Architecture for Multiagent-Based Control Systems

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Abstract. This paper presents a multiagent architecture that covers the new requirements for the new control systems such as the distribution and decentralisation of system elements, the definition of communications between these elements, the fast adaptation in the control and organizational changes. The agents in this architecture can cooperate and coordinate to achieve a global goal, encapsulate the hardware interfaces and make the control system easily adapt to different requirements through configuration. Finally, the proposed architecture is applied to a control system of a solar power plant, obtaining a preliminary system that achieve the goals of simplicity, scalability, flexibility and optimization of communications system.

1 Introduction

The control systems have evolved to a complex system that employs more and more equipment and sensors. The hardware diversity of the sensors and actuators greatly affects the portability of the control system and the complexity may differ from each other. A goal of control systems is to enable the integration of different types of devices in a scalable and flexible system. The problem is how communications among the different parts of the system is organised and optimized [1]. To resolve problems in the control system it is necessary have knowledge and experience working in the field. In this paper, the solutions to control problems will be the responsibility of different agents in the system. The agents should handle the problem domain knowledge and be able to communicate this knowledge in order to provide efficient solutions and recommendations. An architecture is proposed that presents an organizational scheme of agents and a global communication protocol. The architecture was constructed to support a wide range of control systems; however, this paper focuses on its application in the control of a solar power plant.

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It has a distributed input-output agent architecture to accomodate the changing requirements. This distributed intelligent agent architecture provides flexible and scalable ways to integrate the different sensors and actuators. The design goal is to create a system architecture that is general enough to support many different kinds of sensors and actuators, while being distributed and scalable.

Finally, to illustrate the application of the architecture, an example system is built (a solar power plant control system). This preliminary implementation of system gives an idea of the spread of knowledge flows in multiagent-based control systems. The spread of this knowledge in the system will not be free since it is determined by the architecture of the system.

2 Problem Domain

The problem discussed here belongs to the field of distributed control systems. An introduction to the subject and issues can be found at [3], [8]. Control systems based on the theory of multiagents, and restricted to specific domains have been developed. For instance, one of the early works by Junpu et al. [7] discusses the feasibility of agent-based distributed hierarchical intelligent control. Another study [5] examines the modeling of multiagent control for energy infrastructures that presents an agent-based control system for distributed energy resources in low voltage power grids.

Other important aspect that is discussed here concerns the spread of knowledge in control systems based on multiagents. In [4] the study of knowledge transfer and action restriction among agents in multiagent systems founded on the definition of patterns of dialogues between groups of agents, are expressed as protocols. This paper is focused in the organization of the elements of the system and the flow of information within the system, with the aim of creating a simple and optimized model.

Finally, the aim is to build a remote and automatic control system for a solar power plant (CARISMA Project) through the use of multi-agent technology, where a set of performance areas controlled by a variable number of agents is defined in the system. These areas will cover some agents assigned to allow coordination among areas, with the purpose of making joint control actions on different areas. This system should be simple and streamline communications, as well as being flexible and robust.

3 Architecture Proposal

It is proposed an architecture divided into three layers looking to optimize the number of messages sent through the network to communicate knowledge and to establish a structure that allows some agents to perform certain recommendations or make decisions based on knowledge dispersed over different parts of the network. Figure 1 shows a diagram of the architecture.

As shown in figure 1, the first layer, called the *input layer* comprises all agents that allow for the entry of new knowledge in the system introduced by a user or generate changes in the knowledge base of the system from information sent by lower layer agents. The number of agents that may belong to this layer is not limited, but the simplest is formed by a single agent (decisions and recommendations centralized generator). The agents of this layer only communicate with the agents of intermediate layers, but allow direct communication with final layer agents when the response speed requirements are high (ocasionally).

The *middle layer* comprises all agents that have the ability to generate decisions or recommendations based on knowledge acquired from different points or areas of the multi-agent system and coordinate the agents belonging to lower layers. This layer can be subdivided into many middle layers as desired, allowing for scale and creating a hierarchy multiagent system for decision or recommendation generation. The number of agents in this layer is not limited. It is usually a number greater than one and less than the number of agents of the bottom layer that controls. In the communication level, the agents of this layer are able to coordinate (horizontal comunication) and disseminate knowledge in the layers in both directions (upper-layer and lower-layer).

The *final layer* comprises all terminal agents that have the ability to obtain environmental data or act on it. The number of agents in this layer is not limited, it is usually a number greater than the nummbers in the rest of layers. These agents can be organized into zones or regions of coverage controlled by a set of agents from the upper layer. The agents of this layer only communicate with the agents of the intermediate layers, but allow direct communication with agents from the input layer when the response time requirements are high (ocasionally).

