Title: Cooperative Control of heterogeneous autonomous vehicles

Thesis Proposal

Universidade do Porto

Faculdade de Engenharia

FEUP

Supervisors:

- Fernando Manuel Ferreira Lobo Pereira, Departamento de Engenharia Electrotécnica e Computadores, Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, s/n 4200-465 Porto, Portugal. E-mail: flp@fe.up.pt

- João Tasso de Figueiredo Borges de Sousa, Departamento de Engenharia Electrotécnica e Computadores, Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, s/n 4200-465 Porto, Portugal. E-mail: jtasso@fe.up.pt (from September 2008 onwards)

Research unit:

Robotics and Systems Institute (ISR), Faculty of Engineering of Porto University

Proposal

Objectives

This thesis addresses the problem of modeling and controlling cooperative networks of vehicles and sensors in a mixed initiative environment. In mixed initiative environments planning procedures and execution control must allow intervention by experienced human operators.

The design and deployment of mixed initiative frameworks in a systematic manner and within an appropriate scientific framework requires a significant expansion of the basic tool sets from different areas (computation, control, communication, and human factors) and the introduction of fundamentally new techniques that extend and complement the existing state of the art. These techniques will be used to develop a mathematical model of a dynamic system, composed by multiple heterogeneous vehicles, sensors and human operators. The expected results will be both conceptual and practical. There is an equal emphasis on conceptual issues and on tools and techniques that yield more immediate practical benefits. All developments will have direct application in the systems that are being developed at the Underwater Systems and Technology Laboratory at FEUP. This will also contribute to the validation of the results.

Background

The last decade has witnessed unprecedented interactions between technological developments in computing, communications, and control, on the one hand, and the design and implementation of networked multi-vehicle systems, on the other. In fact, questions that could not have been formulated a few years ago are being posed. These technological advancements allow us to envision the design of systems which could have not been imagined before. But design is a process that greatly benefits from previous experience, in this case that of implementing networked multi vehicle systems. Today most of the implementations are at the demonstration stage, but important lessons can be learned from them. These developments led to the emergence of various heterogeneous autonomous robotic vehicles. Ocean and air going autonomous vehicles are capable of performing “dirty, dull and dangerous” (3D) missions, which arise not only in military operations, but also in civilian operations [1]. Also, the miniaturization of electronic components like radio transmitters, as well as recent developments in wireless protocols, led to the appearance of low-cost and low-power wireless sensor networks which, embedded in the physical environment, allow data collection and dissemination in real-time, through ad-hoc wireless networks [2].

There are several projects dealing with the cooperative control of autonomous vehicles. Some examples include automated highway systems [3], border patrolling [4], mobile offshore bases [5], robotic soccer [6], large scale monitoring of oceanographic data [7], not forgetting several other projects that are using this technology for military warfare. Some steps have already been made towards the mathematical models of such systems, reusing developments in the fields of control theory [8], swarm intelligence [9] and autonomous agents [10]. The paradigm of dynamic networks of hybrid automata includes models for dynamic interactions e existential quantification that allow the modelling of dynamic components’ interactions [11]. In the areas of computer science and embedded systems, special relevance is given to the developments of formal models that describe how various computing models interact [12] and the Pi-calculus language which allows the abstract mathematical modelling of time-varying interacting processes [13]. Currently, we are lacking models for cooperating vehicles with varying degree of heterogeneity.

There is obvious advantage in having such systems of cooperative vehicles, in which the constituents have different locomotion means, different sensors (or weaponry), different velocities, etc. In the C3UV laboratory from the University of California in Berkeley [14], some steps were made in this direction, with the concept of service provider architecture (SOA), where the vehicles service tasks and the operators demand task execution. In the case of the Underwater Systems and Technology Laboratory (LSTS) of Porto University [15, 16], a control framework for multiple heterogeneous sensor and vehicles is being developed. The control framework consists of two main layers: multi-vehicle control and vehicle control. Each layer, in turn is further decomposed into other layers. The vehicle control architecture is standard for all the vehicles. The vehicle control architecture consists of the following layers: low-level control, manoeuvre control, vehicle supervision and plan supervision. The multi-vehicle control structure is mission dependent.

