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REMOTE-CONTROLLED MOBILE ROBOTS DESIGNED FOR MILITARY APPLICATIONS

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Abstract**—**Military robots are autonomous robots or remote-controlled mobile robots designed for military applications, from transport to search & rescue and attack.There have been some developments towards developing autonomous fighter jets and bombers. The use of autonomous fighters and bombers to destroy enemy targets is especially promising because of the lack of training required for robotic pilots, autonomous planes are capable of performing maneuvers which could not otherwise be done with human pilots (due to high amount of G-force), plane designs do not require a life support system, and a loss of a plane does not mean a loss of a pilot. However, the largest drawback to robotics is their inability to accommodate for non-standard conditions. Advances in Artificial Intelligence in the near future may help to rectify this.

Keywords—military robots; unmanned systems; Spatial Grasp Technology; holistic scenarios; self-navigation; collective behavior; self-recovery

I. INTRODUCTION

Today, many military organizations take the help of military robots for risky jobs. The robots used in military are usually employed within integrated systems that include video screens, sensors, grippers, and cameras. Military robots also have different shapes and sizes according to their purposes, and they may be autonomous machines or remote-controlled devices. There is a belief that the future of modern warfare will be fought by automated weapons systems.

The U.S. Military is investing heavily in research and development towards testing and deploying increasingly automated systems. For example, the U.S. Army is looking to slim down its personnel numbers and adopt more robots over the coming years [1, 2]. The Army is expected to shrink from 540,000 people down to 420,000 by 2019. To keep things just as effective while reducing manpower, the Army will bring in more unmanned power, in the form of robots. The fact is that people are the major cost, and first of all their life. Also, training, feeding, and supplying them while at war is pricey, and after the soldiers leave the service, there's a lifetime of medical care to cover.

Military robots are usually associated with the following categories: *ground*, *aerial*, and *maritime*, with some of the latest works in all three discussed in the paper, including those oriented on collective use of robots.

Most military robots are still pretty dumb, and almost all current unmanned systems involve humans in practically every aspect of their operations. The Spatial Grasp ideology and technology described in the rest of this paper can enhance individual and collective intelligence of robotic systems, especially distributed ones. It can also pave the real way to massive use of advanced mobile robotics in human societies, military systems including and particularly.

II. SOME LATEST DEVELOPMENTS AND DEMANDS TO MILITARY ROBOTICS

A. *Ground Robots*

The ability of robots to save lives has secured future path for ground robotics alongside the warfighter. Ground robotics can be engaged in different missions including Explosive Ordnance Disposal (EOD), Combat Engineering, Reconnaissance, and many others. The US Army plans to refurbish 1,477 of its ground robots, which is about 60 percent of the total fleet [3]. The following may be named among the latest developments in ground robotics.

Boston Dynamics designed the LS3 *"robot mules"* to help soldiers carry heavy loads [4], see Fig. 1*a-c*. LS3 is a rough-terrain robot designed to go anywhere Marines and Soldiers go on foot, helping carry their load. Each LS3 carries up to 400 lbs of gear and enough fuel for a 20-mile mission lasting 24 hours. LS3 automatically follows its leader using computer vision, so it does not need a dedicated driver. It also travels to designated locations using terrain sensing and GPS.


a) b) c)

Fig. 1. Boston Dynamics robot mules: a) Carrying heavy loads; b) Following soldiers; c) Moving through complex terrains

The Boston Dynamics' *Cheetah robot* (Fig. 2*a-b*) is the fastest legged robot in the World, surpassing 29 mph, a new land speed record for legged robots [5]. The Cheetah robot has an articulated back that flexes back and forth on each step, increasing its stride and running speed, much like the animal does. The current version of the Cheetah robot runs on a high-speed treadmill in the laboratory where it is powered by an off-board hydraulic pump and uses a boom-like device to keep it running in the center of the treadmill.

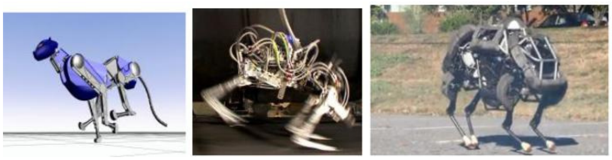

a) b) c)

Fig. 2. Boston Dynamics robots: a) The Cheetah concept; b) Cheetah on a high-speed treadmill; c) Cheetah becoming Wild Cat running untethered

The next generation Cheetah robot, *WildCat*, Fig. 2*c*, is designed to operate untethered. WildCat is an early model for field testing. It sports a noisy combustion onboard engine. Named the WildCat, the outdoor runner is funded by the Defense Advanced Research Projects Agency (DARPA), and is being developed for military use. With a large motor attached, WildCat isn't as fast as its 28mph-plus cousin, being currently limited to around 16mph on flat terrain.

