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Autonomous Intelligent Systems: Opportunities and Needs for the CF/DND

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Autonomous Intelligent Systems: Opportunities and Needs for the CF/DND
Systèmes intelligents autonomes : Possibilités et besoins pour les FC/MDN

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Abstract

This report is intended to introduce the concept of Autonomous Intelligent Systems (AIS), to give some examples of applications, based on AIS, which are being developed today (and which have been developed in the recent past) and to indicate which technologies may be useful in the defence and national security contexts of the Canadian Forces/Department of National Defence (CF/DND), in the near to mid term (say, from 10 to 15 years hence). The intent will be to keep the analysis (and descriptions) short and at a high level, say at the program rather than project level (except where projects are used as illustrative examples). Since the report is written from the Defence Research and Development Canada (DRDC) perspective, it does attempt to take into consideration the work being done at the DRDC laboratories and through DRDC R&D programs and especially to reflect the needs of the various defence/military and national security services within the CF/DND.

Resume

Le présent rapport vise à présenter le concept des systèmes intelligents autonomes (SIA), à fournir des exemples d'applications fondées sur les SIA, de réalisation courante et récente, et à cerner les technologies qui pourraient être utiles à court et à moyen terme (de 10 à 15 ans) aux Forces canadiennes et à la Défense nationale (FC/MDN) dans le contexte de la sécurité militaire et de la sécurité nationale. Le but sera de faire une analyse (et des descriptions) courtes et de les garder à un niveau élevé, par exemple, au niveau du programme au lieu du projet (sauf si le projet sert d'exemple d'illustration. Le rapport est rédigé du point de vue de Recherche et développement pour la défense Canada (DRDC) et de ce fait, il tient compte des travaux entrepris dans les laboratoires de RDDC et dans le cadre des programmes de R & D de RDDC et reflète surtout les besoins divers des FC/MDN en matière de services de sécurité militaire et de sécurité nationale.

Executive Summary

Autonomous Intelligent Systems (AIS) are computer-automated or robotic systems that have a variety of commercial, industrial, medical, physical security and defence/military and national security uses and relate to many scientific and engineering disciplines and applications. Some examples are: discrete event control; artificial intelligence; learning algorithms and methodologies; pattern recognition; image processing; and human-machine interface technologies. AIS may also be coupled to technological advances in such other fields as: micro electro-mechanical systems (MEMS), nanotechnology, biotechnology, sensors, lasers, and numerous other emerging technologies, in order to derive novel synergies. AIS must be distinguished from unmanned (or uninhabited) ground, underwater or aerial "platforms", on which they may be mounted. Unmanned "platforms" may not be autonomous intelligent systems, if they are controlled remotely by humans or by other machines, or if they lack some of the qualities and aspects of "intelligence" or "autonomy", contained in the definition above.

The application of AIS and the technologies derived from them are of great interest in the defence and national security contexts of the Canadian Forces/Department of National Defence (CF/DND), in the near- to mid-term time frame (say, from 10 to 15 years hence). To be able to meet the needs of the CF/DND, in this time frame, Defence Research and Development Canada (DRDC) is already very active, within its own research and development (R&D) laboratories, in partnership with other government departments and agencies, with the private sector and with universities in Canada, as well as in bilateral and multilateral R&D arrangements with allies and NATO partners.

Autonomous Intelligent Systems constitute one R&D activity (of twenty-one) in the DRDC Technology Investment Strategy (TIS). These activities span the defence technology spectrum, and outline the R&D required to develop the Science and Technology (S&T) capacity needed for future defence and national security.

This report gives some history and a high-level review of recent and current Canadian and international activities in AIS (with special emphasis on the various US programs), where AIS have been, and are being, coupled to various unmanned vehicles or platforms (ground, underwater and aerial), some of which are also weaponized. Several recent examples and applications are given of the performance of such systems (from the war on terrorism in Afghanistan and elsewhere, and from some national security domains), as are the advantages and limitations of AIS. While many of these systems involve huge costs and lead-times for their development, the cost savings of unmanned vehicles (including the reduced risk to human life) are pointed out.

The high levels of effort, in terms of human resources and fiscal expenditure, are accelerating the R&D needed to bring to fruition a wide variety of platforms and varied new technologies, coupled to AIS. This is especially true in US-led programs as well as in joint programs with its allied partners (including Canada). The CF/DND is expected to benefit, commensurate with their needs, from the many programs in which DRDC is participating, or co-funding, related to AIS.

Sommaire

Les systèmes intelligents autonomes (SIA) sont des systèmes informatiques ou robotiques qui trouvent leur usage dans le commerce, l'industrie, la médecine, la sécurité physique, la sécurité militaire et la sécurité nationale. Ils sont également associés à de nombreuses disciplines et applications scientifiques et techniques. À noter, par exemple, les mesures contre les événements discrets, l'intelligence artificielle, les algorithmes et les méthodologies d'apprentissage, la reconnaissance des formes, le traitement d'images et les technologies d'interface homme-machine. On peut également, pour obtenir de nouvelles synergies, associer les SIA à des avancées technologiques d'autres domaines telles que les systèmes microélectromécaniques (MEMS), la nanotechnologie, la biotechnologie, les capteurs, les lasers et de nombreuses autres technologies nouvelles. Il faut distinguer les SIA des « plates-formes » sans équipage (ou inhabitées) terrestres, sous-marines ou aériennes sur lesquelles ils peuvent être montés. Les « plates-formes » sans équipage ne peuvent pas être des systèmes intelligents autonomes s'ils sont télécommandés par des êtres humains ou par d'autres machines ou s'ils ne présentent pas les qualités et les aspects d' « intelligence » ou d' « autonomie » définis plus haut.

