The SeaCon Autonomous Underwater Vehicle System

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Resumo: Esta comunicação descreve o sistema de veículos submarinos autónomos *SeaCon* desenvolvido no âmbito do projecto *SeaCon* de I&T colaborativa entre a Marinha Portuguesa e a Faculdade de Engenharia do Porto com financiamento do Direcção Geral de Armamento e Infra-Estruturas de Defesa. O sistema *SeaCon* destina-se a treino e desenvolvimento e refinamento de conceitos de operação. O sistema consiste em 3 veículos submarinos autónomos, sistema de navegação acústica LBL, consolas de operação e num gateway de comunicações. Os veículos submarinos autónomos SeaCon são evoluções do veículo LAUV desenvolvido pela Faculdade de Engenharia do Porto e Prémio BES Inovação 2006 na fileira oceânica. Os veículos SeaCon, na sua configuração base estão equipados com sensores CTD. Estão preparados para a instalação de uma vasta gama de sensores que incluem sonar de varrimento lateral e ainda medidores de clorofila. Podem ainda integrar modens para comunicações acústicas. Por serem um sistema aberto estes veículos possibilitam o seu contínuo desenvolvimento e aperfeicoamento tendo em vista futuras aplicações operacionais em ambiente de guerra de minas e em missões Rapid Environment Assessment (REA).

Palavras chave: Veículo submarino Autónomo, comando e controlo, rápida avaliação ambiental

1. INTRODUCTION

This paper describes the SeaCon Autonomous Underwater Vehicle (AUV) system that is being developed by Porto University in cooperation with the Portuguese Navy under the SeaCon project, funded by the Portuguese Ministry of Defense. The main objective of this project consists of the development of an open and low cost AUV system for training and improvement of concepts of operation for shallow waters. The system will also be used by the Portuguese Navy to test and evaluate underwater technologies in a cost-effective manner and to develop specialized underwater warfare know-how. The modularity of the system makes it easily reconfigurable for Rapid Environment Assessment (REA) missions.

The SeaCon AUV system is based on evolutions of the award winning Light Autonomous Vehicle (LAUV) and of the *Neptus* (Dias *et al.* 2006) (Pinto *et al.* 2006) command and control framework for networked vehicle systems, both developed by Porto University.

The LAUV is a torpedo shaped vehicle made of composite materials (110x16 cm) with one propeller and 4 control fins. It has an advanced miniaturized computer system running modular controllers on a real-time Linux kernel. It is easily configurable for multiple operation profiles and sensor configurations to facilitate test and evaluation of new technologies. In the standard configuration it comes with a low-cost inertial motion unit, a depth sensor, a LBL system for navigation, GPS, GSM and Wi-Fi.

Fig. 1. LAUV Green

With *Neptus*, vehicles, operators, and operator consoles come and go. Operators are able to plan and supervise missions concurrently. Additional consoles can be built and installed on the fly to display mission related data over inter-operated networks. This is aimed at networked operations with other vehicle systems, such as air or surface autonomous vehicles.

The SeaCon AUV is an open system which lends itself to the integration of new systems and technologies developed in Portugal and also COTS state-of-the-art equipment. This presents a major advantage over commercial systems. In general, commercial vehicles have not been developed as open systems. Closed systems tend to raise vehicle and maintenance costs, and may be conducive to forms of market practice that are not necessarily in the benefit of the customer. This is especially critical in a field where technological obsolescence arises rapidly: vehicles and their components have to be upgraded periodically. Some technological trends, namely those related to miniaturization and embedded systems, may contribute to change this state of affairs by contributing to the reduction of cost. Low cost open systems are fundamental for the development of national technologies and know-how and will prove fundamental to the dissemination of networked vehicle systems, the next trend in unmanned vehicle systems.

This paper is organized as follows. In section 2 we briefly describe the main components of the SeaCon AUV system. In section 3 we discuss the version of the Neptus command and framework used in the SeaCon system. In section 4, we discuss operational profiles for the SeaCon system. In section 5, we present the conclusions and discuss future work.

2. SEACON SYSTEM

The SeaCon system is composed of a LAUV, Long Baseline (LBL) beacons, a Portable Acoustic Locator (PAL), a communications gateway, and a command and control console based on the Neptus software.

