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Development of an AUV control architecture based on systems engineering concepts

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A R T I C L E I N F O

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A B S T R A C T

The very nature of a complex system does not allow that a single person be able to master all required competences for its development or operation. Therefore, specialization, team work and coordination are required to achieve the desired goals. In order to assure positive synergy between every participant, system engineering concepts must be taken into account, like development methods, product decomposition, functional classification, design patterns, interface and compatibility assessment, configuration management, technological plans, technical standards, integration policies, system commissioning and validation. These systems engineering concepts are shown in the presented work through the development of a fully functional AUV system and control architecture. The control system and its components are properly described and compared against other state of the art architectures. It is also shown that it was possible to sustain the project development tasks among many successive group or generation of students, demonstrating the benefits of the proposed engineering methods. The proposed system was tested in field tests of the AUV during an oceanographic mission.

1. Introduction

Research institutions working with complex systems typically have developed informal rules to allow parallel work of many researchers, and assure positive synergy between co-workers. Those rules are an essential part of the intellectual capital of the institution, yet they are typically neglected in the academic world, which focus on the physical phenomena themselves. Therefore, new departments or new institutions may face research continuity problems regardless of the academic excellence of the participants, because they do not know how to organize the institutional work to achieve wider and permanent goals.

Similar problems are faced by other institutions developing complex systems, like NASA, which published its Systems Engineering Handbook (NASA, 2007). This publication provides general definitions, best practices, guidelines and alternative approaches in product development, especially for long-lasting life cycles, with many intermediary milestones. In parallel, the Software Engineering Institute (CMMI, 2010) proposes a framework of tools, to improve product development and predictability of results. For questions related to safety, the generic IEC 61508 standard also discuss some important concepts that should be considered.

A number of works have presented control architectures for mobile robots in general, that influenced also the AUV embedded system design. In many cases, the architecture main characteristic is rooted on some artificial intelligence paradigm, such as the deliberative approach (Nilsson, 1969; Bowen et al., 1990), reactive or behaviour-based control (Brooks, 1986; Kumar and Stover, 2000; Bellinghamet al, 1994), and other approaches biologically inspired (Arkin, 1990). More recently, hybrid approaches, combining deliberative and reactive control applications are becoming usual in the robotics community (Gat, 1998; Brutzman et al., 1998; Valavanis et al., 1997; Palomeras et al., 2012; Sheikh et al., 2014; Ranganathan et al., 2001; Goldberg, 2011; Müller, 1996).

On the other hand, with the advance of computer science, hardware resources, software tools and frameworks, the focus on organization of software with possibilities to combine the different paradigms (Hewitt and Inman, 1991; Kim and Yuh, 2004; Amianti and de Barros, 2008;

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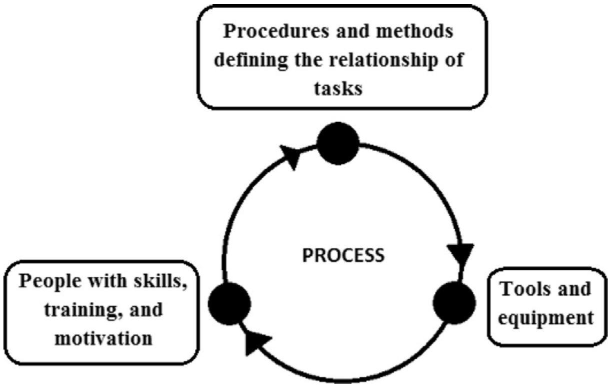


Fig. 1. Components of a generic project (CMMI, 2010).

Eickstedt et al; Chitre, 2008) has becoming dominant specially in the case of service robots.

Inspired by state of art methods in systems engineering (NASA, 2007; CMMI, 2010), this paper presents an AUV control architecture, which took into account unforeseen requirements, beyond the main scientific and technical aspects, such as, the need to master project costs and delays, the understanding and workarounds when dealing with local market constraints, safety requirements, and also the workforce availability and continuity. Systems engineering approach, and software development standards are applied to develop a field robot in the university environment. This AUV has been applied to oceanographic missions.

