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A framework for knowledge creation based on M2M systems for the creation of flexible training environments for specific concepts in control

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Abstract

This paper presents the strategies and technological tools used to design a framework for knowledge creation for the course "Analysis of Dynamic Systems" of undergraduate program at District University Francisco José de Caldas with using of active learning methods. The key feature of the course is the use of OpenRRArch (Open, Robust and Reliable Architecture for the control of autonomous agents). It is an architecture developed for the design of collective systems that embodies the principles of multi-agent distributed systems (robustness through high redundancy), open (hardware and software open-source), minimalist and easy integration (simple and identical agents). The purpose of this architecture is to allow the control of industrial processes using machine-to-machine (M2M) communication. This physical layer of the framework is integrated into a knowledge-building layer to form an active learning system. Results of the course implementation have shown a high level of students training and improvement of their professional skills.

Keywords: distributed systems, dynamic systems, inductive teaching, problem-based learning, significant learning

1 Introduction

Active learning is defined as a teaching method that directly involves learners in the learning process, under the assumption that this immersion makes learning activities more meaningful and generate more understanding [7, 1]. This strategy is contrary to traditional engineering training techniques, which tend to focus on the educator (the teacher should organizing the knowledge, selecting the topics and develop the necessary strategies to enable the student learning processes).

Broadly speaking, a process of active learning is characterized by being learner-centered. In this type of process the learners participate directly in activities that promote the analysis, synthesis and evaluation of the class content. There are many active learning strategies that involve different activities, one of which is Problem-Based Learning (PBL) [11, 5, 13, 6].

The positive impact of these techniques at the cognitive, motivational and emotional levels on the learner has been widely documented [4, 12, 17]. Moreover, in principle, active learning improves understanding of concepts, improves thoughts and links between different topics, increases practical skills, and activates other related cognitive functions.

The main idea of the work presented in this paper relates to the implementation of a framework designed for active learning of distributed control schemes. Main targets of such a work are as follows:

- Increase learners' expectations for course and control.
- Bring apprentices closer to designing real control schemes.
- Allow and encourage creativity in the design of control schemes.
- Adapt the learning process to learners' learning models.
- Increase the consolidation of concepts and their relationship with other fields of study.

In particular, we present OpenRRArch (Open, Robust and Reliable Architecture for the control of autonomous agents). This is a system developed specifically for the learning of distributed control schemes, embodying the principles of multi-agent systems (robustness through high redundancy), open (hardware and software open-source), minimalist and easy integration (simple and identical agents). The purpose of this architecture is to allow, among other functions, the control of autonomous modules, and the coordination of sensors/actuators and processing units with M2M communication capability. This architecture, however, can be used in other types of systems with similar configurations, as in the case of wireless sensor networks [8, 10].

Other important features incorporated into the proposed architecture include high performance in both hardware and software. In hardware, special care is taken in energy consumption [3], to the IP-WSN communication scheme (protocol for the interconnection between IP networks, and wireless sensor networks) [8], and the resources available in the agents [9]. In terms of software, we seek to facilitate the construction of data collections [3], the use of specific agents for the collection of information [2], the easy interaction between agents [16], and simplify the communication architecture [14, 15, 18]. The architecture as such presents a modular structure designed by layers, which allows isolating specific problems during the design stage.

The paper is organized as follows. In Section 2 objectives pursued with the use of PBL are discussed, Section 3 describes the learning strategies used with the group of students. Section 4 Shows the characteristics of the industrial plant used in the performance tests. Section 5 introduces some results obtained with a group of students. Section Finally, conclusion and discussion are presented in section 6.

2 Objectives

With the intention of linking the learner to the design of distributed control schemes, we structure a design platform for distributed control strategies with industrial standard. This platform is supported in embedded agents, with modular structure and layers, allowing a transparent implementation.

The layered structure must be able to separate and implement different functions at different levels according to the level of performance required. In addition, the communication system must be efficient, backed by an easy-to-implement but reliable protocol. The elements to integrate in this architecture are:

1. An M2M communication link between all agents under some standard protocol. This protocol must be easy to implement at the hardware level on any embedded device (microcontrollers, CPLDs, FPGAs, DSPs, ARM and x86 processors) over wireless links. These characteristics are expected in applications where short messages are transmitted for short periods of time.

2. Easy connection to this communication scheme by all embedded modules of the multi-agent system. Each module of the system is, besides a communication element, a control node with capacity for sensing, processing and actuation. These make up the lowest layer at the control level, and in fact execute direct control algorithms. Since the processing capacity is limited, it is expected that the communication scheme will not consume its resources.

3. A top control layer supported in the convergence of the control algorithm, which is reflected in the behavior of the system (of all modules as a whole). Although in general terms a central control unit is not expected given the nature of the multi-agent system, the architecture should allow the inclusion of embedded modules with greater processing capacity to coordinate communication. These modules should also play the role of data collection constructors (and thus be easily integrated into an IoT environment), and high-level information sensing/processing (intelligent sensors from image or sound processing, for example). They may also have a more complex operating algorithm that affects the overall behavior of the system.

