore, but a combatant changing its role from villager to fighter constantly. Today's enemies are driven by various factors like hatred, opposition against occupation, religion, etc. Even civilians take up arms or commit suicide missions. To understand and operate within this complexity is extremely difficult, even for human soldiers. The present danger to our forces come from IED and suicide attacks, among others, instead of direct classical assaults. Battle field automation via robotics should find answers to these problems and hence adding to the already technical complexity of the robots. Because of this complexity today's military robots identified from the Matrix are remote controlled, by wire or wireless. Only few robots truly work autonomous. We can conclude that current technical restrictions prevent most military robots from working fully autonomously. As a result most robots have to be controlled remotely, like UAV. The main advantage of operating remote controlled is to keep a human in the loop of events. The next generation military robots need to more autonomous and should be able to work together. For this, real-time analysis of the hostile environment and the enemy is necessary. New processing technology is needed for metadata extraction from images and video streams, sensor data, and multi-media objects. This should than be translated for the robots to execute pre-determined objectives within the ever changing frame work.

VIII. CONCLUSIONS

Military robots are here to stay. Their success is proven on modern battlefield like Afghanistan and Iraq. They prevent loss of human lives while doing so in some cases quite efficiently and cost effectively. From the "Military Robotics Driver Matrix" we learn that the objectives for these robots are economic and humanistic or a given scaled combination of these two factors.

Today's military robots fall within each of the four quadrants, with clear roles as Logistical, Reconnaissance to Prevention and Assault robot. Some robots combine some or all roles. The industry for military robotics is growing, and will continue to grow pushed by national and geopolitical interests. Constraints currently exist and will determine the future development challenges for military robots.

Technical issues like energy supply and suitable algorithms for vision target recognition and motion over unknown terrain prevent full autonomy today. The biggest constraint is perhaps the ethical issue on the use of Assault Robots. These robots can work in the future autonomously from a technical viewpoint but probably shouldn't as they do not operate from a moral point of view. Today our military robots are mostly are remote (therefore not a robot in their manner) controlled and hence have a man-in-the-loop.

A weak point, if we consider that machines are faster and more intelligent. But at least the human factor brings the needed moral anchor. With tomorrow's technology military assault robots could work autonomously. It is a matter of time before algorithms and smart software combined with new fast computing hardware makes this possible. The robots should be equipped with some sort of moral intelligence. A military robot that kills indiscriminately like landmines or biochemical agents are in general morally rejected.

REFERENCES

[1] US Department of Defense, "Unmanned Systems Integration Roadmap 2009-2034", source: http://www.aviationweek.com/media/pdf/UnmannedHorizons/UMSIntegratedRoadmap2009.pdf

[2] BARTOLI G. et al, "*Leonardo, the wind and the flying sphere*", EACWE 5 Conference proceedings, , page 1, Florence, Italy, 19th – 23rd July 2009

[3] TESLA, Nikola, "My Inventions", Electrical Experimenter magazine, Feb, June and Oct, 1919, p106-107.

[4] JAUGITZ, Markus, " Funklenpanzer, A History Of German Army Remote- And Radio-Controlled Armor Units", Fedorowicz (J.J.), Canada 2001, ISBN: 0921991584

[5] Teletank, source: http://en.wikipedia.org/wiki/Teletank accessed 26-02-2012

[6] K-Max remote controlled helicopter, source: http://hight3ch.com/k-max-unmanned-helicopter/ accessed 26-02-2012

[7] Big Dog, source: http://www.bostondynamics.com/robot_bigdog.html, accessed 26-02-2012.

[8] Davor Antonić, Željko Ban, Mario Žagar , " *Demining Robots –Requirements and Constraints*", proceedings Mediterranean Conference on Control and Automation, http://med.ee.nd.edu/MED9/Papers/Robotics/Robotics_3/MED01-121.pdf accessed 11-03-2012

[9] UAV deployment and growth, source: http://www.cotsjournalonline.com/articles/view/100867 accessed 26-02-2012

[10] HEATH, S.G. ,"*Unmanned systems: A Genuine revolution in military airfares?*", The Royal Air Forces Air Power Review, 6 *(2)*, 2003, p33-55

[11] Armed Robotics Vehicle, source: http://defense-update.com/products/a/arv.htm accessed 03-03-2012

[12] UAV by other countries, source: Newsweek: http://www.thedailybeast.com/newsweek/2010/02/25/defending-against-drones.html accessed 18-03-2012.