3.1 Architecture Overview

A general system architecture is proposed that is composed of four types of agents: Teleoperator Agent (TA), Coordinator Agent (CA), Operator Agent (OA) and Device Agent (DA). This architecture is the basis of the CARISMA project. The number of coordinator, operator and device agents is free (specified in the configuration of the system), while there is only one teleoperator agent. The network can expand or shrink according to the number of the solar power plants and the complexity of the control system. The architecture of individual agents is based on the paradigm

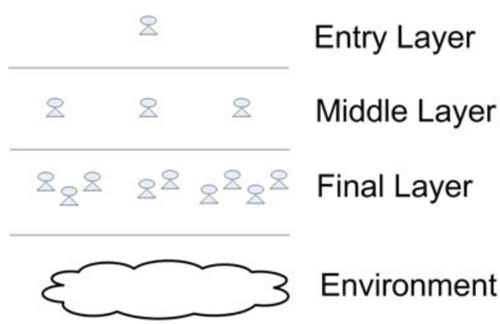

Fig. 1 Our model proposes the organization of a multiagent system in at least three layers. This is in the capabilities knowledge management and communication with agents (the fact that an agent belongs to one layer or another will depend primarily on the behaviors that it implements).

Belief-Desire-Intention [2]. An example of the network topology including the three zones is shown in figure 2.

The Teleoperator Agent is the entry point into the system, providing a user interface that allows configuration, deployment and knowledge input to the platform. The main responsabilities of the TA are to:

- Define the hosts that make up the platform, and define the CAs and OAs and also define the areas
- Register agents in the corresponding hosts and areas
- Generate the specific DAs for the sensors and actuators to be controlled and their asociation with the corresponding OA
- Provide user GUIs and interfaces to manage the configuration
- See agent status and view data acquired by sensors
- Introduce new knowledge (insert, modify or delete rules, concepts, predicates and actions)

The Coordinator Agents goals are to coordinate global solutions for a state of failure or alarm detected from multiple points in different areas. The main responsibilities of the CAs are to:

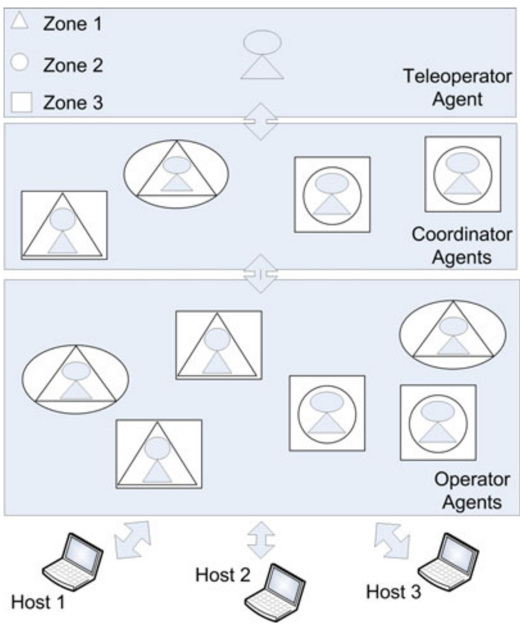

Fig. 2 Communication among agents is restricted: TA can communicate with any agent of the system (and vice versa), while CAs and OAs will have specific information about what other agents they can communicate with. The DAs may only communicate with the OA to which they are assigned. This configuration allows us to define flexible areas, by supporting different communication channels among agents living in the system, which can lead to the possibility of overlapping in these areas.

- Control the OAs in their area
- Manage the different rules of global action
- Coordinate with the TA to give advice or solutions in a global alarm
- Serve as an intermediate point of communication of new knowledge among the TA and OAs

The Operator Agents are responsible for controlling the various DAs, and if they detect failures or local alarms in accordance with information received from the DAs, they communicate them to the rest of the system.An example of communication among OAs and DAs is shown in figure 3. The main responsibilities of the OAs are to:

- Obtain data and comunicate operation commands to DAs that have allocated
- Detect local fails or alarms
- Perform direct actions to address failures in case has the necessary knowledge
- Communicate recommendations to other agents

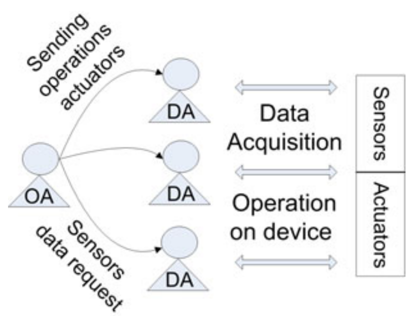

Fig. 3 The Dispositive Agents are hybrid agents (Cognitive and Reactive), that have the ability to alert the OA or act directly in case of changes in the state of a device. Each DA will have a concrete implementation intended to obtain data from a particular sensor or perform actions on a given actuator.