3 System architecture

The architecture of the framework is structured on two functional layers: 1) A layer of knowledge construction, focused on the process by which the learner shapes concepts and skills (visible directly from the learner's perspective), and 2) A layer of technological tools, focused on the physical technology used as a medium for the development of specific skills (visible directly from the educator's perspective).

The knowledge construction layer is formed around three ontologies: 1) Learner ontology, 2) Teaching strategy ontology, and 3) Industrial processes ontology (Fig. 1). Each one of them establishes necessary conditions and characteristics that must be fulfilled by the others, thus conforming the conditions of the system. The learner defines the conditions of the control problem based on the needs of the industrial plant, and according to the design conditions imposed by the teacher. The teacher defines the design conditions according to the previous performance of the trainees and the requirements of the course.

The technological tools layer is organized horizontally according to the processing capacity of the modules, and vertically according to their function in the system (Fig. 2). The system allows a large number of modules in both the low control level and the high control level. However, it is normal to have a single broker module at this last level (and, in fact, there must be at least one). If more high-level control modules are included, they are connected to the system as MQTT (MQ Telemetry Transport) clients. The only elements that are optional in the architecture are the terminals, which are used to visualize system variables.

In terms of functionality, the architecture distinguishes two layers: the communication layer and the application layer. The first one is supported in the MQTT standard. This is an ISO standard (ISO/IEC PRF 20922) supported on a very lightweight messaging protocol that operates with subscription-publishing methods. It is designed for TCP/IP (Transmission Control Protocol/Internet Protocol) network control applications that require a small implementation code, such as embedded hardware. The protocol requires a broker, which distributes

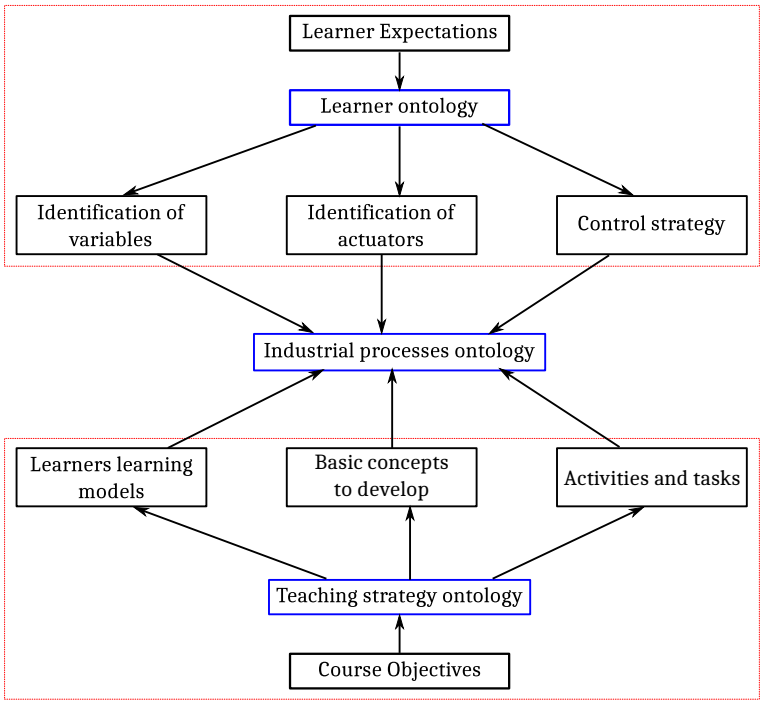

Figure 1: Architecture of the layer of knowledge construction.

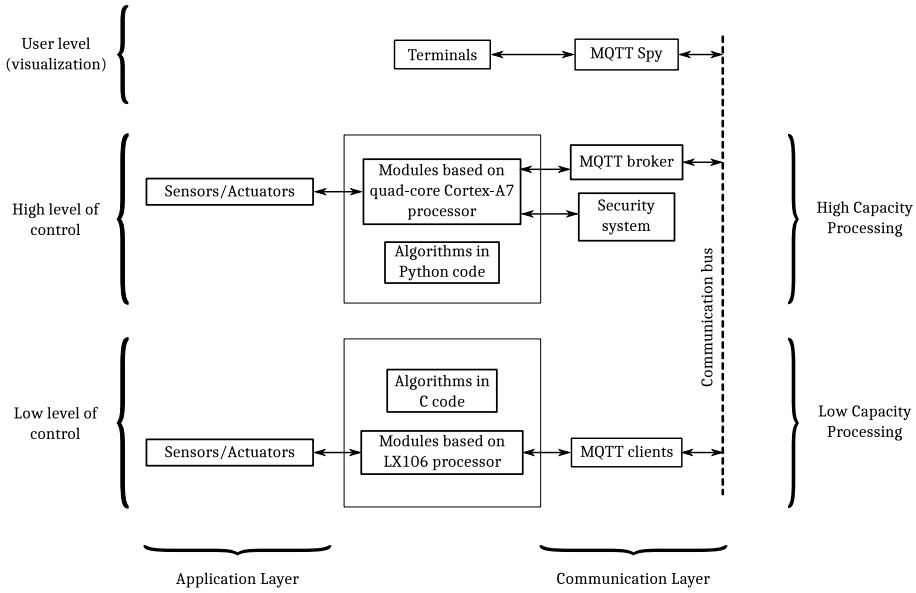

Figure 2: Architecture of the layer of technological tools.