New military technology 2014 *supersoldier* robot has been developed [6]: all-terrain, highly mobile, and with high precision shooting (Fig. 3*a-c*). It is logical to assume that killer robots are already here, and the new science discoveries of 2014 may be used to create real terminators.


a) Ammunition b) All terrain chassis c) Field trials

Fig. 3. Supersoldier robot

B. Aerial Robotics

The US Army, Air Force, and Navy have developed a variety of robotic aircraft known as unmanned flying vehicles (UAVs). Like the ground vehicles, these robots have dual applications: they can be used for reconnaissance without endangering human pilots, and they can carry missiles and other weapons [7].

The best known armed UAVs are the semi-autonomous Predator Unmanned Combat Air Vehicles (UCAV) built by General Atomics which can be equipped with Hellfire missiles. The military services are also developing very small aircraft, sometimes called Micro Air Vehicles (MAV) capable of carrying a camera and sending images back to their base. Some newest UCAV developments are mentioned below.

The Northrop Grumman X-47B is a demonstration unmanned combat air vehicle (UCAV) designed for carrier-based operations [8], see Fig. 4*a-c*. Developed by the American defense technology company Northrop Grumman, the X-47 project began as part of DARPA's J-UCAS program, and is now part of the United States Navy's Unmanned Combat Air System Demonstration (UCAS-D) program.

Fig. 5. Drones with lasers: a) HELLADS mounted on a drone, b-c) Drone laser in operation


a) b) c)

Fig. 4. Northrop Grumman X-47B: a) Front view; b) Land-launched; c) Carrier-launched

The X-47B first flew in 2011, and as of 2014, it is undergoing flight and operational integration testing, having successfully performed a series of land- and carrier-based demonstrations. In August 2014, the US Navy announced that it had integrated the X-47B into carrier operations alongside manned aircraft. Northrop Grumman intends to develop the prototype X-47B into a battlefield-ready aircraft, the Unmanned Carrier-Launched Surveillance and Strike (UCLASS) system, which will enter service around 2019. X-47B can stay in the air for 50 hrs, carry 2 tons of weaponry, and be refuelled in the air.

Doubling the Threat: Drones + Lasers. The research and development arm of the US Department of Defense plans to establish drone-mounted laser weapons, a scheme referred to as _Project Endurance‘ in the agency‘s 2014 budget request [9], see Fig. 5*a-c*. The Pentagon edged closer to mounting missile-destroying lasers on unmanned and manned aircraft, awarding $26 million to defense contractors to develop the technology.


a) b) c)

General Atomics is getting increasingly excited by the HELLADS— the High-Energy Liquid Laser Defense System. It is designed to shrink a flying laser into a package small enough to cram into an aircraft. This will give a potentially unlimited shooting magazine to the drone.

Hypersonic aircraft. The SR-72 [10] could fly as fast as Mach 6, will have the ability to gather intelligence, conduct surveillance and reconnaissance, and launch combat strikes at an unprecedented speed, see Fig. 6*a*. SR-72 could be operational by 2030. At this speed the aircraft would be so fast that adversary would have no time to react or hide.


a) b)

Fig. 6. Hypersonic vehicles: a) SR-72 with Mach 6; b) DARPA HTV-2 with Mach 20

DARPA rocket-launched HTV-2, 13,000 mph *Hypersonic Glider* [11] (see Fig. 6*b*), was designed to collect data on three technical challenges of hypersonic flight: aerodynamics, aerothermal effects, and guidance, navigation and control. A technology demonstration and data-gathering platform, the HTV-2‘s second test flight was conducted to validate current models and increase technical understanding of the hypersonic regime. The flight successfully demonstrated stable aerodynamically-controlled flight at speeds up to Mach 20.

C. Maritime Robotics

Sea-based robots—unmanned maritime systems, or UMSs, can be either free-swimming or tethered to a surface vessel, a submarine, or a larger robot [12], see examples in Fig. 7. Tethers simplify providing power, control, and data transmission, but limit maneuverability and range. Recently developers have built highly autonomous systems that can navigate, maneuver, and carry out surprisingly complex tasks. UMSs can operate on the ocean‘s surface, at or just below the surface, or entirely underwater. Operating above or near the surface simplifies the power and control, but compromises stealth. The U.S. Navy has devoted particular attention to unmanned underwater vehicles (UUSs) during the past 10-15 years. Its unmanned surface vehicles (USVs) are much less far along (Fig. 7*a*); the Navy has put a higher priority on using automation to reduce crew size in U.S. warships. Some latest works on UUSs follow.

Large Displacement Unmanned Undersea Vehicle (LDUUV) [13], see Fig. 7*b*, is to conduct missions longer than 70 days in open ocean and littoral seas, being fully autonomous, long-endurance, land-launched, with advanced sensing for littoral environments. The vehicle's manufacturing and development phase will begin in 2015 with testing planned for 2018. According to the Navy's ISR Capabilities Division, LDUUV will reach initial operating capability as a squadron by 2020 and full rate production by 2025.