L'application des SIA et les technologies qui en dérivent représentent un grand intérêt dans le contexte de la sécurité militaire et de la sécurité nationale en ce qui concerne les Forces canadiennes/le ministère de la Défense nationale (FC/MDN), de court à long terme (de 10 à 15 ans). Pour pouvoir remplir les besoins des FC/MDN dans ce laps de temps, Recherche et développement pour la défense Canada (RDDC) s'active déjà considérablement dans ses propres laboratoires de recherche et développement, avec ses partenaires d'autres ministères et agences, le secteur privé et les universités canadiennes et dans le cadre d'arrangements bilatéraux négociés avec les alliés et les partenaires de l'OTAN.

Les systèmes intelligents autonomes constituent l'objet d'une des vingt et une activités de R & D de la stratégie d'investissement technologique (SIT) de RDDC. Ces activités couvrent le spectre technologique de défense et définissent les travaux de R & D requis pour engendrer la capacité scientifique et technologique nécessaire à la sécurité militaire et la sécurité nationale de l'avenir.

Le présent rapport retrace quelque historique et un examen de haut niveau des activités internationales courantes et récentes liées aux SIA (avec accent sur divers programmes étasuniens) où les SIA ont été et sont associés à divers véhicules ou plates-formes sans équipage (terrestres, sous-marins ou aériens) dont certains sont utilisés comme armes. On y donne plusieurs exemples et plusieurs applications récents de la performance de ces systèmes (depuis la guerre terroriste en Afghanistan et ailleurs et dans les domaines de sécurité nationale). Les avantages et les limites des SIA sont aussi exposés. Un grand nombre de ces systèmes font l'objet de dépenses et de délais d'exécution considérables mais l'économie de coûts qu'on réalise grâce aux véhicules sans équipage (et l'avantage de ne pas risquer des vies humaines) est soulignée.

Le niveau élevé des efforts, compte tenu des ressources humaines et des dépenses fiscales, accélèrent les travaux de R & D nécessaires pour réaliser une grande diversité de plates-formes et de nouvelles technologies associées aux SIA. Cela est particulièrement vrai pour les programmes exécutés sous la direction des É.-U, ainsi que pour les programmes réalisés avec la collaboration d’alliées et de partenaires (y compris le Canada). Les FC/MDN sont prévus bénéficier, selon leurs besoins, des nombreux programmes liés aux SIA auxquels RDDC participe ou qu’elle cofinance.

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Background

Definition

Autonomous Intelligent Systems (AIS) are computer-automated or robotic systems which have a variety of commercial, industrial, medical, physical security and defence/military and national security applications and relate to many scientific and engineering disciplines and applications, such as: robotics and manufacturing systems; artificial intelligence; discrete event control; learning algorithms and methodologies; computational geometry; graphics; pattern recognition; image processing; computer vision; and other multi-disciplinary, autonomous systems, such as computational linguistics and human-machine interface technologies. Academic institutions, in the industrialized countries, offer a wide variety of courses (neural networks, fuzzy logic) in one or combinations of these disciplines; entire laboratories may exist (usually within universities or federally-funded institutes, or in the private sector) in one of these subject areas, or in cross-disciplinary areas.

There is a fine but significant distinction to be made between AIS and unmanned (or uninhabited) ground, underwater or aerial "platforms". Unmanned "platforms" may not be autonomous intelligent systems, if they are controlled remotely (and completely) by humans or by other machines, or if they lack some of the qualities and aspects of "intelligence" or "autonomy" contained in the definition above.

Aim

This report is intended to introduce the concept of Autonomous Intelligent Systems, to give some examples of applications, based on AIS, which are being developed today (and which have been developed in the recent past) and to indicate which technologies may be useful in the defence and national security contexts of the Canadian Forces/Department of National Defence (CF/DND), in the near to mid term (say, from 10 to 15 years hence). The intent will also be to keep the analysis short and at a high level, say at the program rather than project level (except where projects are used as illustrative examples). Since the report is written from the Defence R&D Canada (DRDC) perspective, it does attempt to take into consideration the work being done at the DRDC laboratories and through DRDC programs and especially to reflect the needs of the various defence and national security services within the CF/DND.

Scope

Some of the development work on AIS, being carried out by other government departments (with whom DND is collaborating), by the private sector (some of whom are receiving funds through DRDC programs), as well as the progress being made by allies (especially by the US) within their own programs, bilaterally with Canada, or multi-laterally through programs such as The Technology Cooperation Program (TTCP) or the NATO Research and Technology Organisation (RTO), will also be noted. Future directions of AIS will also be explored, as will the applicability of particular technological advances in AIS to more than one military service (army, navy or air force) or to one delivery "platform" (ground, underwater or aerial) within a given service.

