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Integration in industrial automation based on multi-agent systems using cultural algorithms for optimizing the coordination mechanisms

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ABSTRACT

Integration in industrial automation can be approached from the theory of Distributed Artificial Intelligence. One approach is the modeling of different production units by agents that interact through interaction protocols, which are implemented following a coordination mechanism. Under this approach, integration in automation can be achieved through the optimization of implicit interactions in such mechanisms. This paper presents a strategy for integrating industrial processes based on Multi-Agent Systems (MAS), which consists of optimizing coordination mechanisms that implement conversations between agents, by using cultural algorithms. The cultural algorithm uses formal models of interaction protocols between agents, such as auction and tender, and the integration scheme comes from automation architectures based on MAS, to which their interactions are optimized. The proposed scheme enables data and service-oriented integration. The proposed strategy is applied in two industrial case studies related to the oil production process.

1. Introduction

The trend of automated systems is toward distributed architectures, whose heterogeneous components of software and hardware interact among them, seeking to achieve common goals that optimize the process performance. In this context, the integration of different existing technologies in industrial environments has become a key factor in the production process, and particularly, in the automation strategies of these processes [1]. Fundamentally, the integration is based on the development of models for the information exchange, the cooperation and the common data representation, to coordinate and implement actions or objectives. A definition of integration proposed in [1] is "the coordination of the operations of all company elements working together, to achieve an optimal compliance of the company mission".

There are two major approaches to system integration architectures: data-oriented integration (DOI) and service-oriented integration (SOI). DOI involves combining data that reside at different sources and platforms. DOI provides the users a unified view of such data [2]. SOI flexibly handles the problems associated with heterogeneous and legacy systems, enabling the organizations to offer existing applications as reusable services [3].

SOI is defined in [4] as the integration of computational entities using services based on service-oriented architecture (SOA). SOA is a software architecture based on software components, which provide functionality to applications as services. A service is an autonomous logical representation of a repeatable function or activity [4]. Several works address the combination of the paradigms of agents and services. In [5] the services are used to provide a generic scheme of interaction between agents. In [6], an extension of Web Services (WS) is proposed through an integration tool called WS2JADE, to manage the WS that are framed by the FIPA standards for MAS. One approach for integration in industrial automation is the definition of architectures based on service-oriented MAS.

Other works state that MAS is one of the approaches for orchestrating of integrated automation activities, through distributed architectures that implement the required services at different levels of automation [5–13]. Having as reference agent-based automation architectures, such as those ones in the works presented previously, the integration can be accomplished in a

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vertical or horizontal manner. Vertical integration is the flow of decisions/actions between components that are in different levels of the architecture, and the feedback derived from the same flow (inter-level flow). Horizontal integration arises due to the flow of products and information in the same architecture level (intra-level flow). In vertical integration, the decision management occurs in a hierarchical architecture where the different functions of the company are associated with a hierarchy. In horizontal integration, different components in the same level perform complementary activities, without requiring information units of other level [1].

Through a suitable multi-agent modeling, which implements the basic functionalities of an industrial automation system as services, it is possible to achieve the expected integration through the coordination of agent interactions.

Recently, a system based on cultural algorithms (CA) [14] has been developed to address the coordination of MAS from the perspective of the collective learning approach [15]. The collective or distributed learning is carried out by groups of agents (e.g., by sharing knowledge, or by observing other agents) [15]. One of the most common coordination mechanism in the literature is the negotiation, and its interaction protocols are auction and tender [16]. Their representations in formal mathematical models are presented in [17], where each conversation between groups of agents is implemented through the combination of protocols properly selected and instantiated by a CA. MAS's agents learn to discern the most convenient coordination mechanism for a conversation, through a cultural model. In [18], the learning model based on CA is called model of cultural learning, and it aims to optimize interaction protocols, in which the speech acts are performed in order to achieve the coordination of interactions between agents.

