International Journal of Advanced Logistics, 2014
Vol. 3, Nos. 1–2, 10–16, http://dx.doi.org/10.1080/2287108X.2014.953625

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MAS-based control in industrial controllers

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The use of Multi-Agent Systems (MAS) in industry is a promising technology that provides agile and flexible solutions to tackle complexity in manufacturing companies. Unfortunately, the use of agents in industrial application is still limited due to their inherent difficulty for implementation and test. This paper presents a way to increase the visibility of MAS sharing information between agents hosted on Programmable Logic Controllers. This information exchange has been modelled using Coloured Petri Nets and implemented on an experimental platform representing the facilities of a local bottling company.

Keywords: industrial control; multi-agent systems; materials handling; coloured Petri Nets

1. Introduction

AN increasing necessity for flexible and reconfigurable solutions is becoming apparent for the coordination between production and distribution. The need for production to adapt to customers requests and the pace in which incoming orders have to be fulfilled, has led to the development and application of new production automation and control paradigms. A promising approach is to consider production entities as a conglomerate of distributed, autonomous, intelligent and reusable units, which operate as a set of collaborating entities [1]. As a result, systems can be formed by collaborative units, that can dynamically interact with each other to achieve both local and global objectives [2]. Following these principles, different approaches have been proposed to define reconfigurable production systems, such as Multi-Agent Systems (MAS) [3], Multi-disciplinary Design Optimization (MDO) [4] and Holonic Manufacturing Systems (HMS) [5].

The aim of the present research is the development of more efficient control and management methodologies, supported by the visibility offered by radio frequency identification (RFID), and focused on its future application in factories with high levels of production and large distribution or logistic centres. As to try different control approaches in a factory under production is impractical, it has been necessary to build an experimental platform, which closely reproduces the facilities of an existing distribution centre, to test these new technologies.

This paper shows implementation details for the lower level of a MAS architecture on Programmable Logic Controllers (PLCs) over the experimental platform of a distribution centre.

The next section will provide some background of the work focusing on the implementation of MAS. A MAS architecture will be described to then use section 4 to present the model that describes a feasible information exchange between PLCs. Finally, some conclusions are extracted from the performance of this model over an experimental platform.

2. State of the art

A multi-agent system (MAS) can be defined as a set of agents that represent the elements of a system, and are capable of interacting in order to achieve their individual goals, even when they do not have enough knowledge and/or skills to achieve individually their objectives [6]. The spreading of the use of multi-agent systems in many research branches lays on the capability of negotiation they offer. This negotiation is usually applied to decision-making problems, and has a heterarchical nature; in other words, there is no central decision entity. This feature allows the distribution of complex systems in small parts, making easier the control of the entire system. Consequently, the main application of agents is the development of distributed systems. Noteworthy literature surveys on MAS applications are [7], focused on continuous industrial processes, and [6], oriented to manufacturing applications. But, obviously, there are also issues

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to overcome for the final adoption of agent structures, such as information integration, the problem of alignment, real world implementation, robustness and deadlocks.

Different studies on decentralized control systems focus on trying to obtain robust and interconnected systems able to cope with uncertainties. In [8] a MAS modifies the process plans and the schedules attending to unforeseen disturbances in the manufacturing system. Gathering and sharing of knowledge gives the key for the integration of the information among planning, control and execution to provide the required alignment. Huang and Wu [9] proposed a multi layer architecture, where a middle layer is in charge of filtering the information and, thus, determining the overall system performance. This way, it is possible to face the myopic behaviour [10] presented by agents, and therefore the un-alignment of the systems. In [11] this problem is faced by combining the multi-agent system with a hierarchical coordination. As has been seen un-alignment is a problem that arises commonly during the performance of multi-agent system.

There are some initiatives for the implementation of MAS in industry. Some of the most representatives are MAST [12], ADACOR [13], JACK [14] or DACS [15]. Another way to implement agents in a very direct and relatively easy way is through defining their beliefs, desires, and intentions (BDI). Nevertheless, the use of agents in industrial application is still limited due to the complexity of the frameworks, making difficult a real-time performing [16]. These solutions require a considerable processing power, memory, and bandwidth. Moreover, it is difficult to find approaches where real-control equipment, as PLCs, is taken into consideration. However, there are some exceptions to this, as is the case of [17], where a solution is proposed for some specific applications.