Owing to the broad, high-level nature of the present report, there still exists the need for a more in-depth "gap analysis", one that will focus on the technological details of AIS, that is, identify many of the current leading-edge technologies, assess which of (and in what manner) these technologies may evolve and determine how the relevant ones may be merged to achieve synergies, in order to meet the future needs of the CF/DND. This will require a very clear picture of where the CF/DND wants to be, in which specific time frame, in order to determine which technologies will be most appropriate and how quickly today's technologies must be accelerated and eventually merged to fill the identified and timely needs of the CF/DND. This in-depth "gap analysis" will be the subject of another report.

Context

In the defence context, according to the current DRDC Technology Investment Strategy (TIS 2002) (Ref 1), "AIS are automated or robotic systems that operate and interact in the complex unstructured environments of the future battlespace. Key R&D issues include the capabilities of such systems to perform complex tasks through the perception and understanding of unstructured environments with minimal human direction and oversight as well as the ability to learn, adapt and share information between platforms and their sensors and to achieve collective intelligence and enhanced system effectiveness."

Applications

General

Beyond the more straightforward manufacturing robotics (as in assembly lines or in repetitive, routine commercial or industrial applications), AIS are characterized as operating as cognitive networks, that is, as nearly independently-acting, perceiving agents. The degree of independence and "intelligence" will be a function of the amount of programming logic, "experience" and decision-aiding complexity that is built into the particular AIS.

Simpler forms of "intelligent" devices include those under the direct (wireless or satellite-enabled) manipulation of an operator (often referred to as "man-in-the-loop"), as in robotic arms (such as the CANADARM) or in the lunar and planetary explorers. Other well-known and familiar examples of AIS are robots for operating in commercial and office environments and those used in conventional bomb disposal or in the handling of chemical, biological, radiological and nuclear (CBRN) hazardous material. At the other extreme of the intelligence spectrum will be those systems which are truly "intelligent", that is, those that can operate as part of multi-component systems, that can communicate, interact, learn and collaborate with other "members" of the same system, or with other distinct but compatible systems, and that are interoperable with, as opposed to controlled by, "human" systems.

In the spirit of "letting robots do the dangerous work", robots can assist the human (through automation or where heavy lifting is involved) or replace the human (where dirty, dangerous or dull, repetitive tasks are involved). They may also complement the human (through multi-spectral sensing, information processing and task reporting).

Defence and National Security

For the CF/DND, AIS present numerous technological opportunities and applications, in the national security (domestic and cross-border counter-terrorist, urban operational, and littoral) but more especially in the defence (including peacekeeping) realms. Naturally, there are (and may be in the future) applications relevant to both domains, which are (and may be) the beneficiaries of dual-use (civilian/military), technological advances.

The application of AIS to defence/national security situations will generally be in specific platforms or delivery systems, such as "unmanned vehicles". These will take the form of unmanned ground vehicles (UGVs), unmanned underwater vehicles (UUVs) and unmanned aerial vehicles (UAVs). Some defence applications may arise in space-based vehicles, such as geo-synchronous or other satellites. Unmanned vehicles, operating as sensor or weapon platforms in a variety of good or poor weather conditions and favourable or hostile environments, can increase situational awareness, extend effective engagement ranges and eliminate crew exposure. They may also be used in a sort of "defensive" capacity, for example, in the detection and destruction of the enemy's land mines. Spaced-based platforms can become increasingly necessary as the control of space becomes a vital part of practically all missions. In this capacity, space assets will depend on an enhanced, countermeasure-immune Global Positioning System (GPS), coupled with strong lightweight material and structures, to permit their own self-defence and to provide (potentially) offensive, combat capability.

A particular unmanned vehicle need not be limited to a particular military service. For example, a UAV (launched from an aircraft carrier) could be used by the Navy or, independently, by the Army; it could be used in a joint military air operation with an Air Force UAV or with manned aircraft; it could inform a UGV of a hidden danger or a beyond-the-horizon obstacle or direct the fire of the UGV; and, it could be used in conjunction with a UUV. There are a fascinating number of permutations and combinations, which R&D scientists, military strategists and tactical operational planners may conceive of, involving all manner of combinations of AIS and unmanned vehicles.

Unmanned vehicles can be constructed far less expensively than manned vehicles, and in many cases are seen as cost-effective alternatives to manned vehicles, especially if they are recoverable and reusable. Some can and will be constructed so cheaply (and for limited and highly-specific) missions, as to be considered non-recoverable or expendable. For many missions, the unmanned aircraft will provide capabilities far superior to those of manned aircraft. For example, the shape and function of unmanned aircraft will not be constrained by a cockpit, a human body (and thus to the potentially large gravitational acceleration forces experienced by a pilot in an aircraft) or an ejection seat. The design freedom so generated will allow a reduction in the radar cross section of the aircraft. The reduced risk to human pilots or other vehicle operators is another desirable feature of unmanned vehicles, especially in highly dangerous missions and environments, involving both conventional weapons and non-conventional weapons or agents (the latter including CBRN agents). When used in combination with manned vehicles, unmanned vehicles are effective force multipliers, augmenting the capabilities of the manned vehicles.

