Ravos: Exercising Contextually Aware Distributed Autonomic Control in Land Vehicles

Benjamin Campbell, Glen Pearce, Ant Perry, Brendan Sims, Mohammad Zamani, Lance Newby and Robert Hunjet
Land Division
Defence Science and Technology Group
Edinburgh, Australia

***Abstract*—This paper explores the need for contextually aware distributed autonomic control of land vehicle mission systems. It proposes Ravos, a distributed, autonomic land vehicle mission system controller. It describes exemplar applications enabled by contextually aware autonomic control and the architectural requirements to achieve them in an integrated manner. We explain how the capabilities provided by these systems would be beneficial to land forces and conclude with a description of the planned future work required to develop Ravos.**

Keywords—autonomic control; distributed control; context awareness; resilient positioning; collaborative pose filter; low probability of detection

I. INTRODUCTION

The transition of land military vehicles to digitised platforms brings with it growth in the number and complexity of mission systems hosted on these vehicles. This has and will continue to increase the cognitive burden imposed on vehicle operators in administering and controlling their mission systems in complex military environments. It can be assumed that this complexity is further exacerbated in the case where coordinated operation of these systems over multiple vehicles is required. To this extent, full capabilities of these mission systems remain unexploited. Given these challenges, we argue it would be advantageous for low level mission systems to be supervised and controlled by an intelligent software system (referred to here as an autonomic manager), enabling optimal configuration across multiple sub-systems and reducing the cognitive load of the vehicle operators. This control would be responsive to environmental and system state change (context-aware), and autonomic, i.e. self-Configuring, self-Healing, self-Optimising and self-Protecting (self-CHOP) [1].

The initial research efforts on autonomic control have mainly been focused on complex Information Technology (IT) applications [2]. The Advanced Vehicle Systems (AVS) research team in DST Group is aiming to extend the applicability of autonomic control to mission systems on and across military vehicles. AVS is developing an intelligent software solution called Ravos that exercises contextually aware autonomic management of distributed land mission systems. A number of technical challenges specific to land vehicles and military environments need to be tackled before achieving this goal. One noteworthy example is that distributed context awareness needs to be achieved with respect to mission systems of different domains such as positioning, communications, electronic warfare and vehicle protection. Moreover, exercising correct autonomic control with respect to the context needs to extend across various mission systems across these different domains in order to be effective. Furthermore, mission system operational scope is often distributed across multiple land vehicles that rely on a congested and potentially contested local wireless network.

The contributions of this paper are:

- a number of proof of concept applications being developed by AVS in order to validate the general framework of the Ravos software. In particular, we provide an exemplar autonomic software concept for control of networking devices that seeks to adaptively adjust transmission power to ensure connectivity with friendly vehicles while also trying to minimise probability of detection by enemy. In another example we introduce a prototype of autonomic software for adaptive navigation sensor selection and configuration based on context derived from user needs, sensor performance and other relevant situational awareness considerations. Finally, a collaborative localisation application is introduced that leverages communication and non-GPS positioning devices as a distributed autonomic controller for dealing with GPS challenged situations.

- architectural considerations proposed for Ravos which addresses the effective integration of various autonomic controllers. Integration of context aware, distributed, self-adaptive autonomic controllers has a number challenges in terms of mechanisms for dissemination of information and objectives, timeliness of decisions, coordination and arbitration of conflicting actions between autonomic controllers. For example, rather than incorporating a stovepiped network device controller and a stovepiped collaborative localisation controller that may counteract each other by contentious requests on a radio device, we seek an architecture that avoids this problem by providing appropriate cross-domain information, interfacing protocols and coordination and arbitration.

- distributed context awareness considerations and the approach taken in Ravos for translating high level mission goals to appropriate low level objectives and constraints for individual autonomic controllers. The ultimate goal of Ravos is to unburden the vehicle operator in low level situational assessment, decision making and control of mission systems. In this paper we discuss the enablers which Ravos amalgamates in order to translate operator’s intent to mission system controllers.

The remainder of this paper is structured as follows. Section II describes three autonomic control applications (low probability of detection communication, navigation system selection and collaborative pose filtering), which have been developed to exercise the Ravos architecture and demonstrate the value of an autonomic manager. Section III then describes the adaptable architecture developed for Ravos which aims to support coordination and arbitration between multiple autonomic control systems. This is followed by an explanation of the need for distributed context awareness and a brief description of our proposed approach for context awareness in Ravos in Section IV. Finally, Section V presents conclusions and future work.