3. Multi-Agent Architecture

There are some previous manufacturing MAS models as PROSA that allow a common definition of all these customized agents as: products, resources, and orders at the same platform. This is an effective initial approach, but for the fact that, after that, the implementation needs a specialization of the agents and its organization to support interaction with the existing physical machinery and Information and Communications Technology (ICT); customized agents in specialised layers of platforms. Especially poignant is the real-time communication layer with the plant in order to be able to automatically take in account the disturbances for the initial planning. It supposes a great specialization not affordable to be integrated in a unique logic element. This can be achieved because of the adaptability features of the BDI reasoning and the information coming from visibility frameworks. BDI paradigm provides mechanism for separating the activity of selecting a plan and its execution; from Beliefs about the environment to Desires to be obtained and Intentions on how to proceed to get them. The BDI approach allows including different configurations of reasoning depending on specific functional modules: Beliefs, Desires, and Intentions or plans. Therefore, based on this capacity for customization, a division of the manufacturing agent space is proposed that is supported by the customized deliberation capacity of the BDI reasoning and the feedback of the visibility frameworks.

Table 1 details the BDI characteristics of both classes: the physical BDI agent and the IS agents. Inside the physical BDI agents we can find resource and product agents. Resource agents represent elements that tend to manufacture the product: robots, converses, fork-lifts, carts, etc. In fact, this is only a functional division because during the development both types of physical agents include the same software modules. In the physical BDI agents, the beliefs are given and as simple as to simply specify whether the element is ready or busy. The desires of the physical BDI agents are also very straightforward as the objective is to finish processes or operations depending of the policy parameters. Resources take simple desires during the processing of the products; the main objective is to finish the process in time. In the product agent, the desires are to achieve the goal state, which means that the instruction is fully executed. And finally, the intentions of this type of agents are machinery movements or physical actions that can be done as single operations during the plan. Most of them are direct actions that can be performed by a hardware instruction, by a simple activation or by human processing. The physical intentions are specific actions closely related to the desires; they are so simple that can be achieved in only simple instruction; this definition of simple operation correspond with the tasks in operational levels of the Supply Chain Management (SCM).

Table 1. BDI agent classification.

Type of Agent	*IV. Beliefs*	*V. Desires*	*VI. Intentions*
Physical	Fixed	Simple	Low level
Information System	Complex	Flexible	High Level, Composed

Another type of agents can represent the information system elements; these are complex functional components as the Enterprise Resource Planning (ERP), Warehouse Management System (WMS) or Point of Sale (POS). The beliefs of these agents are complex because they are feeding data from several sources: databases, other IT systems, physical elements, human constraints, etc. The desires, which are currently addressed by business intelligent system, are dynamic and flexible; with a high flexible strategy, i.e. the desires/objectives can change frequently. Finally, the intentions are complex, supposing a plan of low-level intentions; they are composed in order to define the tactical decision making level. This definition of IS agents takes in charge of the tactical/strategically operations of the SCM.

For most real applications, it is usual to have agents that can be defined from the two different viewpoints discussed before. Some agents are closely related to the physical world, as they command machinery or moving objects; associated with the reactive agents. While others are more related with management strategies and scheduling, and therefore associated with the deliberative agents. One of the most representative architectures that takes into account this division into two agent types is this MAS-DUO, where the term DUO makes reference to this duality of agents [18].

MAS-DUO proposes two autonomous platforms of agents: a physical platform implemented on the physical elements – these agents get the beliefs from the elements of the plant – and the Information System (I.S.) platform that take the beliefs from the RFID readers or other external information sources. This division makes possible for the physical platform to work in an autonomous way by providing robustness in case of errors or communication failures. Based on the concepts defined in [18], a multi-agent architecture has been designed for its application at the Autolog Platform. The system is structured into two levels: reactive and deliberative (Figure 1).

MASs have the inconvenience of an excessive dependency on the availability and reliability of information. Therefore, they can strongly benefit from the deployment of RFID systems and from PLC Scada systems. Thus, RFID and PLC information technology applied to MASs provides flexibility and intelligent control for its application in production, distribution, storage, etc. Therefore, while the MAS provides on-line control of the system, the PLC network generates and manages updated information.

4. Information flow at the reactive level

Agent-based systems require a straightforward online feedback of data. RFID and PLC data can be applied to fix the well-known problem of the lack of field information in the upper logistics and manufacturing levels. This subsection explains how to integrate product/resources PLC events with MAS and shows the way in which this has been done for our platform. In our platform a specific instruction is generated for each complete pallet movement – from an origin to a destination – that has to take place at the distribution centre (additional details can be found at [19]). This instruction is sent to the PLC network for its execution by the MAS that drives the 3D model forming part of the experimental platform. The PLC network controls the experimental platform over Profibus-DP. The system is composed by six PLCs SIMATIC S7 200 CPU 224 which act as slaves, and a SIMATIC S7 300 CPU 313C-2DP acting as master.

The PLC Master is in charge of collecting the data packets (instructions) coming from the management system and of sending them to the corresponding slave PLC (Figure 2). Additionally, the master is also in charge of collecting messages (instructions at different processing stages) as they are returned by slave PLCs, once their respective parts of the process have been finished, and of redirecting the instructions to the following link in the processing chain (another PLC). Once all execution steps have been processed, the master PLC uses the communication interface to inform the deliberative level about the completion of the instruction (data packets include a status field to report possible incidences). In this way, this master PLC controls and manages the traffic of instructions through the PLC network. Incidentally, for this specific set-up the master PLC is also the link between the virtual I/Os of the PLCs in the network and the interface with the 3D visualization of the simulated plant they have to control.