Fig. 7. a) Unmanned surface vehicle; b) Large Displacement Unmanned Undersea Vehicle, LDUUV; c) Underwater glider

Underwater gliders [14], see Fig. 7*c*, will not require fuel but will instead use a process called —hydraulic buoyancy,‖ which allows the drone to move up and down and in and out of underwater currents that will help it move at a speed of about one mile per hour. Carrying a wide variety of sensors, they can be programmed to patrol for weeks at a time, surfacing to transmit their data to shore while downloading new instructions at regular intervals.

D. Collectively Behaving Robots

To be of real help in complex military applications, robots should be integral part of manned systems, they should also be capable of being used massively, in robotic collectives. The tests on Virginia's James River represented the first large-scale military demonstration of a *swarm of autonomous boats* designed to overwhelm enemies [15], see Fig. 8*a*. The boats operated without any direct human control: they acted as a robot boat swarm. This capability points to a future where the U.S. Navy and other militaries may deploy multiple underwater, surface, and flying robotic vehicles to defend themselves or attack a hostile force.

a) b) c)

Fig. 8. a) Swarm of autonomous boats; b) Harvard University multiple robots operating without central intelligence; c) Sci-fi image of future robotic armies

Harvard University scientists have devised a swarm of 1,024 tiny robots that can work together without any guiding central intelligence [16], see Fig. 8*b*. Like a mechanical flash mob, these robots can assemble themselves into five-pointed stars, letters of the alphabet and other complex designs. Swarm scientists are inspired by nature's team players—social insects like bees, ants and termites; schools of fish; and flocks of birds. These creatures collaborate in vast numbers to perform complicated tasks, even though no single individual is actually in charge. These results are believed to be useful for the development of advanced robotic teams even armies, (with futuristic image in Fig. 8c).

E. General Demands to Military Robotic Systems

A thorough analysis of aims and results of the development and implementation of military robots, including the ones briefed above, helps us formulate general demands with regard to their overall management and control, which may be as follows.

- Despite the diversity of sizes, shapes, and orientations, they should all be capable of operating in distributed, often large, physical spaces, thus falling into the category of distributed systems.
- Their activity is to include navigation, movement, observation, gathering data, carrying loads which may include ammunitions or weapons, and making impact on other manned on unmanned units and the environment.
- They should have certain, often high, degree of autonomy and capability of automatic decision making to be really useful in situations where human access and activity are restricted.
- They should effectively interact with manned components of the systems and operate within existing command and control infrastructures, to be integral parts of the system.
- They should be capable of effective swarming for massive use, and this swarming should be strongly controlled from outside -- from manned parts of the system or from other, higher-level, unmanned units.
- Their tasking and retasking (including that of swarms) should be flexible and convenient to humans to

guarantee runtime reaction on changing goals and environments, especially on battlefields.

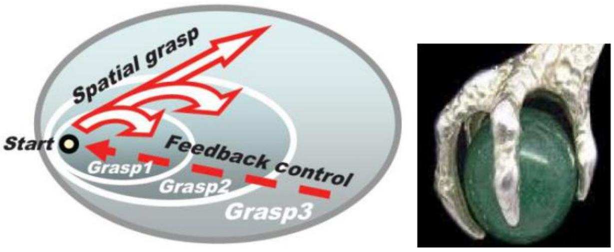
- The use of unmanned units should be safe enough to humans and systems they are engaged in.
- Their behaviour should satisfy ethical and international norms, especially in life-death situations.

III. SPATIAL GRASP TECHNOLOGY FOR MANAGEMENT OF ROBOTIC SYSTEMS

The developed high-level Spatial Grasp ideology and Technology, SGT, for coordination and management of large distributed systems [17] allows us to investigate, develop, simulate, and implement manned-unmanned systems in their integrity and entirety. Also gradually move to fully unmanned systems with dynamic tasking and managing individual robots and their groups, regardless of the group's size. SGT can believably satisfy most of the demands to military robotic systems formulated above.

A. SGT General Issues

SGT is based on coordinated integral, seamless, vision & navigation & coverage & surveillance & conquest of physical, virtual, or execution spaces, as shown in Fig. 9*a-b*.



a) b)

Fig. 9. SGT basics: a) Controlled parallel and incremental space grasp; b) Symbolic physical analogy

It has a strong psychological and philosophical background reflecting how humans, especially top commanders, mentally plan, comprehend and control operations in complex and distributed environments. SGT pursues *holistic*, *gestalt* [18], or *over-operability* [19] ideas rather than traditional multi-agent philosophy [20], with *multiple agents and their interactions appearing and disappearing dynamically,* on the implementation level, and only if and when needed in particular places and moments of time.