In its basic configuration the LAUV *SeaCon* is equipped with a CTD sensor and is capable of housing one acoustic modem and one side-scan sonar. Due to its modular architecture, the sensor payload may be further customized to suit the client's needs. Sensors such as imaging and bathymetric sonars and optical backscatter sensors can be installed easily.

Fig. 2. LAUV SeaCon

The LBL beacons developed for the SeaCon system are narrowband acoustic transponders that by replying to the vehicle's interrogations (pings) allow the vehicle's software to compute the one-way travel time to each beacon.

The PAL is based on the same technology as the LBL beacons and is used to pinpoint in real-time the position of the AUV, by listening to the vehicle's acoustic pings and respective responses from the LBL beacons. It allows the operator to abort the execution of the current plan and track the vehicle's progress when it is submerged.

Fig. 3. PAL (left) and LBL Beacon (right)

The command and control console presents a comprehensive real-time summary of the vehicle's position, state and health and allows the operator to design, follow and review the execution of plans.

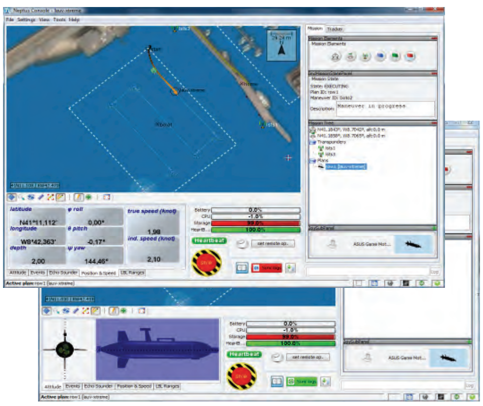

Fig. 4. Operator's console

The communications gateway is a portable and centralized communication hub for maritime assets supporting several types of wireless networks. This device can be used from shore, ships or installed on buoys. The system is capable of transparently route data between heterogeneous network links, balancing bandwidth and range. Routing and store-and-forward is implemented with the aid of the Delay Tolerant Networking (DTN) (Fall 2003) Reference Implementation.

3. COMMAND AND CONTROL

Neptus is a Command, Control, Communications, Computer and Intelligence (C4I) framework. The interactions with human operators are classified according to the phases of a mission life cycle: world representation; planning; simulation; execution and post-mission analysis.

The planning of a mission is supported by the Mission Planner. It provides a map editor that allows the construction of a virtual representation of the mission site. Maps are composed of several geo-referenced elements: marks to denote points of interest, geometric figures, surface images (with optional elevation map), generic 3D models, and paths (composed by line segments). Mission plans are also specified in this environment through the use of high level abstractions, such as maneuvers. Mission parameters encompass the definition of the local coordinate systems, navigational aids, points of interest and obstacles.

For the execution phase, Neptus provides support for the creation of operator consoles that can be configured in terms of displays and controls. In the configuration process visual components can be chosen, arranged and grouped spatially according to a specific system/vehicle or to an operational scenario. Neptus, as a software framework, can be used to develop new visual components to be added to operational consoles as plug-ins. All console configurations can be read and stored to disk as individual XML files.

After mission execution, all collected data can be analyzed using Neptus' Mission Review and Analysis tool. The collected data can be displayed in different ways such as tables, plots, and color maps. This feature is also available for mission replays. This tool also provides plug-ins for exporting data into different formats like PDF and CSV. Moreover, an embedded web server can also be activated in order to provide web access to real-time mission data and post-mission analysis.

Neptus supports different communications protocols by having a communications layer that gives support to message based protocols, being agnostic to the chosen transport protocol (UDP, TCP, NDDS, HTTP...). Neptus supports distributed networked vehicles operating in wide areas. This is done with the help of the Inter Module Communications (IMC) message protocol (Martins *et al.* 2009) that defines a common control message set understood by all types of LSTS systems (vehicles, consoles, or sensors) in networked environments. IMC provides for standard coupling of heterogeneous components in terms of data interchange.

4. OPERATIONS

Operational deployments are the opportunity to test and evaluate tools and technologies. Figure 3 depicts a diagram of the networked vehicle system we deployed in June 09.