Figure 2 shows the way in which the master PLC receives and analyses the incoming instructions and sends them to the specific slave PLC within the Profibus DP network.

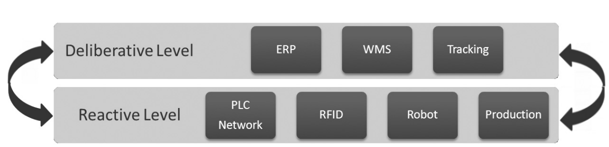

Figure 1. Multi-agent architecture.

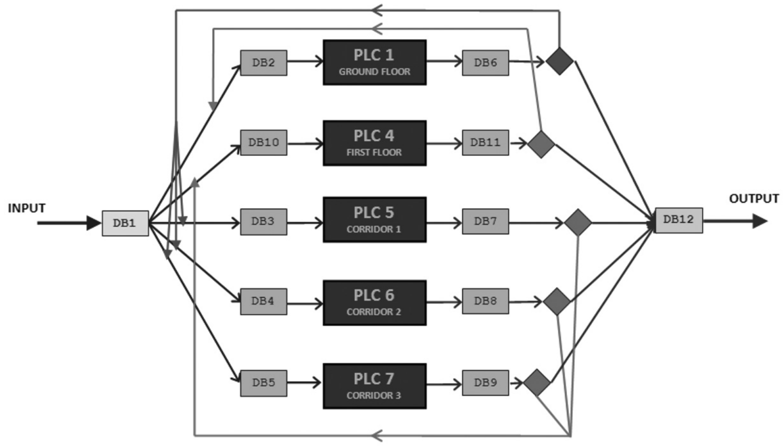

Figure 2. Information flow at the master PLC.

A Coloured Petri Net (CPN) have been used to model the way in which instructions are sent from the S7-300 (master PLC) to the corresponding S7-200 (slave PLCs) as shown in Figure 3. For each master-slave link the model consists of three parts: S7-300, Profibus-DP, and S7-200. The S7-300 part has two transitions, which can *Send Instructions* and *Receive ACKs* (transmission codes for the acknowledgement of a reception). The Profibus-DP network has three transitions which can *Transmit a Request*, *Transmit an Instruction* or *Transmit an ACK*. Finally, the Receiving part has two transitions which can *Process an Instruction* or *Request an Instruction*. The interface between the S7-300 and the Profibus-DP contains places B, C and F (i.e. it can take these states), while the interface between the Profibus-DP and the S7-200 contains places A, D and E.

Incoming instructions arrive from the deliberative level through place "*New*" and before being transmitted through the *Profibus-DP* network they are stored at place "*Send.*" An instruction goes from "*New*" to "*Send*" when the value of the ACK is zero, that is, when there is no pending acknowledgment of reception. An instruction is sent if there is a *Request* from the S7-200 (right-up corner in Figure 3).

Received messages are stored at the place *Process Instruction*. At this point, the incoming instruction is checked to make sure it is different from the last one processed; in which case it is sent to *Received*, where it is stored in the input-job buffer of the S7-200. Then, this S7-200 processes the instruction beginning by checking whether this is a new one through the *LastReceived* place. Any time a new instruction is received, the S7-200 sends and ACK

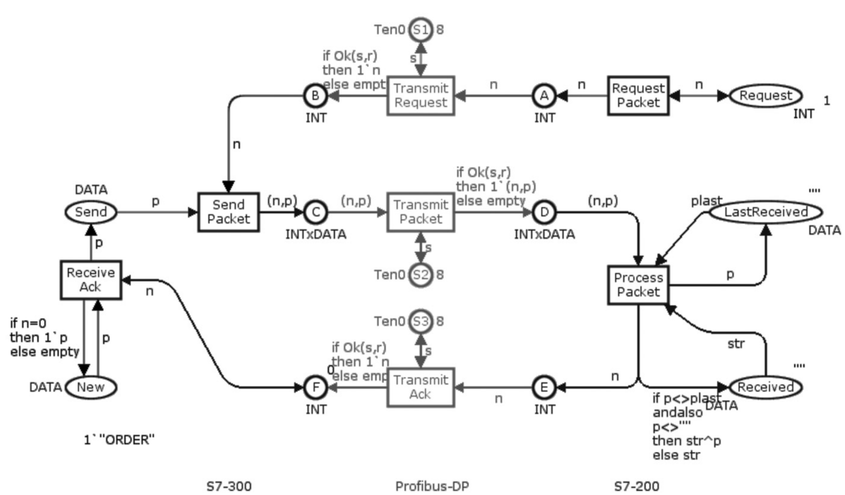

Figure 3. CPN of the communication between PLCs.