SGT can be practically implemented in distributed systems by a network of universal control modules embedded into key system points (humans, robots, sensors, mobile phones, any electronic devices, etc.), which altogether, collectively, understand and interpret mission scenarios written in a special high-level Spatial Grasp Language, SGL [17], see Fig. 10.

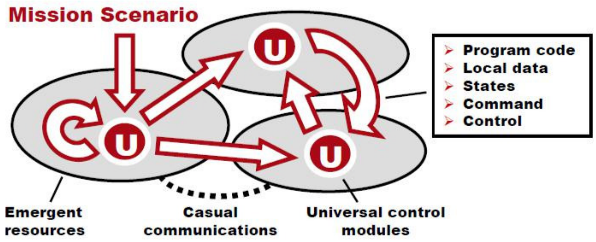


Fig. 10. Collective spatial interpretation of SGL scenarios

Capable of representing any parallel and distributed algorithms, these scenarios can start from an arbitrary node, covering at runtime the whole system or its parts needed with operations, data, and control, as shown in Fig. 11. Different scenarios can intersect in the networked space while cooperating or competing (Fig. 11).

They can establish distributed runtime information and control infrastructures that can support distributed databases, command and control, situation awareness, autonomous decisions, also any other existing or hypothetical computational and/or control models (Fig. 12).

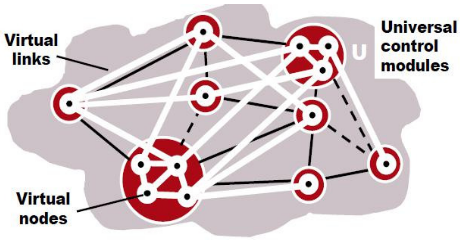


Fig. 12. Creating spatial infrastructures

B. Spatial Grasp Language, SGL

SGL allows us to directly move through, observe, and make any actions and decisions in fully distributed environments. SGL scenario develops as parallel transition between sets of progress points (or *props*) reflecting progressive spatial-temporal-logical stages of the scenario development, which may be associated with different physical, virtual or execution locations in distributed worlds. *Any sequential or parallel, centralized or distributed, stationary or mobile algorithm operating with information and/or physical matter can be written in SGL at any levels.*

Fig. 11. Spreading scenarios intersection & cooperation,

SGL directly operates with the following worlds:

- *Physical World* (PW), infinite and continuous, where each point can be identified and accessed by physical coordinates, with certain precision.
- *Virtual World* (VW), which is finite and discrete, consisting of nodes and semantic links between them.
- *Executive world* (EW) consisting of active doers which may be humans, robots, sensors or any intelligent machines capable of operations on matter, information, or both, i.e. on the previous two worlds.

Directly working with different worlds, SGL can provide high flexibility, convenience, and compactness in expressing complex scenarios within the same formalism. From one side, it can support high level, semantic descriptions abstracting from physical resources which can vary and be assigned at runtime, and from the other side, detailing some or all such resources, and to the full depth, if necessary.

For example, working directly with PW, like moving through and impacting it, can be free from naming physical devices which can do this (e.g. humans, robots), the latter engaged and disengaged automatically upon necessity, availability, or uselessness. Directly working with VW, like creating knowledge, operational, or C2 infrastructures, can also abstract away from physical resources (humans or computing facilities) which can be assigned or reassigned at runtime. Working directly with EW, can bring any necessary details for execution of missions, like particular human, robotic or sensor units and their interactions and subordination. Any combination and integration of these three worlds can be possible, with direct management of the mixture in SGL too. Integration between PW and VW can be named as PVW, with other cases presented as PVW, PEW, VEW, and all three together as PVEW.

SGL has universal recursive syntactic structure shown in Fig. 13 capable of representing any parallel, distributed and spatial algorithm working with arbitrary complex data. This structure, following the spatial grasp ideology of SGT mentioned above, also allows any language obeying it to be arbitrarily extended with new operations, data and control.

VI. CONCLUSIONS

Robots can assist humans in many areas, especially in dangerous and hazardous situations and environments. But the fate of robotics, military especially, will depend on *how it conceptually and organizationally integrates with manned systems within overall management and command and control*.

The developed high-level distributed control technology, SGT, based on holistic and gestalt principles can effectively support a unified transition to automated up to fully unmanned systems with massive use of advanced robotics. The practical benefits may be diverse and numerous. One of them, for example, may be effective management of advanced robotic collectives, regardless of their size and spatial distribution, by a single human operator only, due to high level of their internal self-organization and integral responsiveness provided by SGT. More on the SGT philosophy and history, details of SGL with its networked implementation, and the researched applications, some of which have been mentioned throughout this paper, can be found elsewhere [22-28].

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