Early interest in unmanned aircraft goes back to the days of World War 1. In more modern times, Israel used surveillance UAVs effectively (in combination with ground-based armour and tanks) in the 1973 war with its Arab neighbours to locate (and then to counteract) the surface to air missiles (SAMs), which were causing disastrous losses of its combat aircraft. Again, in the Israeli invasion of Lebanon in 1982, advanced surface to air missiles (SAM6s) were used against Israeli fighter planes, with devastating effect. This time, Israel developed more sophisticated UAVs, having similar radar images to its manned fighter planes, and used the UAVs as first-wave decoys to trick the enemy into exposing its SAM6 sites, which were subsequently destroyed by a second wave of manned fighters. Since that time, the USA, UK, France, several other NATO partners (including Canada), Japan and Australia have also entered the field of UAVs, with aggressive programs, involving ever-increasing efforts to move the technology forward (together with other compatible and synergistic technologies such as synthetic aperture radar, infra red vision cameras, etc.). Recent interest by the USA in UAVs, for example, has accelerated during the past decade. Deployment of UAVs has increased markedly over that period of time, for example, in the Gulf War, in Bosnia, in Kosovo and, even more recently, in the war on terrorism (in Afghanistan and in Yemen).

Unmanned vehicles (or drones) in their most basic AIS forms can be used for passive (non-weaponized) intelligence, surveillance and reconnaissance (ISR) missions, relaying data and images back to their home base or local control stations, via satellite or line-of-sight wireless transmission. While on a given mission, they can also take on a new mission, in response to commands from headquarters or from local (manned or unmanned) control stations. In the more advanced forms, and especially in the defence context, the unmanned vehicle may take the form of both the passive (surveillance) and the active (weaponized) modes. That is, a weaponized, unmanned vehicle (commonly referred to as an Unmanned Combat Aerial Vehicle, or UCAV) could detect and identify an enemy, and take (pre-programmed) offensive action against that enemy without any further intervention by the command and control station or, in other circumstances, at the direction of the command and control station. The US Air Force Predator A was used in the weaponized mode (a UCAV, armed with two anti-tank missiles), to a limited extent, in Afghanistan (during Operation Enduring Freedom, in 2001), though primarily in an ISR capacity. Another example of a UCAV was the recent and effective (November, 2002) missile strike in Yemen, carried out by an unmanned aerial vehicle (reported to be under the control of a local command and control station), against an automobile transporting six members of a terrorist organization.

The above two examples illustrate how a UCAV, having extended "stay-time" over enemy territory, could wait for a hidden weapon (such as a mobile missile launcher or other mobile, time-critical target) to emerge from its underground bunker and attack it, with a variety of lethal and non-lethal weapons, before that missile launcher or other target has time to get back to its hiding place. Such a UCAV (or simply a UAV in the more general case) could also "direct" the fire of other delivery systems (bombers, naval surface vessels, submarines) whose ordnance could include "bunker-buster" bombs, smart cruise missiles, precision-guided cluster bombs, or other specialized weapons, once the (stationary) hiding place has been discovered. It is worth noting, however, that even the new generation of global positioning system-based precision-guided weapons tends to be less than effective against most mobile targets, a major technological deficiency that must still be overcome. There is also the possibility of extending UCAV performance into the hypersonic velocity range to enable strikes, within a matter of minutes, from a variety of take-off points on high-value targets.

Micro-robotic "swarms" (or "robo-flies") of low-flying, unmanned aerial vehicles could be used in the future military battlespace, for surveillance (or more broadly for ISR functions) in confined or "indoor" spaces, or for urban warfare, where higher-flying UAVs or satellite-based sensors may not be effective. These micro-robots could have greater or lesser autonomy, be linked to local or more remote operators, and even have limited "offensive" capability. The small size and weight of micro-robots have both advantages and disadvantages: the smaller the size and weight, the more manoeuverable and inconspicuous, and the less the power requirements of the platform; however, as the size, weight and power requirements of the platform are increased, greater varieties and degrees of autonomy and intelligence are possible (such as information sharing among distributed, networked, intelligent systems for collective intelligence, cooperation and collaboration, and in stay-time over a potential target, in decision-making, and in additional “offensive” capabilities).

An excerpt from the mission of the (US) Navy Center for Applied Research in Artificial Intelligence (NCARAI) is a good example of the kinds of R&D performed in AIS in major military laboratories in the USA and elsewhere: The research program of the Center is directed toward understanding the design and operation of computer systems capable of improved performance based on experience; efficient and effective interaction with other systems and with humans; sensor-based control of autonomous activity; and the integration of varieties of reasoning as necessary to support complex decision-making. …The emphasis at NCARAI is the linkage of theory and application in demonstration projects that use a full spectrum of artificial intelligence techniques. (Ref 2)

In the national security domain, potential applications of AIS relate to: support for first responders in counter-terrorism attacks; support for police in (federal) criminal activities; aid to counter-intelligence and risk/threat assessment; assistance in customs/coast guard/border patrol surveillance for interdicting drugs and illegal immigrants, for countering the smuggling of weapons/explosives and for intercepting terrorists.