II. Autonomic Control Exemplars

A. Low Probability of Detection Communications

Decreasing transmission power of RF communication systems will decrease the likelihood of a hostile receiver detecting a transmission [3]. It has also been shown that decreasing transmission power reduces interference and enables simultaneous transmissions, increasing the resilience and capacity of the network [3], [4]. Unfortunately current deployed communications systems often have a small number of fixed power settings and standard operating procedure is often to select the maximum power setting in order to assure communications. The consequences of a loss of command and control caused by lost communications means that very few operators have the situational awareness or expertise required to confidently make the decision to lower their transmission power. This problem only becomes more complex and more critical in mobile ad hoc networks transmitting both voice and data, where various techniques including packet stuffing, multi hop links and spectrum sharing are all available. Appropriately conducted coordinated power control techniques for one situation may reduce the RF footprint and improve data throughput and latency but could have the opposite effect in a different situation. Take the very basic example of a group of vehicles moving in single file from a headquarters element towards a known enemy location. In order to minimise probability of detection the lead vehicle should minimise transmission power and make use of multi hop links. If all the vehicles did this it could result in the total bandwidth of the network being insufficient to meet requirements. It would be better if the rearward vehicles were able to take advantage of their increased distance from the enemy and use higher power transmissions with improved bandwidth. This configuration is complex, heavily dependent on the exact positions of the vehicles, the RF propagation, link losses caused by the environment and the bandwidth and latency requirements of the network. When any of these factors change the network will need to be quickly reconfigured in order to continue to provide the required performance. There are centralised minimum spanning tree (MST) techniques that can solve this problem, however as stated by Santi [4], centralised MST protocols are “not suitable to be implemented in a mobile scenario” and “not resilient to mobility” due to the computation and communication overheads of the requirement to reconfigure the network every time the relative position of two nodes in the network changes. There is a large body of work in topology control that attempts to overcome this challenge for the purpose of battery conservation [5], [6], [7], [8], [4], [9] using distributed or decentralised control techniques. The development work for Ravos is modifying these techniques for Low Probability of Detection (LPD) applications by creating new algorithms for evaluating the cost of RF links based on vehicle’s relative position in the network and context information. These algorithms have been validated in a static simulation. Research into LPD is also simplifying the routing and node clustering algorithms in order to reduce communication and computation overheads by utilising knowledge on doctrinal vehicle hierarchies and manoeuvres to reduce assumed randomness in node positions and movements. These modifications will be demonstrated in a dynamic simulation in future work.

B. Navigation System Selection

Vehicle navigation systems can comprise a number of sensors and components. In a complex environment, their configuration and management can become a tedious task. Every time there is a failure, a change in performance or change to operator objectives there is a reason to change the selected sensor or alter its operating parameters. With the appropriate architecture, these tasks could be managed by an autonomic controller.

1) Types of Navigation Systems: While a Global Navigation Satellite System (GNSS) receiver is often used as the primary navigation device on military vehicles, there are a number of different types of devices that are in common use. These include:

- Selective Availability Anti-spoofing Module (SAASM) GPS receivers: spoof and jam resistant satellite navigation receivers that use the US government satellite constellation.
- commercial GNSS receivers: standard satellite navigation receivers that use multiple satellite constellations.
- differential GNSS receivers: satellite navigation receivers that use multiple satellite constellations and use a correction data service to improve accuracy and integrity.
- radio-based positioning devices: sensors that determine position based on time of flight calculations using radio signals (e.g. Enhanced Position Location Reporting System (EPLRS)).
- Inertial Navigation Systems (INS): systems that use some combination of magnetometers, odometers, accelerometers and gyroscopes to estimate position using dead reckoning (without GNSS).

2) Navigation Sensor Integration: Military vehicles often have more than one navigation sensor, however each receiver may be tightly integrated with a particular application. Unfortunately the tight integration of each sensor with an application means that a failure of one navigation sensor disables or significantly degrades the performance of that application, even though the other sensors may be working perfectly. If the systems are more loosely coupled and integrated through a separate interface, then each position sensor becomes available to multiple applications. An autonomic manager can better match a navigation sensor to the changing needs of applications, replace the function of a preferred sensor if it fails, and even monitor performance through cross-comparison of the sensor outputs.

3) Enhancing Navigation System Selection: An autonomic controller could be used to select the most appropriate navigation sensor for an application under changing user needs and sensor performance. The situational awareness moving map display might use differential GNSS as long as it is within the error ellipse of the SAASM GPS, coupled with the INS as backup when travelling through urban canyons. A friendly force position tracking device might normally use the SAASM GPS, but could switch to a position feed from the EPLRS radio if the GPS were jammed. When travelling in a group, the spoofing of the lead vehicle's satellite based positioning sensor could trigger the reconfiguration of the remaining vehicles; each decoupling their satellite based positioning sensors from their INS before their position estimates are corrupted. The navigation system selection application developed for Ravos uses a policy-based mechanism based on [10] for adaptive control via configuration and selection of devices on a single vehicle based on environmental context. Our simulation study [11] shows that the policy based mechanism of Rosa et al. [10] is suitable for context-aware adaptive control of vehicle devices based on heuristic rules and domain knowledge of field experts.