As seen in CMMI (CMMI, 2010), there are three critical dimensions that organizations typically focus on: people, tools and equipment, and procedures and methods. Tools are products and equipment used by the people to execute their work. They can be: physical spaces - like rooms and workbenches, equipment - like workstations, servers and instruments, or software tools - like integrated development environment (IDE) for computer programming. Of course, tools require qualified personnel for their proper use. Procedures and methods result from the academic work, embracing theories and other scientific data, used to predict results, like Newton's mechanical laws. Of course, in the scope of a project, methods need to be applied by people mastering them.

These three dimensions are connected altogether through a process (Fig. 1). Process is the set of rules people follow during the project. Most typically a process describes "who" does "what" and "when". CMMI (CMMI, 2010) states "process definition" as a measure of maturity for an institution.

This work advocates that researchers and engineers should share in their articles not only their methods and tools but also the process, because of its importance. Going ahead, it may be stated that process and methods are more relevant, and potentially more permanent, than the tools, as the tools evolve very quickly and may be particular for some place in the world. On the other hand, a valid process may probably be applied everywhere and anytime in the world, as the human nature is almost the same, except for some particular law or culture.

In the last 20 years, AUVs have gained an important economical place. They offer advantages such as the ability to act as platforms that can use survey sensors close enough to the seabed, thereby obtaining high-quality results, free from surface and ship noises. In addition, they are unconstrained, since they do not need to be connected to a ship-borne power supply, not even requiring the control of an operator. For some applications they offer great increases in cost effectiveness and true 'force multiplication', for the military and financial leverage for all sectors.

Given the multidisciplinary nature of designing AUVs, and its increasing complexity, this theme should be considered as a systems engineering activity, even for small vehicles developed by universities. There are, at least, problems from mechanical engineering (pressure resistant vessels, seals), naval engineering (arrangement, hydrodynamics and propulsion), electrical engineering (actuators, energy supply, energy storage, embedded electronics, electromagnetic compatibility and interference), computer engineering (processor architecture, memory, buses), telecommunication engineering (telemetry and on-board

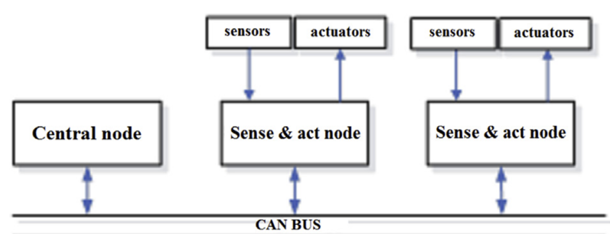
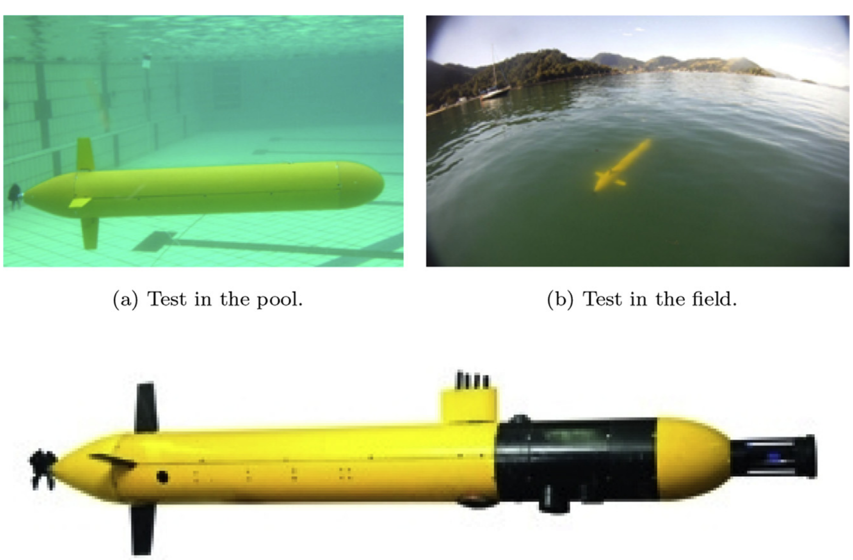


Fig. 3. General physical architecture.



(a) Test in the pool.

(b) Test in the field.

(c) Oceanographic version.

Fig. 2. Pirajuba AUV.