In the USA, with the recent establishment of the Department of Homeland Security, one can expect to see a more concerted, integrated effort to use unmanned vehicles (mainly UAVs and UUVs) for many of the national security applications cited above, for example by the US Coast Guard and US Border Patrol.

In a land-based, CBRN attack (for example), use could be made of robotic vehicles (on the ground and/or in the air) equipped with a variety of sensors, (as part, or in advance, of a first-response team), to detect and identify the particular hazard, and to communicate this information to the human first-responders, who could remain, initially, at a safe distance from the hazard, until it is identified. Robots could also play a role in containing, reducing the spread, or in the handling, clean up, transport and general management, including disposal or destruction, of the hazard.

In the Washington, DC-area sniper attacks in 2002, the use of a military Predator (UAV) was considered (though not actually used) to assist local police in their hunt for the snipers. Such assistance by DoD would have also involved the use of a system of sensors that could detect flashes of gunfire on the ground. The snipers were eventually caught by more mundane, low technology methods, but this example is illustrative of the kinds of potential dual-use applications of AIS, coupled to an unmanned vehicle.

<u>DRDC/DND Activities Concerning AIS</u>

Ongoing activities at DRDC/DND laboratories

As the "technology push" for the CF/DND, DRDC issues a number of documents, including the previously mentioned Technology Investment Strategy (TIS). The TIS views AIS as one of twenty-one fundamental areas of R&D activity for the evolving global security environment. In terms of the strategic objectives set out for AIS, the following is the list of objectives, in increasing, time-ordered complexity:

- Develop methods by which robotic systems can measure/sense, interpret and classify their environment and identify opportunities, threats and challenges;
- Develop algorithms, software and hardware to control the automated/robotic system's behaviour as it responds to a changing environment;
- Develop adaptive learning based on collective intelligence for intelligent systems to cooperate on shared tasks through individual effort with minimal direction. The aim is to develop intelligent systems that collaborate to accomplish missions (a collection of tasks) that they are otherwise unable to perform individually, demonstrating higher order behaviours (higher levels of intelligence and autonomy) to perform higher-level mission assignments and tasks. In the land environment, collective intelligence achieved through swarms of interacting, mission-specific sensors and platforms will be pursued.

In TIS 2002, the text emphasizes the following: "Operation in the land environment provides the greatest challenges to mobility and machine learning, and the greatest opportunities and requirements for automated, cooperative and collective intelligence gathering and information sharing among robotic systems. Throughout, the focus will be on data fusion and the development of cooperative, intelligent systems, for various platforms, rather than on the development of specific new platforms."

Activities concerning AIS are being pursued at DRDC Suffield, DRDC Atlantic, DRDC Ottawa and at the Canadian Forces Experimentation Centre (CFEC). Some of the work being carried out at DRDC research centres may also be under the auspices of national or international (bilateral or multilateral) programs or collaborations, as noted in some of the examples below.

- DRDC Suffield: Much work on autonomous (unmanned) ground vehicles has been conducted at DRDC Suffield (including collaboration with the Robotics Institute of Carnegie-Mellon University, in the USA), over the past decade. These studies have concentrated on such areas as: visual navigation, remotely operated vehicles, computer vision and image processing. Currently, tactical unmanned (ground) vehicles (UGVs) are being investigated to exploit the potential for increasing soldier survivability, lethality and mobility by reducing the risk to personnel and their workloads, and by improving the efficiency of existing tasks. Other autonomous land systems will attempt to demonstrate that multiple AIS are capable of augmenting manned reconnaissance capabilities by sensing and interpreting their environment and using their collective machine intelligence to react effectively. In order to achieve the aim, it will be necessary to develop certain capabilities in machine perception combined with intelligent collective and collaborative behaviour.

- DRDC Atlantic: During most of the 1990s, research was conducted by DRDC Atlantic on UUVs, mainly to improve the navigational accuracy, sonar speed sensors and a variety of inertial, acoustic and optical systems (for the purposes of homing, tracking, and telemetry) in long-range, ice-covered waters. The aims of these studies, employing AIS, were not directly related to developing a traditional UUV for ISR purposes or a specific unmanned combat underwater vehicle. In more recent years, however, the emphasis has been on advancing the uses of AIS in other situations: command and control, especially in littoral areas and where interoperability with UN/NATO Coalitions is a factor; decision-support capabilities (integrated into the ship's existing command and control system) and where capabilities related to fusion of data, formulation of an accurate dynamic maritime picture (situational awareness), identification of courses of action and action implementation are all needed; visualization by the Command Team of the tactical situation; real-time intelligent situation assessment, using a combination of advanced technologies; uses of and defences against UAVs in naval combat. Attention has also turned to the development of remotely controlled naval vessels: for mine-sweeping operations; as autonomous underwater vehicles; and, for more sophisticated underwater warfare.