In this paper, we use the formalism presented in [15,17,18], to optimize the coordination mechanisms of the conversations in MAS that are modelling industrial automation systems, as an integrating strategy of automated environment. This strategy allows the integration of the services provided by agents and the resource management for the development of activities, which includes the utilization of data shared between all agents. Thus, by optimizing the coordination mechanisms in the conversations of the different agents at different levels of abstraction, a better integration between them is guaranteed for the development of industrial activities. In this sense, the services of industrial automation offered by the agents are executed during the conversations, with proper interaction protocols which are selected by an optimization process using CA. This allows performing different forms of integration (horizontal and vertical, oriented to data and services), based on the coordination of interactions between agents.

Our work is based on known ideas about MAS modeling for automation, which are properly used to construct our contribution. The interactions between agents, i.e. conversations, to accomplish the activities and tasks in the corresponding automation process, are described through coordination and communication models, and the set of conversations determines the coordination scheme of the MAS. In our knowledge, there are not researches widely reported that propose the optimization of MAS coordination from the perspective of collective learning, where processing and communication costs are the main aspects to consider for real time implementations, such as the applications in industrial automation. We only need the specification of the interaction type characterizing in a general manner the communicative acts between agents, how many agents are assumed to implement the service, and the variables describing the processing and communication costs. Consequently, our approach avoids the necessity of having empirical data for validating our optimization approach.

Particularly, our optimization model is based on an evolutionary algorithm working off-line, which evaluates different interaction protocols among the agents, in each algorithm's iteration. One conversation can have several interaction protocols, for each communicative act between agents in such conversation. As a consequence, in each algorithm's iteration, our approach proposes and evaluates different coordination schemes for the same MAS, and the most convenient scheme regarding some objective function is considered as a belief by all the agents in the MAS.

The main contributions of our paper are summarized as follows: (i) The generic modeling of the interaction protocols proposed by FIPA, such as auctions and tender, (ii) The modeling of vertical and horizontal integration in industrial automation through a MAS architecture, using proper conversations as coordination mechanism, (iii) The generic characterization of conversations in any MAS by defining types of interaction, such as: consult, assign, inform, and request, (iv) The development of a collective learning approach based on a cultural algorithm, which evaluates the best set of interaction protocols for implementing the generic types of interaction in the conversations of a MAS, as a way to reach data and service oriented integration in industrial automation tasks.

This paper is organized as follows. Section 2 presents a review of recent results about the use of MAS oriented to services and their coordination, applied to industrial automation. Section 3 describes the optimization model using CA for coordination of the conversations in MAS, which requires the characterization of the interaction types (IT), and uses formal models of the interaction protocols, such as auction and tender. Section 4 proposes the automation integration approach based on coordination of MAS, and several general premises are presented for the integration under automation architectures using MAS. Section 5 shows two case studies to test the proposed integration approach, and discusses a comparative table between our approach and integration models proposed in other works. Finally, Section 6 presents the conclusions.

2. MAS, services and coordination in automation architectures for industrial applications

The use of MAS and WS in industrial automation applications have been reported in the literature, where service-oriented architectures supported by MAS have been defined. The work in [7] points out that the combination of WS and MAS provides a promising computing paradigm for the selection of an efficient service, and the integration of business processes between organizations. In that paper, the goal of WS is to support business collaboration to achieve high-level of distributed and reconfigurable integration. In [8], the production process is seen as a collection of services. The coordination of services, handled by an orchestrator, and the execution of the service sequence, handled by an orchestration engine, is offered by a service-oriented middleware; this middleware also includes a decision support system, which is integrated through MAS for conflict resolution between the orchestrator and the orchestration engine. Finally, to integrate existing legacy MAS applications, messages between agents described by the Agent Communication Language (ACL) are translated to a service-oriented message (WS-ACL) that can be treated by the mentioned middleware. A similar approach, where agents are used for the composition of services by negotiation, is presented in [9]. The integration architecture is a hierarchical structure where the lowest level is the level of services. Each service is modeled as an agent, and the agents negotiate the