[13] DARPA Defense Advanced Research Projects Agency, Department of Defense, "*Fiscal Year (FY) 2011 President's Budget, February 2010, , Justification Book Volume 1, Research, Development, Test & Evaluation, Defense-Wide – 0400"*

[14] Kurzweil, Ray, "*The Singularity is Near*", Penguin Group, 2005, pp. 135-136

[15] Captured UAV by Iran, source: http://en.wikipedia.org/wiki/Iran%E2%80%93U.S._RQ-170_incident accessed 26-02-2012

[16] UAV strikes allies in Pakistan, http://www.geo.tv/GeoDetail.aspx?ID=36579

[17] Manning, D. Sharon, "*The Role of Human Causal Factors in U.S. Army Unmanned Aerial Vehicle Accidents*", USAARL Report No. 2004-11

[18] South African robot accident, source: http://www.wired.com/dangerroom/2007/10/robot-cannon-ki/ accessed 18-03-2012

[19] ARKIN, Ronald C., "The Case for Ethical Autonomy in Unmanned Systems", Journal of Military Ethics, Volume 9, Issue 4, 2010, Special Issue: Ethics and Emerging Military Technologies ,DOI: 10.1080/15027570.2010.536402, pages 332-341

[20] SULLINS, John P, "*Roboethics and Telerobotic Weapons Systems*", IEEE Conference on Robotics and Automation, Kobe, 12-17 May 2009

[21] VON CLAUSEWITZ, Carl, "*on War*", http://www.qotd.org/search/search.html?aid=959&page=3 accessed 18-03-2012

[22] WALLACH, Wendell , "*Robot minds and human ethics: the need for a comprehensive model of moral decision making*" , Ethics Inf Technol (2010) 12:p243–250

[23] DARPA Department of Defense, FY2011 President's Budget, February 2010, *Book Volume 1, Research, Development, Test & Evaluation, Defense-Wide – 0400, page 236.*

[24] DARPA Department of Defense, FY2011 President's Budget, February 2010, *Book Volume 1, Research, Development, Test & Evaluation, Defense-Wide – 0400, page 125.*

[25] SZABOLCSI, R. *Conceptual Design of the Unmanned Aerial Vehicle Systems for the Firefighter Applications*, CD-ROM Proceedings of the 12th International Conference „AFASES 2010", ISBN 978–973–8415–76–8, p4, 27–29 May 2010, Brasov, Romania.

[26] SZABOLCSI, R. *Conceptual Design of the Unmanned Aerial Vehicle Systems for the Police Applications*, CD-

ROM Proceedings of the 12th International Conference „AFASES 2010”, ISBN 978–973–8415–76–8, p4, 27–29 May 2010, Brasov, Romania.
[27] SZABOLCSI, R.: *Modeling of the Human Pilot time delay Using Padé Series*, International Journal of “Academic and Applied Research in Military Science” AARMS, ISSN 1588-8789, Vol. 6., Issue 3, p(405-428), 2007.
[28] SZABOLCSI, R. *Stochastic Noises Affecting Dynamic Performances of the Automatic Flight Control Systems,* Review of the Air Force Academy, No. 1/2009, pp (23–30), ISSN 1842-9238, Brasov, Romania.
[29] SZABOLCSI, R. *Identification of the UAV Mathematical Models*, CD-ROM Proceedings of the VIth International Conference „New Challenges in the Field of Military Sciences, ISBN 978-963-87706-4-6, 18-19 November 2009, Budapest, Hungary.

SOURCES OF FIGURES AND PICTURES

Figure 1. Military Robotics Driver Matrix. By Bob Struijk 2012
Picture 1. Nazi tracked mine robot Goliath. Source: http://www.historynet.com/goliath-tracked-mine-the-beetle-that-started-the-rov-craze.htm
Picture 2. Dragon Runner reconnaissance war-bot. Source: http://www.military.discovery.com
Picture 3. BigDog. Source: http://www.bostondynamics.com/robot_bigdog.html
Picture 4. Demining robot. Source: Cpl Marc-Andre Gaudreault, Imaging Division, Valcartier Garrison http://www.combatcamera.forces.gc.ca
Picture 5. Predator UAV. Source: http://www.fastcompany.com/1695219/cia-predator-drones-facing-ip-lawsuit