- DRDC Ottawa: At the present time, DRDC Ottawa is involved with many aspects of automating the analysis of radar sensor signals and imagery, including: development and improvement of detection algorithms for ground and maritime targets; ground and air-moving target indicators; automation of image focusing, segmentation and fusion; autonomous recognition of targets from high-range resolution profiles and synthetic aperture radar imagery.

- CFEC: The Canadian Forces Experimentation Centre is actively pursuing a concept development and experimentation program involving UAVs and their integration into the Canadian Forces networked command and control system. This involves the development a UAV system simulation facility as well as a number of experimental flights of different UAV systems. A focus is being placed on the autonomous aspects of the systems with work progressing in the areas of automatic target detection/tracking and identification using biomimetic intelligence (the science of replicating the brain process in man-made systems) and other specialized algorithms. Networked system architectures and open infrastructure concepts are being developed for system command and control. Simulations will be verified through field experiments.

Joint activities and those funded by DRDC

DRDC's R&D links related to AIS also exist with other government departments, such as the National Research Council (NRC), with federally-funded institutions, such as the Institute for Robotics and Intelligent Systems (IRIS) managed by Precarn Incorporated, (under the Network of Centres of Excellence), and with the private/academic sectors through a number of DRDC programs (such as the Defence Industrial Research Program (DIRP), the Technology Demonstration Program (TDP) and the Technology Investment Fund (TIF)).

- NRC: DRDC and NRC have initiated discussions aimed at renewing their collaboration in connection with the broad needs of the Air Force in autonomous intelligent systems, airborne sensors, image recognition and other areas. NRC (through its Institute for Aerospace Research) also provides expertise in air platforms in projects that are generally conducted with matching funds between DRDC and NRC. This collaboration will also work to orient the R&D delivered by the Institute with the priorities of the DRDC's Technology Investment Strategy.

- Precarn: The Institute for Robotics and Intelligent Systems (IRIS) is a federally-funded Network of Centres of Excellence that brings together top Canadian researchers who collaborate on projects that focus on the essential elements of an intelligent system - the ability to perceive, reason and act. IRIS is managed by Precarn Incorporated and, together, these two organizations have successfully harnessed Canada's capacity for Intelligent Systems innovation. The IRIS mission is to promote high-quality collaborative applied research, in intelligent systems, which is of strategic importance to Canadian industry and to strengthen the R&D interaction between universities and industry, thereby improving the competitiveness of Canadian firms. The technologies being pursued in this program include robotics, sensors, knowledge-based software and the enabling human-machine interfaces.

- DIRP: The Defence Industrial Research Program supports eligible research projects from the Canadian private sector, at the fifty-percent funding level, that have a sufficient level of defence relevance to Canada and/or its allies. The DIRP is a mechanism for introducing innovative technologies into DND from the industrial base. DIRP-supported AIS research projects cover the areas of multiple-UAV aircraft simulations, intelligent cognitive internet search engines, airborne hyperspectral image analyses, characterization and analysis of images of space objects, intelligent trackers for incoming missiles and aircraft, simulation and modeling of incoming threats to ships, and other similar AIS areas of research.

- TDP: The Technology Demonstration Program demonstrates and validates technology solutions for new and emerging CF operational systems and concepts without having to develop fully new products. As an example of a project in this program, DRDC and CFEC are co-sponsoring (with funding assistance from Director General Strategic Planning and General Dynamics Canada) an Unmanned Airborne Surveillance Technology Demonstration to demonstrate the military utility of advanced technology, multi-level, UAV-based surveillance and reconnaissance capabilities in the Canadian context.

- TIF: The Technology Investment Fund supports forward-looking, high-risk, but potentially high-payoff, research projects. In this program, DRDC is supporting a collaborative project (to be carried out between DRDC Valcartier and a private sector company) to develop, from a decision-centred perspective, an innovative Decision-Centred Evaluation Capability. This capability is intended to assess and measure net human decision-making performance and operational impact of computer-based C4I decision-support systems for military command and control applications.

Activities of DRDC/DND under multi-lateral S&T arrangements

The collaborations of DRDC/DND with The Technical Cooperation Program (TTCP) (comprised of Australia, Canada, New Zealand, the United Kingdom and the United States) and with the NATO Research and Technology Organisation (RTO) promote cooperative research and information exchanges with Canada's allies that support the development and effective use of national defence research and technology to meet the military needs of Canada and its allies. Some examples of projects are given below.

- TTCP: The development of automated detection, tracking and identification algorithms for the maritime environment has been ongoing by DRDC Ottawa (in conjunction with TTCP sensors working groups) in order to facilitate better maritime surveillance by each nation's current maritime patrol aircraft or future UAV capabilities. Methods for target detection within wide area surveillance as well as automatic target recognition of small craft have been areas of recent focus. In another application, joint projects (involving CFEC) under the auspices of TTCP using the Proteus aircraft (US) (in airspace integration), Global Hawk (US) (in maritime patrol) and Aerosonde (Australia) (in autonomous littoral patrol) are planned over the next year. Results of these flights will provide data for further autonomy research as well as simulation validation. The results of the CFEC study will be a detailed recommendation of the way ahead for UAV acquisition by the CF.

