Canadian Food for Thought Paper: Mapping Autonomy

The Government of Canada wishes to reinforce that this paper has been developed to contribute to in-depth discussion of the concept of Lethal Autonomous Weapons Systems (LAWS). As such, it discusses the creation and deployment of such systems in the hypothetical. This should not be construed as support by the Government of Canada for or against such systems as we continue to believe that further careful study is needed nationally and by the international community prior to any decision in this regard.

In the last two decades, unmanned air vehicles (UAVs), unmanned ground vehicles (UGVs), and unmanned underwater and surface vehicles (UUV and USV) have become increasingly common battlefield tools.

When a robot design can cope with environmental complexity (such as airspace, vegetation, or terrain), mission complexity (such as identifying friend from foe, working towards a target despite opposition, etc.), and mechanical control (such as controlling multiple legs, rotors, or flippers), observers may describe the system as *autonomous* in terms of certain functions or tasks. In other words, *autonomy* is a subjective assessment of a robot's capabilities given the demands of mission, environment, and mechanical system. The less help the system needs, the more autonomous it seems.

This paper will provide a brief summary of developments in autonomous technology in the civilian and military spheres with the view to providing foundational technical knowledge for discussing the strategic, military and humanitarian implications of LAWS.

Current Developments in the Civilian Sphere

Civilian autonomous systems exploit a small group of technologies to achieve limited *navigational* autonomy under very narrowly defined environments and missions – often bounded by regulation.

Virtually all robots exploit Global Positioning System receivers that determine small timing differences from different GPS or GLONASS satellites to compute the receiver's position and altitude. GPS provides a precise global coordinate and time synchronization system through which a robot can use simple control rules to navigate from one GPS position to another.

However, in many cases, GPS alone is not sufficient for the system to navigate or, for that matter, remain mechanically stable. Magnetometers, a crucial sensor for quadcopters and submarines, are used to measure the direction to magnetic North while other sensors may be added to reinforce position estimates such as laser altimeters, barometers, and pitot-static velocity measurement systems. Nevertheless, all these systems serve only to create an accurate estimate of the system's position, velocity, and acceleration.

To achieve greater autonomy requires some degree of *external* sensing. In the case of Google Cars, for example, these sensors include LIDAR (a surveying technology using light to measure distance), radar, and some camera based systems necessary to navigate busy road networks. LIDAR and radar collect range data and, if swept over an arc, can create a local map of the environment's physical structure. Image sensing can produce similar results through either *stereo cameras* or *structure from motion* techniques such as *simultaneous localization and mapping* or SLAM, a non-real-time intense method, or simpler, faster, but less detailed *motion flow* for structural mapping.

LIDAR, SLAM, and stereo cameras are the most common 3D techniques. These methods produce enormous data sets over relatively short ranges (e.g. <100m), making safe highway speeds impossible using these methods alone. However, in the case of Google Cars, pre-mapped databases supplement real-time sensing and extend the sensor range for planning purposes. Google has established very large maps of Northern California to facilitate driving and planning at highway speeds. Theoretically, a large fleet of Google Cars could maintain a continuously updated geometric database of the road network.

These maps, combined with the regimented rules of the road and safety logic, make driverless cars a near term possibility.

More recently, machine vision methods, such as Mobileye's promising vision systems, can be used to navigate using imaging alone. In this case, the vehicle's path is governed entirely by carefully designed real-time image recognition of road and traffic features. It is not clear whether this method will be as generally applicable to complex traffic or unexpected events or off-road manoeuvre as Google's model-based approach.

Similar techniques, combined with radar are used for the 'autonomous mode' on Tesla vehicles, but are limited to lane keeping, smart cruise control, braking, and parking and do not include rules of the road.

Motion flow systems have appeared in commercial UAVs that permit GPS-free indoor navigation. Though these techniques rely on visual texture for accuracy and fail in uniform monochrome surroundings, they provide position hold capabilities and autonomy approaching outdoor UAVs.

Obstacle avoidance capabilities have been demonstrated using motion flow on systems indoors and outdoors, for example the AR Parrot's visual odometry indoors and the DJI Phantom 4's collision avoidance capability outdoors.

Current Developments in the Military Sphere

Military unmanned systems are virtually all tele-operated with only unmanned aircraft and submarine craft possessing any degree of 'autonomous' capability. Line of sight and satellite communications permit long range operations including over-the-horizon for aircraft. Autonomous functions are reserved either for internal system operation (e.g. low-level flight control) or for emergency recovery.

Both unmanned aircraft and submarines operate in very simple navigational environments with few if any obstacles. Consequently, many systems have no external sensing other than mission payload sensors: electronic warfare, electro-optical or infrared cameras for aircraft and sonar for submarines. Payload sensors are rarely exploited for autonomous functions by the aircraft, but may have autonomous capabilities themselves: data recording, target tracking, etc.

For aircraft, autonomy is usually limited to specific aspects of flight, such as take-off, waypoint navigation, and landing. Emergency recovery is also highly automated and will include loss-of-communications and loss of GPS automatic procedures. If present on aircraft, weapons are targeted and released by human operators. These weapons, too, may have limited navigational autonomy and be directly operator controlled (e.g. laser designation) or track an operator selected target criteria (e.g. air-to-air missiles pursuing a pilot selected IR source).

Poor underwater communications forces unmanned submarines to operate more autonomously than above-water systems. Nevertheless, the missions and environment are not more complex than unmanned aircraft. Autonomy is entirely limited to navigation based on deduced reckoning from on-board inertial navigation systems supplemented by periodic surfacing and GPS sampling. Some re-tasking is possible from human operators, but unreliable, low data rate communications keep messages simple and limited to a relatively short range. Underwater range sensing is limited to sonar that provides a comparatively crude geometric world model.

As in the commercial case, greater autonomy requires additional environmental sensing, more complex world models, and plans. For example, as unmanned aircraft enter more complex environments or missions new sensing and algorithms are required.

Unlike proposed civilian driverless cars, unmanned ground vehicles must operate over irregular terrain often when no accurate maps are available. Given that vegetation, terrain, and structures make the land environment radically more complex than air or sea, autonomy on the ground is limited to slow, short range navigation, principally using LIDAR and imaging to collect data for modeling and

Manoeuvre. Only the most sophisticated laboratory systems have functional autonomy equivalent to simpler air or maritime systems – for example, returning home when communication is lost.

Notably, Boston Dynamics has made considerable progress improving legged systems that can cope with highly irregular, slippery, and unstable surfaces using both quadruped and biped systems. Though these systems can absorb some complexity of real world terrain – therefore reducing the need for detailed modeling – navigational autonomy in these environments remains difficult.

Conclusion

Levels of autonomy vary according to a variety of factors. It is likely more useful to think in terms of a spectrum of autonomy, with the level of autonomy closely tied to a system's technology and capabilities, operational environment, and chosen task, rather than merely the qualities of the system itself. In the short-term, advances in the civilian sphere are outpacing the military sphere in certain contexts that can be somewhat predicted, mapped and bounded according to rules and laws (e.g. self-driving cars). In the military realm, due to a combination of necessity and environmental characteristics, greater levels of autonomy are being achieved in the air and maritime environments.

While technological change is always difficult to predict, the utility of both civilian and military robotic systems remains closely tied to the ability of these systems to navigate in complex environments. Until these system are as capable as humans in a given mission and environment, these systems will be limited to very specific roles where their performance adds to human capabilities despite the cost of training maintenance and support. For the foreseeable future, these roles will be contained within very simple regulated environments, require reliable high speed sensing, and be used in the execution of low complexity tasks.