the messages in the network, and in the case of Fig. 1 is implemented in a Debian Linux OS on a H3 Quad-core Cortex-A7 platform with Mali400MP2 GPU. To this broker subscribes and publishes all the other modules of the system as clients. The communication scheme used is M2M, so that each module can communicate directly with any other module of the system (as long as they are within range of the router).

The application layer includes the set of sensors and actuators connected to the different modules of the system. In the test documented in this paper, the broker has an optical sensor (digital camera) that is used to identify from images the content of oxygen in a flame. The image processing code was written in Python with OpenCV support. Other modules were also implemented on microcontroller platforms (with the microcontroller LX106), these modules were equipped with temperature, rotation and distance sensors. All modules have antennas and the ability to connect to the WiFi network.

The implementation of the algorithms in both types of modules is quite simple. The LX106 microcontroller runs the codes much faster than the Cortex-A7 platform. Python is interpreted, and the capture and processing of images is much slower than the reading of analog signals. However, this is not of importance in the application due to the delay in the action of the plant (large carbonization furnaces).

4 System for learning: Carbonization of vegetable waste

The industrial plant for the implementation of the system belongs to Tecsol Industries Limited. It is a prototype process for the thermal treatment of vegetable waste in order to produce activated carbon for industrial applications. Key elements of this process are two furnaces with demands critical control of temperature (500 and 800 degrees Celsius respectively) and control of oxygen in the flame. Other important elements in the process are the filling of feed hoppers of material and supervision of the whole process.

Access to the plant was carried out by a small group of undergraduate students in the electrical area as part of their training in applied research.

5 Results

The preliminary evaluation of the proposed system was carried out in two phases. The first phase through the implementation of three expecialized laboratory works. The first task focused on the communication layer, that is, on the definition and implementation of the system communication bus. The second task focused on the physical layer, specifically on the identification and sensing of system state variables. The last task was focused on the development and implementation of the plant control algorithm. Throughout these three tasks students were presented with the basic theoretical elements necessary to investigate and propose solution schemes. All the proposals were discussed with the faculty and engineers of the industrial plant in order to correct and define the work proposals. After completing the laboratory tests, students prepare technical development reports. These reports contain all the details of the project implementation task by task.

The second phase of the evaluation of the system sought to establish the perception of learners about the potential role that OpenRRArch has and the proposed scheme of work for training. The apprentices used the framework for about six months, and at the end of this period a survey was applied with questions related to the implementation of the system and its use in general. The results of this survey are shown in Fig. 3.

	Question	Overall grade (Maximum value = 5.0)
1	Do you consider the use of the system important?	4.8
2	Do you consider that the system improves learning?	4.4
3	Do you think the system motivated you in any way?	4.6
4	Do you think it can be used in other courses?	3.6
5	Would you have had less work without the system?	4.7
6	Use of the system must be permanent?	3.8

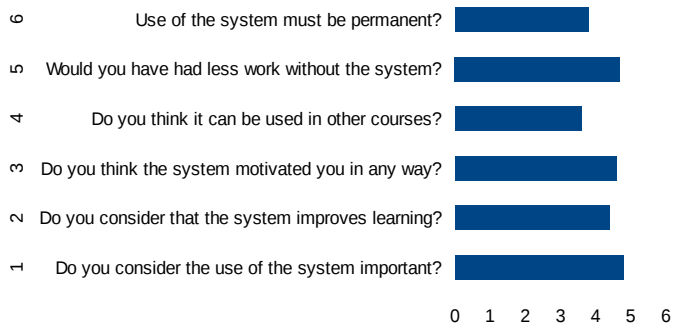

Figure 3: Student survey agreement analysis.

The results of the survey show strong agreement on all questions. Students mostly support the use of the system and see a great improvement in the learning process in flexibility and performance.

6 Conclusions

The paper proposes a distributed architecture for the implementation of multi-agent systems called OpenRRArch. This architecture is intended to be used as an active learning tool in specialized training in distributed control systems. As design criteria we consider the use of open source hardware and software tools as well as robustness, scalability and reliability characteristics. OpenRRArch enables fast, low-cost, high-performance implementation of systems with real-time cooperation and communication capabilities. The architecture allows the integration of agents with different processing capabilities, which allows adaptation to the needs of the task. The functions of each of the agents can be reduced or increased from their code, and/or by selecting other embedded hardware. Laboratory tests determined that learners are motivated by the tool, and think positively about their widespread use.

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