- NATO RTO: DRDC Ottawa is actively participating in NATO task groups, including ground target recognition by synthetic aperture radar and the generation of synthetic databases for non-cooperative air target by radar, which aim to assist in the development of automatic target recognition algorithms by using shared databanks and evaluation methods. The baseline for the ground target automatic target recognition has been adopted from DRDC Ottawa work, and both task groups are using, to a great extent, a Canadian-made commercial classifier. The most successful algorithms will be candidates for use in automating radar analysis for the CF and NATO allies.

Recent Developments in Unmanned Vehicles in USA

While a number of Canada's NATO allies and TTCP partners (and some other western, industrialized countries) have S&T and development programs with respect to unmanned vehicles, the spending on such programs being carried out in the USA dominates the field.

As the world's only remaining superpower, the USA has the largest defence and largest S&T budget, among both its allies and potential foes. While the emphasis in this report has been on unmanned vehicles, the USA distributes its Department of Defense funds (both on AIS and on unmanned vehicles) through its military bases and military research laboratories, through civilian national laboratories operated by other government departments (for example, the Department of Energy and NASA) and through the funding of contracts with the private and university sector. It also contributes S&T funds widely through a variety of bi-national arrangements (including those with Canada) as well as through multi-national cost-sharing arrangements involving TTCP, NATO RTO, and other international organizations. As noted above, Canada (through DND) has been a partner in joint activities on AIS with the USA (through DoD), while private sector companies in Canada have been recipients of contracts (or sub-contracts) from DoD through a number of S&T programs, such as those under the Defense Advanced Research Projects Agency (DARPA).

In the last few years, and especially with the added incentive occasioned by the terrorist attacks of September 11, 2001 (and the subsequent budget increases to support the war on terrorism), the efforts of the USA and the allied countries have burgeoned with respect to R&D related to unmanned vehicles. In the USA alone, there have been several dozen contracts, related to unmanned vehicles, awarded by all segments of the military (often in collaboration with DARPA or other government agencies). A small sampling of these contracts (awarded in the first half of 2002), which highlights the diversity among aerial, ground and underwater, unmanned vehicles, follows (Ref 3):

- The US Air Force Global Hawk, a high altitude (up to 65,000 feet), long-endurance (up to 30 hours) UAV provides intelligence, surveillance and reconnaissance information to the warfighter in near real-time. It was used (and is still being used) in Afghanistan for reconnaissance missions. (Although the main purpose of the Global Hawk is military, some thoughts are already being given to a civilian version, to operate in the US civil air space as a surveillance drone: for law enforcement and homeland security roles, including drug interdiction, border patrol and port security; for monitoring nuclear power plants and remote oil pipelines; for weather monitoring and forest fire surveillance.)
- The US Air Force Predator B, a UAV (a "Predator A" version, exploited under the US DoD (Advanced Concept Technology Demonstration (ACTD) program, was used in Afghanistan, armed with two anti-tank missiles) is now being developed as a higher, faster, better armed (up to ten weapons) attack vehicle. Although capable as an attack vehicle in Afghanistan, it was used primarily as a spotting and tracking vehicle for ground targets for more heavily armed helicopter

gunships, and remained on station, providing battle damage assessment. It is also being envisioned as carrying air-to-air Stinger missiles to attack other aircraft and perhaps cruise missiles.

- The US Army is seeking advanced sensors capable of detecting anti-personnel and anti-tank mines at a minimum distance of 10 metres, with the sensor fieldable on an autonomous robotic platform or hand carried by a soldier. The objective will be to integrate such a sensor into an autonomous robotic vehicle (still to be developed) by about 2005. Other uses of such sensors are also planned.
- The US Navy is also interested in developing a re-usable fighter aircraft class combat drone, suitable for autonomous operation from an aircraft carrier (by 2020).
- The US Coast Guard is pursuing the development of a Vertical Take-Off and Landing UAV (VUAV), tiltrotor aircraft, which will allow such aircraft to take off and land vertically, and fly like a traditional turboprop aircraft. It will be used for a variety of coastal surveillance missions, from counter-terrorism to drug traffic interdiction to fisheries law enforcement.
- As an example of the development of multiple, new technologies, the US Air Force is looking to develop a modular support electronic jamming device, which can be mounted on a wide range of host platforms, including expendable or recoverable UAVs and fighter aircraft.
- In a non-military application of UAVs, NASA has signed an agreement to explore development of a centre to investigate science and commercial applications of UAVs equipped with high-resolution digital imaging systems. The charter of the new UAV applications centre is to conduct collaborative research and development, leading to enhanced utilization of solar-powered UAVs as high-resolution imaging platforms in the (civilian) National Air Space.