C. Collaborative Pose Filtering

Positioning is critical to most military applications. GPS challenged environments are identified as a persistent issue for modern military mission systems. Ravos is aiming to facilitate and to exploit information sharing across distributed mission systems on different vehicles in order to remedy this problem. As one component of Ravos, AVS is working on a collaborative localisation application referred to as Collaborative Pose Filtering (CPF). CPF exploits relative positioning measurements with respect to nearby friendly vehicles and their communicated positioning information in order to improve the positioning state estimate of the vehicle despite not having reliable GPS. The algorithmic part of CPF is a fusion mechanism that incorporates information obtained from the relative measurements and communicated estimates, and their associated confidence weightings, into absolute measurements as a replacement for a GPS measurement. In other words, CPF geolocates a vehicle based on nearby vehicles treated as non-stationary landmarks. CPF has been validated using simulations and is currently under experimental validation on small unmanned ground vehicles.

III. Adaptable Architecture

Ravos is designed as a distributed management framework that applies the principles of the Viable Systems Model (VSM) [12] to the management of competing components within a self-same compositional model. VSM describes the attributes of human organisations that allow them to endure while planning for the future and responding to unexpected events. VSM is recursive in structure and ensures that control occurs at the lowest level possible while maintaining access to relevant contextual indicators and policy. The high level structure of Ravos is shown in figure 1. Distributed instances behave independently and interact through the environment, be it in a permissive communications zone or one that is actively contested. The architectural scope of this paper is limited to the behaviour of Ravos in-situ, during an operation. Many decisions regarding configuration, fit out and planning are assumed to create the active environment for our architecture to perform. We describe this state as the 'Rolling start'. The boot-strapping process is outside the scope of this paper.

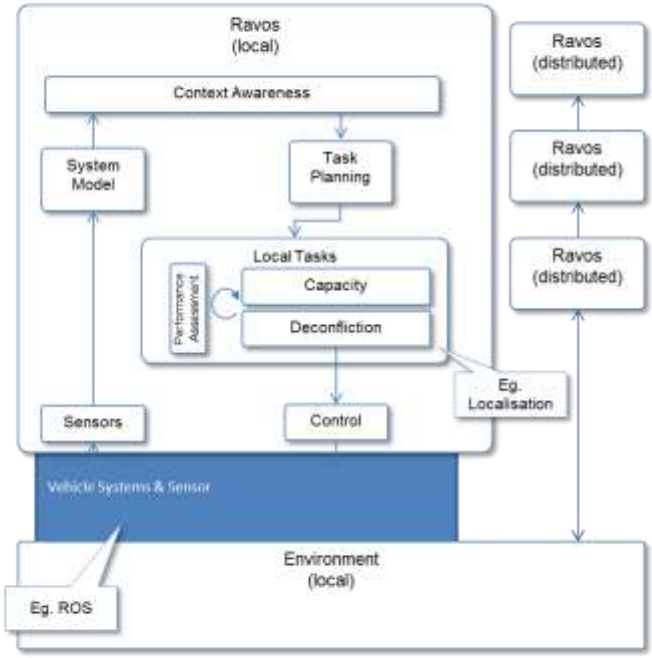

Fig. 1. The Ravos component diagram

System Model is the collection of relevant data sensed from the environment. Policies for data retention and logging are dependent on the system context and are negotiated with the other system priorities as a resource.

Context Awareness is dependent on Ravos' ability to measure its own effectiveness in its operational environment against metrics representing individual applications and the mapping of these applications to the value of the self-managing actions in terms of warfighting objectives. Changes in these metrics or violations of relevant metric thresholds provide an indication for Ravos to adapt. This may involve low level configuration changes or adaptation of global control strategies. Therefore, ongoing monitoring ensures Ravos retains the vehicle mission systems in a desirable state. The implemented Ravos solution will also combine a number of localised measurements (e.g. computation overhead, persistence of core functionality, ability to recover from faults) to dynamically monitor its own overall performance and feed into the contextual awareness picture to inform other self-adaptation actions.

Task Planning is initiated when required by a change in context. This includes changes in the system model that impact context (or projected changes, should Ravos have the capacity instantiated to predict relevant future states), or second order effects that effect mission objectives.

Local Tasks are compositional hierarchical structures that can provide control signals for hardware, services that support planning or process sensor data to inform system context. A capacity is provided by Ravos to perform a task either locally or on a distributed Ravos instance. The performance is assessed to provide local context and capacities that compete for resources or share control must be deconflicted

IV. Distributed Context Awareness

Any system that attempts to seamlessly assume responsibility for the control of vehicle mission systems will be required to respond to changes in threats, the environment, the available assets and resources, mission and task requirement and priorities, and friendly and enemy actions, as well as measures of effectiveness of the current system state. This broad set of information is referred to here as context. In developing context awareness capabilities for Ravos, inspiration is taken from the concept of situation awareness in the data fusion community. Situation awareness is defined in [13] and [14] as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future"*.