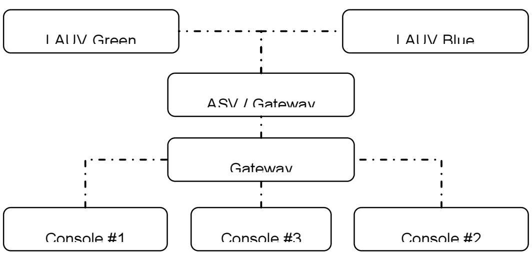

Fig.5. June 2009 network topology (dashed lines are Wi-Fi links)

In this experiment we deployed two LAUV vehicles carrying CTD sensors and the Swordfish ASV. The submarines performed coordinated temperature samplings maneuvers while the ASV performed the task of extending the network range using a communications gateway. The vehicles and the base station (consisting of three laptop computers, a power generator and a communications gateway) were deployed close to the Tapada do Outeiro outfall in the Douro River in Portugal. This outfall creates a plume which is basically characterized by the temperature field. Prior to the deployment, the map of the environment and planned surveys were created using the Neptus software which provides the domain awareness required for coordination.

All three operators were able to follow the vehicles deployment in real-time and also communicate with the LAUVs while operating at the surface. After the execution of each plan, the operator uploaded the logs to a central server which allowed the remaining operators to revise data from other vehicles. Data revision was carried out with the help of the Neptus Mission Review and Analysis which eases the comprehension of large data-sets

We are planning demonstrations of cooperating air and ocean going vehicle systems which will take place in Portugal in collaboration with the Portuguese Navy and Air Force.

There are several obstacles to the practical deployment of unmanned vehicle systems. This state of affairs should not prevent us from deploying them. On the contrary, we are learning important lessons from our deployments. These may prove invaluable for the development of legal frameworks, standards and concepts of operation.

Currently, there are no legal frameworks to encompass the operation of unmanned vehicles. In most countries the operation of air vehicles in controlled air space is severely restricted. Efforts are underway to address this problem in some European countries and in the United States. The operation of unmanned ocean going vehicles also presents legal challenges. The Society for Underwater Technology published a recommended code of practice and has published reports on this topic since the last decade. This legal void precludes practical deployments with ocean-going vehicles. Each deployment is the exception, and not the rule.

The lack of standards for inter-operability prevents users to inter-operate, in a transparent manner, vehicles from different vendors in a network environment. The lack of standards is not unique to inter-operability. Currently there is no standardization in the area of underwater communications. There are several initiatives addressing these issues. NATO has been working on standards for inter-operability, namely the STANAG 4586 which has seen some acceptance in the UAV community. The Joint Architecture for Unmanned Systems (JAUS) is receiving wide acceptance in the military, especially across the Atlantic in the United States. A word of caution is needed here: the existence of standards does not imply standardization.

5. CONCLUSIONS

Networked vehicle systems have the potential to revolutionize environmental field studies and mine warfare. The SeaCon project is one major step in this direction.

By providing an open platform targeted at network operations, the SeaCon systems provide an invaluable tool for the development of new concepts of operation and for the integration of lessons learned from operational deployments in evolutions of these systems. This will contribute to strengthen the national capabilities in unmanned vehicles and to demonstrate these capabilities in unprecedented operations of heterogeneous networked vehicles from different branches of the Portuguese Armed Forces and also from other countries.

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REFERENCES

Dias, P., Gomes R., Pinto, C., Fraga, S., Gonçalves, G., Sousa, J., e Pereira, F. (2006). Mission Planning and Specification in the Neptus Framework. *ICRA2006 IEEE International Conference on Robotics and Automation.* Orlando, Florida, USA.

Pinto, J., Dias, P., Gonçalves, G., Gonçalves, R., Marques, E., Sousa, J., e Pereira F. (2006). Neptus - A Framework to Support a Mission Life Cycle. *MCMC2006, 7th IFAC Conference on Manoeuvring and Control of Marine Craft*, Lisboa, Portugal.

Martins, R., Dias, P., Marques, E., Pinto, J., Sousa, J., Pereira, F. (2009). IMC: A Communication Protocol for Networked Vehicles and Sensors. *IEEE Oceans 2009, Bremen, Germany.*

Fall, K., (2003). A Delay-Tolerant Network Architecture for Challenged Internets. *ACM SIGCOMM 2003, Karlsruhe, Germany.*