Future Directions of AIS

With the ever-greater national interests in defence advancement among the western, industrialized countries (along with their like-minded allies and friends), with the great advances in many fields of novel and strengthened materials, miniaturization (in the form of micro electro-mechanical systems (MEMS)), nanotechnology, sensor technology, radar, computing power, logic, biotechnology, lasers, communications, satellite technology, and myriad other scientific and engineering disciplines, there are enormous opportunities for the merging of the above technologies to accomplish a variety of military and counter-terrorism objectives, and to enhance (in a much compressed time frame) future S&T capabilities. AIS lend themselves to just such "quantum-leap" advancements and opportunities, by being able to accommodate a wide variety of technological systems on moving (air, underwater, ground and spaced-based) platforms.

However, this S&T "technology push" must be matched by a defence "customer pull", that is, by an operational requirement of a given (or multiple) military service(s). In the practical world, "visioning" by a military service of its future needs, in isolation and without knowledge of the multitude of today's current and emerging technological advances, will be difficult, and much less than optimal. Hence there is the obligation for the S&T community to inform the military services about current and emerging technologies, so that relevant technologies may be identified by the military and thus help it in the formulation of its future needs. Such reciprocal interaction will help build and continue to refine the specific needs of the military and give better direction to the S&T community as to which technologies require acceleration, which ones should be combined, and in what manner. It will also help in determining the level of resource allocation that should be devoted to the highest priority projects and problems.

As noted above, S&T advances in many disciplines have permitted recent predictions made only a few years ago to be realized much earlier. In 1995, the US Air Force Science Advisory Board predicted (Ref 4) that within the next 10-15 years, uninhabited (unmanned) combat aircraft would be an operational reality. The reality is that an operational version of such an aircraft was demonstrated in 2001, during Operation Enduring Freedom in Afghanistan, and in November 2002, in the destruction of a car and its terrorist occupants in Yemen. The vastly increased effort being expended (in both R&D budgets and in human resources) by the USA and its allies will bring a wide variety of AIS to operational fruition over the next few years. In TIS 2002, there is the following expectation regarding the operational use of AIS: "Robots or remotely controlled platforms, such as unmanned combat air and land vehicles, will be prevalent on the battlefield of 2020". Once again, the rapid and accelerating pace of progress in many domains of AIS will almost certainly see this reality sooner than predicted.

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List of Abbreviations

ACTD	Advanced Concept Technology Demonstration
AIS	Autonomous Intelligent Systems
CBRN	Chemical, Biological, Radiological and Nuclear
CF	Canadian Forces
CFEC	Canadian Forces Experimentation Centre
DARPA	Defense Advanced Research Projects Agency
DIRP	Defence Industrial Research Program
DND	Department of National Defence
DoD	Department of Defense
DRDC	Defence Research and Development Canada
GPS	Global Positioning System
IRIS	Institute for Robotics and Intelligent Systems
ISR	Intelligence, Surveillance and Reconnaissance
MEMS	Micro Electro-mechanical Systems
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NCARAI	Navy Center for Applied Research in Artificial Intelligence
NRC	National Research Council
R&D	Research and Development
RTO	Research and Technology Organisation
SAM	Surface to Air Missile
S&T	Science and Technology
TDP	Technology Demonstration Program
TIF	Technology Investment Fund
TIS	Technology Investment Strategy
TTCP	The Technology Cooperation Program
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Aerial Vehicle
UGV	Unmanned Ground Vehicle
UUV	Unmanned Underwater Vehicle
UN	United Nations
VUAV	Vertical Take-Off and Landing Unmanned Aerial Vehicle

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14. ABSTRACT

(U) This report is intended to introduce the concept of Autonomous Intelligent Systems (AIS), to give some examples of applications, based on AIS, which are being developed today (and which have been developed in the recent past) and to indicate which technologies may be useful in the defence and national security contexts of the Canadian Forces/Department of National Defence (CF/DND), in the near to mid term (say, from 10 to 15 years hence). The intent will be to keep the analysis (and descriptions) short and at a high level, say at the program rather than project level (except where projects are used as illustrative examples). Since the report is written from the Defence Research and Development Canada (DRDC) perspective, it does attempt to take into consideration the work being done at the DRDC laboratories and through DRDC R&D programs and especially to reflect the needs of the various defence/military and national security services within the CF/DND.

(U) Le présent rapport vise à présenter le concept des systèmes intelligents autonomes (SIA), à fournir des exemples d'applications fondées sur les SIA, de réalisation courante et récente, et à cerner les technologies qui pourraient être utiles à court et à moyen terme (de 10 à 15 ans) aux Forces canadiennes et à la Défense nationale (FC/MDN) dans le contexte de la sécurité militaire et de la sécurité nationale. Le but sera de faire une analyse (et des descriptions) courtes et de les garder à un niveau élevé, par exemple, au niveau du programme au lieu du projet (sauf si le projet sert d'exemple d'illustration. Le rapport est rédigé du point de vue de Recherche et développement pour la défense Canada (DRDC) et de ce fait, il tient compte des travaux entrepris dans les laboratoires de RDDC et dans le cadre des programmes de R & D de RDDC et reflète surtout les besoins divers des FC/MDN en matière de services de sécurité militaire et de sécurité nationale.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Research and Development; Technology; Autonomous Intelligent Systems; UAV (Unmanned Autonomous Vehicles); Unmanned platforms