The design of graphical user interfaces (GUI) for mixed initiative interactions is also an active area of research; examples include command and control frameworks for autonomous vehicles [17, 18]. However, these projects are still in the first stages of development. This proposal also addresses the design of GUIs allowing operators to interface with networks of cooperating vehicles and sensors; this entails systems where the users can perceive and control the overall system state effortlessly. This interaction will be conceptualized in terms of mathematical models which describe the mixed initiative interaction between operators, heterogeneous vehicles and sensors.

References

1] D. A. Schoenwald, "AUVs: in space, air, water, and on the ground", IEEE Control Systems Magazine, 2000;

[2] D. Culler, D. Estrin, "Overview of Sensor Networks", IEEE Computer Magazine, August 2004;

[3] J. K. Hedrick, M. Tomizuka and P. Varaiya, "Control issues in automated highway systems", IEEE Control Systems Magazine, 1994;

[4] A. Girard, A. Howell and J. K. Hedrick, "Border patrol and surveillance missions using multiple unmanned air vehicles", IEEE Conference on Decision and Control, 2004;

[5] A. Girard, K. Hedrick and J. Borges de Sousa, "A Hierarchical Control Architecture for Mobile Offshore Bases", Marine Structures Journal, 2000

[6] R. D'Andrea, "Robot soccer: a platform for systems engineering", Computers in Education Journal 2000;

[7] T. Curtin, J. Bellingham, J. Catipovic and D. Webb, "Autonomous ocean sampling networks", Oceanography, 1993;

[8] P. Varaiya, "Towards a layered view of control", Proceedings of the 36th IEEE Conference on Decision and Control, New York, 1997;

[9] S. Martinez, J. Cortes and F. Bullo, "Motion Coordination with Distributed Information", IEEE Control Systems Magazine, 2007;

[10] G. Sukthankar and K. Sycara, "Efficient Plan Recognition for Dynamic Multi-agent Teams", Grace Hopper Conference, 2007;

[11] A. Deshpande, A. Gollu and L. Semenzato, "The SHIFT Programming Language and Run-time System for Dynamic Networks of Hybrid Automata", California PATH Report, 1997;

[12] S. Edwards, L. Lavagno, E. Lee and A. Sangiovanni-Vincentelli, "Design of Embedded Systems: Formal Methods, Validation and Synthesis", Proceedings of the IEEE, 1997;

[13] R. Milner, "Communicating and mobile systems: the Pi-calculus", Cambridge University Press, 1999

[14] A. Ryan, X. Xiao, S. Rathinam, J. Tisdale, M. Zennaro, D. Caveney, R. Sengupta, and J. K. Hedrick, "A Modular Software Infrastructure for Distributed Control of Collaborating UAVs", AIAA Conference on Guidance, Navigation, and Control, 2006;

[15] Laboratório de Sistemas e Tecnologia Subaquática, Faculdade de Engenharia da Universidade do Porto, http://www.fe.up.pt/~lsts/

[16] J. Borges de Sousa, K. H. Johansson, J. Silva and Alberto Speranzon, “A verified hierarchical control architecture for coordinated multi-vehicle operations”, International Journal of Adaptive Control and Signal Processing, accepted for publication.

[17] C. S. Lee, "NPS AUV Workbench: Collaborative Environment for Autonomous Underwater Vehicles", Master´s thesis, 2004

[18] J. Pinto, P. S. Dias, G. Gonçalves, R. Gonçalves, E. Marques, J. Sousa and F. L. Pereira, "Neptus – A Framework to Support a Mission Life Cycle", 7th IFAC Conference on Manoeuvring and Control of Marine Craft, 2006