DIGITAL INFANTRY BATTLEFIELD SOLUTION

INTRODUCTION TO GROUND ROBOTICS

DIBS project

Part I

Milrem in collaboration with

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

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

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THE IMPACT OF TECHNOLOGY ON MILITARY TRANSPORT

Dr. Juris Ķiploks

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

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

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

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

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

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

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

URBANISATION AND OF-ROD MOBILITY

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

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

TRANSPORT PROPULSION SYSTEMS

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

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

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

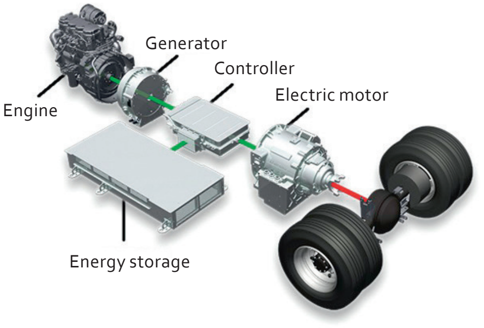

Figure 1: Integration the series hybrid into available vehicle

Table 1. Hybrid Electrical vehicles expected benefits

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

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

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

Figure 2. Reconnaissance, Surveillance, Targeting Vehicle Shadow

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

SPECIFIC MILITARY VEHICLES REQUIREMENTS

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

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

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

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

Figure 3. Hybrid electric vehicles modular components

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

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

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

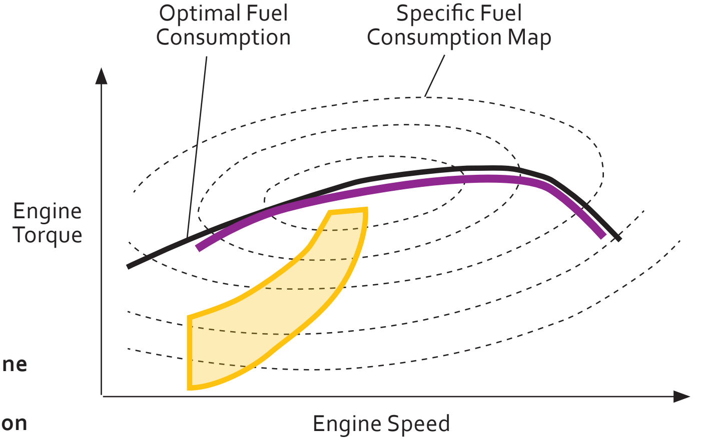

Figure 4. Engine optimum fuel economy region

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

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

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

TECHNICAL DEVELOPMENT AND CHALLENGES

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

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

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

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

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

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

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

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

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

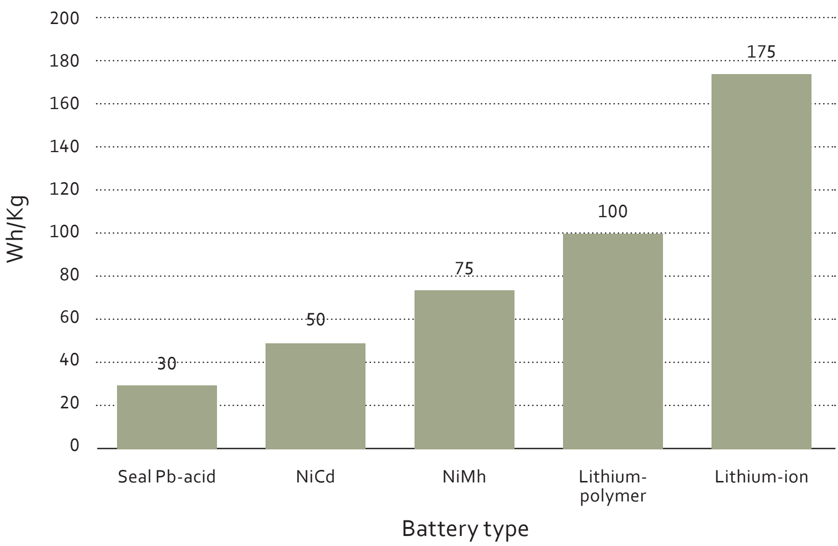

Figure 5. Battery energy density comparison

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

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

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

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

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

CONCLUSION

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

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

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

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