In terms of hardware, there are no restrictions on the number or type agents that can reside in a device or style of devices that compose the system, but these have to be capable of computation. Generally, the agent node device consists of an embedded system with support for various transmission technologies (RF, Ethernet, Bluetooth, ...). One agent node is attached various sensors and actuator devices. The sensors include thermal sensors, humidity sensors, CO2 sensors, sensors for signal from solar plant appliances and various intelligent meters such as solar irradiation and video control [6]. The attached actuators include various valves, motors, and switchers for heating system, ventilation, humidity control, screen control, etc.

3.2 Knowledge Spreading in the Agents Network

Another important aspect to consider in a multiagent system is the spread of knowledge (represented by ontologies, [10]) in the system. As shown in Figure 4 the possibilities that can be implemented using expert systems [11] are:

(A) Communication of new knowledge by a human user, or propagation of an action in the system from a global knowledge of system.

(B) Communication of local knowledge: In this case, knowledge spreads from the final agents to agents of the *middle layer* or *input layer*. In the latter case, the spread is usually done through the middle layer, and it can be performed directly among agents from the final layer and the input layer (dotted lines) if response time requirements are high.

(C) Communication of knowledge to the input layer or final layer by an agent of the middle layer, from a partial knowledge of the system.

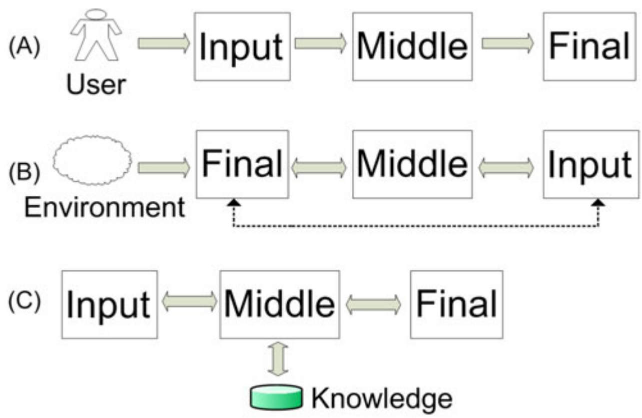

Fig. 4 The different possibilities of the communication flow modeled, according to the source of knowledge to be communicated

4 Implementation

When applying the architecture proposed in section 3, an automatic control and decision support system which is very simple, reliable and scalable can be implemented. For instance, figure 5 shows an example of spreading knowledge in CARISMA, for the B case seen in figure 4 (generation of knowledge in the final layer).

Note that information travels in phases throughout the system and if the necessary knowledge is not available, then a human is requested. This allows for the optimization of the information or knowledge exchanged in the system, and easily increases the knowledge base of system, with scalability.

4.1 First Results

From exposed architecture, a preliminary implementation of the system CARISMA has been carried out. This implementation was performed using the JADE development platform [9] and using hardware devices such as embedded systems and

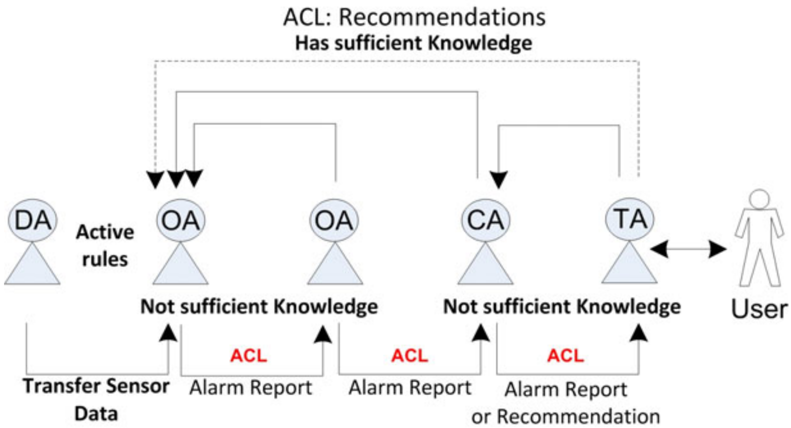

Fig. 5 OAs and DA are in the final layer of the system. CA represents the middle layer and TA of the input layer.

PCs. The base case system developed is composed of 19 agents (among AOs, ACs, ADs and AT) distributed in four areas. The first significant results obtained were: (A) Simple system design, (B) Short implementation time (less than two months), (C) Main features of the control system were covered, based only on the premises exposed architecture, (D) The initial knowledge base of multi-agent system was extended in a quick and easy way by a user without programming knowledge or agents.

5 Conclusions

Traditionally, control systems have had difficulties as far as their design because they must meet high requirements. Using our model of architecture in the design of a multiagent-based control system, we can obtain many benefits, such as simplicity. Based on the organization of agents in layers exposed, we can easily program control systems. Other problems in control systems are scalability and flexibility: this architecture does not limit the number and types of agents and inclusion / exclusion of layers is possible. It also allows for dynamic configurability, so we can dynamically change parts of the system since agents can move from one layer to another, or new types of agents can be added. It is even possible to dinamically add new layers with certain restrictions, only by changing the behavior of agents.

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