Without context awareness a control system will be limited to a very small set of "canned" responses to specific sensor data hard coded at design time. Furthermore, a control system will have no way to perform arbitration between conflicting goals reliant on contextual information (e.g. communication range and stealth trade-offs when controlling radio transmission power) and control decisions would fall back to the operator. In addition, in well-connected teams of vehicles there is an opportunity to share context information between platforms in order to generate broader or more accurate context awareness than could be achieved by a single operator or platform thereby exploiting the heterogeneity within the vehicle deployment. Finally, there are many on board sensors that generate context information relevant to control systems beyond the purpose for which they were originally designed (e.g. a handbrake sensor can be used to indicate when the vehicle is stationary, which can allow for more accurate GPS configurations to be employed). Without a distributed context awareness service these opportunities will remain unrealised.

The Ravos system aims to provide this "man in the middle" distributed context awareness service by utilising a hierarchical ontological approach to context representation and communication. Ravos will define a high level ontology which captures broadly relevant context information as well as defining the lower level structure. This will be built on by domain specific subclass ontologies. This approach creates a scalable information structure that can be built upon as more applications are added [15]. In this framework sensing applications will be able to push data into the ontology and ontological solvers will be used to infer when the system is in a situation relevant to a particular domain/controller.

V. Conclusion

This paper has described how Ravos will provide context aware distributed autonomic control of land vehicle mission systems and presented example applications that it will enable in order to demonstrate its value. Future work will include demonstration of the Ravos architecture incorporating multiple autonomic controllers on unmanned robotic ground vehicles. These vehicles will undertake shared tasks related to the applications presented in this paper whilst demonstrating context awareness. This is a key step in fully utilising contextual awareness for autonomic control and is expected to provide insights to relevant trade-offs and dependencies. In addition, the application space which Ravos controls will be broadened to consider vehicle survivability concepts that utilise context awareness and threat models to enhance land vehicle survivability.

References

[1] J. Kephart and D. Chess, "The vision of autonomic computing," Computer, vol. 36, pp. 41 – 50, 2003.

[2] IBM, "An architectural blueprint for autonomic computing," IBM White paper, pp. 1–32, 2005.

[3] R. Hunjet, "On simultaneously increasing manet survivability, capacity, power efficiency and security," International Journal of Information, Communication Technology and Applications, vol. 2, no. 1, pp. 85–107, 2016.

[4] P. Santi, "Topology control in wireless ad hoc and sensor networks," ACM computing surveys (CSUR), vol. 37, no. 2, pp. 164–194, 2005.

[5] N. Li, J. C. Hou, and L. Sha, "Design and analysis of an mstbased topology control algorithm," IEEE Transactions on Wireless Communications, vol. 4, no. 3, pp. 1195–1206, 2005.

[6] X.-Y. Li et al, "Localized low-weight graph and its applications in wireless ad hoc networks," in INFOCOM 2004. 23rd Annual Joint Conference of the IEEE Computer and Communications Societies, vol. 1. IEEE, 2004, pp. 431–442.

[7] X.-Y. Li, "Localized construction of low weighted structure and its applications in wireless ad hoc networks," Wireless Networks, vol. 11, no. 6, pp. 697–708, 2005.

[8] M.-T. Sun et al, "Distributed topology control for energy-efficient and reliable wireless communications," IEEE Systems Journal, 2017.

[9] I. Schweizer et al, "ktc-robust and adaptive wireless ad-hoc topology control," in 21st International Conference on Computer Communications and Networks (ICCCN). IEEE, 2012, pp. 1–9.

[10] L. Rosa et al, "Self-management of adaptable component-based applications," IEEE Transactions on Software Engineering, vol. 39, no. 3, pp. 403–421, 2013.

[11] G. Pearce et al, "An adaptive policy based control framework for land vehicle systems," in ICRA 2018, in press. International Conference of Intelligent Robotics Applications, 2018.

[12] S. Beer, "The viable system model: Its provenance, development, methodology and pathology," Journal of the operational research society, vol. 35, no. 1, pp. 7–25, 1984.

[13] M. R. Endsley, "Toward a theory of situation awareness in dynamic systems," Human factors, vol. 37, no. 1, pp. 32–64, 1995.

[14] J. Scholz, D. Lambert, D. Gossink, and G. Smith, "A blueprint for command and control: Automation and interface," in 15th International Conference on Information Fusion. IEEE, 2012, pp. 211–217.

[15] C. Anderson, I. Suarez, Y. Xu, and K. David, "An ontology-based reasoning framework for context-aware applications," in International and Interdisciplinary Conference on Modeling and Using Context. Springer, 2015, pp. 471–476.