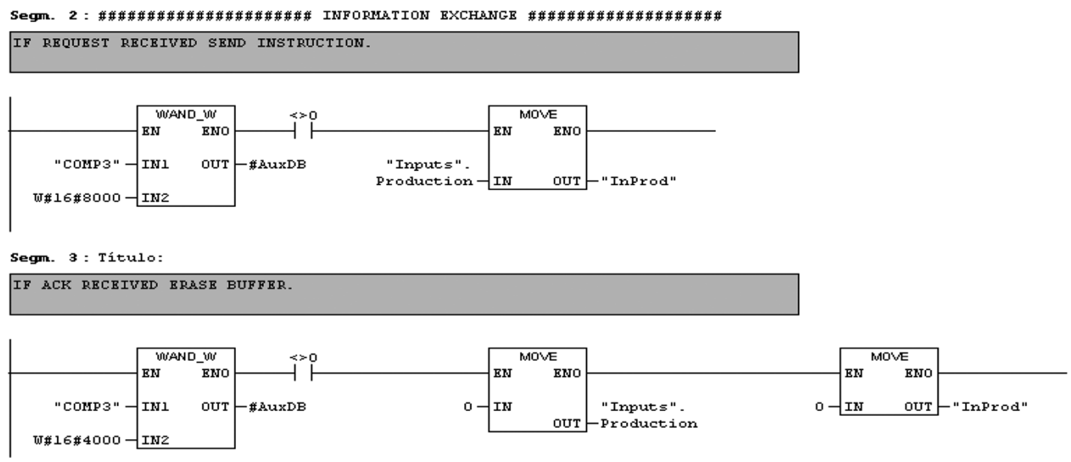

Figure 4. Detail of the Ladder-logic program.

to the S7-300. If the S7-300 receives the ACK, it clears the current instruction from the input buffer and continues with the next one. As can be observed, the next instruction will be sent as soon as the S7-200 makes a request. The fact of erasing an instruction is reflected with transition "*Receive ACK.*" This model has been developed using CPN tools [20].

The protocol used to send instructions copes with the constraints of the Profibus-DP network by providing a pull strategy for requesting such instructions. This way, as a slave S7-200 pulls instructions from the master S7-300, it allows the deliberative level to negotiate the sequence in which instructions are processed until the next is requested, enabling dynamic re-scheduling without interfering in the normal operation of the plant. This helps all the agents implemented over PLCs to perform their roles effectively while tackling unexpected situations.

By means of CPN tools it is possible to carry out some simulations in order to test the performance of the model. After running a state-space analysis, some information related to properties as fairness and responsiveness has been obtained. On this case, the Profibus-DP network was modelled in a pessimistic way, defining a 20% of lost packets. The results concluded that a message is send from sender to receiver on an average of 21 steps. In any case, the model allows programmers to put this communication protocol into practice on PLCs, following the IEC 61131-3 Standard and ladder programming, as shown in Figure 4.

5. Conclusion

A MAS architecture formed by two different platforms of agents has been presented. The top platform represents the deliberative level, where the management of the enterprise take place; the second platform copes with the shop floor control in a reactive way. This paper deals with the implementation of the reactive level over real PLCs to face the problem of the lack of visibility in MAS. In order to do that, it has been necessary to set up a PLC network over Profibus-DP and to study a feasible way for sharing the information between all the elements in the system.

A Coloured Petri Net model developed over a CPN package has been used for implementing and validating the communication protocol between PLCs. This model has been deployed over PLCs in an experimental platform for which satisfactory results have been obtained.

As future work it is planned to study the throughput of the model in the PLC network. As a consequence of that study, we will be able to estimate the maximum information sharing between agents in the reactive level, and adequately set the communication between the platforms of agents. This fact is very important in unforeseen scenarios. The application of this model allows the system to quickly react against disturbances (i.e. incoming of rush orders) by dully reallocating orders. The model provides the flexibility necessary for the deliberative level to deal with different lots at the same time, in contrast to traditional systems. In addition, this model will also be applied to acquire information and monitor the state of the plant with a SCADA tool. A considerable improvement in the use of resources is also achieved.

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Pablo García Ansola received the M.Sc. degree in computer science and MBA from the University of Castilla-La Mancha, Spain. He is a currently a Research Scientist in the Autolog Labs at the UCLM, with a stay at the University of Cambridge. He is also the manager of the Autolog spin-off, called "Securware," which received several innovation awards like the IDEA, Innovared and Desafio22. Before joining the UCLM, he was involved in the business intelligent area of a major Spanish consultancy, INDRA, as a consultant. His research interests include integration of intelligent systems in operational decision-making support.

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