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Holonic coordination obtained by joining the contract net protocol with constraint satisfaction

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ABSTRACT

Present manufacturing systems are facing significant challenges concerning their adaptability. Holonic manufacturing systems are among the technologies that can provide solutions to such requests, if certain conditions are met. As being included in the class of semi-heterarchical control architectures, holonic systems need appropriate coordination and planning schemes, together with validation tools to increase the beneficiaries' trust. This paper proposes a coordination scheme for holonic systems, based on a mix between contract net protocol and distributed constraint satisfaction problems. The distinct phases of this method are explained, with details referring to the adaptation of contract net protocol. About the constraint satisfaction mechanism, a guide is provided on how a manufacturing problem can be expressed according to this formalism. To validate the introduced coordination scheme, a coloured Petri net model was developed. This allowed several simulation experiments for scenarios regarding a manufacturing system with four robots to be carried out. The obtained solutions showed that the proposed method can determine both the right holarchy related to the manufacturing goal, and optimal plans for robots. Moreover, as proven by the reachability graphs obtained for different goals, the proposed method reached correct results for all goals and diverse constraints, and it determined all possible solutions. An advantage is about how knowledge possessed by different types of holons is efficiently used, without producing an increased communication load. In conclusion, our method can ensure the right trade-off between complexity and optimality, and the attached model can constitute the required link between design and implementation, thus contributing to an easier deployment of holonic systems.

1. Introduction

Holonic manufacturing systems (HMSs) are between the new technologies that can bring about characteristics requested to present companies; even so, HMSs are still not in common use due to several reasons, as explained in [1]. This paper presents an additional step toward the application of holonic schemes, by considering practical cases and treating holons' coordination and validation of HMSs. It shows how holarchies can be formed through a combination between the contract net protocol (CNP) and distributed constraint satisfaction problem (DisCSP) and how the designed method can be confirmed by appropriate models and analyzing tools.

HMSs regard semi-heterarchical structures, where intelligent entities – holons – cooperate for solving manufacturing tasks; depending on current conditions more holons dynamically form teams – holarchies. This paper takes into account the classification of holons and their operation according to a specific holonic architecture [2,3]. It was developed starting from PROSA reference architecture [4]. The focus is on the shop-floor level of a company, meaning a manufacturing goal must be solved by a holarchy including order/product holons, which imply the needed resource holons. The considered scenarios, inspired by the experimental manufacturing system existing in our laboratory [3], refer to a robotized process where more robots must fill in a pallet with parts of different types (see Fig. 1). Manufacturing goals include specifications on types of parts, their positions and order of placement; moreover, some constraints must be considered: parts being available in different storages, robot collision avoidance and technological restrictions. These constraints are not known at global level, so that a centralized approach is difficult to apply. It is

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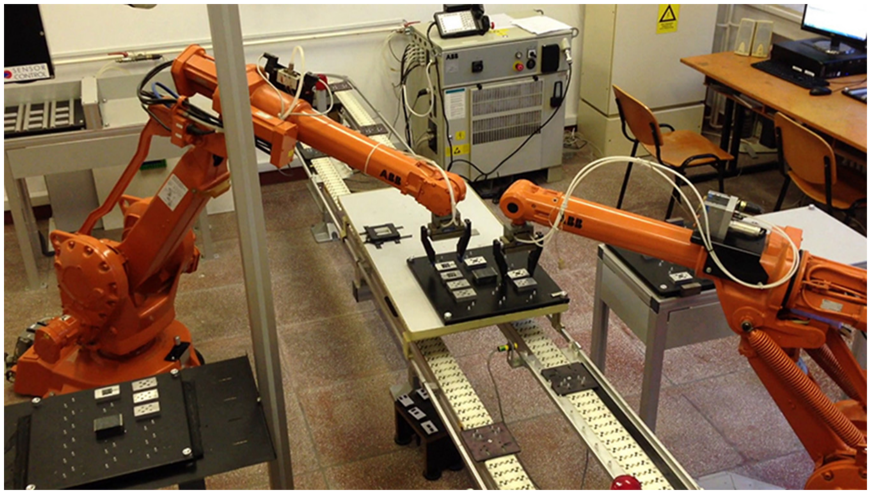

Fig. 1. The experimental manufacturing environment including robotized applications.

to notice the generality and applicability of such scenarios: they can appear in assembling/palletizing processes. With slight changes, a case when more robots are involved in a car body welding process can include a similar solution; instead of transferring parts, robots must move in certain positions near the car body (the welding points) and perform welding operations [5].

2. Related work; proposed research goals

HMSs regard a control architecture that applies the multiagent approach. Thus, the presented method can be related with the state of the art on application of multiagent systems. A distributed solution should not be decided based only on advantages of a distributed mechanism, but also considering the way agents are tightly/loosely coupled, they naturally embed certain knowledge in a dispersed manner and the way information can be shared and communicated [6–8]. One must take into account issues regarding privacy and availability of different types of information [9], the need of a minimal communication load [10], and issues concerning the moment when a partial solution is to be communicated between agents – sooner or later [11]. Knowing these issues, our approach is exploiting the specificity of a manufacturing environment and the benefits of holonic method. The information about fabrication of a certain product is gathered and handled by a product holon, while specifications for operations of resource holons are managed by themselves; this is in our scenarios the case of robot resource holons.

Constraint satisfaction problem (CSP) was taken into account as a technique to be applied for a large class of manufacturing related problems. These range from concurrent product configuration and planning [12], monitoring [13], optimal production scheduling [14] and event management in the supply chain [15]. The already made researches revealed benefits for CSP-based manufacturing control schemes, like: the way planning and configuration specifications can be efficiently passed between the two stages, as soon as they are expresses as constraints; the capability of using constraint-based modeling and reasoning for obtaining highly reactive systems; the natural way of expressing time specifications as constraints and the resulted possibility of determining the best manufacturing schedule in a CSP-based framework; the increased adaptability obtained for a CSP-based management of the supply chain processes. Our research is completing this list, by showing how CSP can be involved in a negotiation process with two phases in order to obtain the best, as well as reliable decisions about formation of holarchies. Application of CSP for real manufacturing problems still reveals certain open problems [16]; between them, the issue of expressing manufacturing scenarios according to CSP formalism is to be mentioned, this being addressed by our paper.

In this paper, one targeted issue concerns an optimal, as well as safe resource allocation mechanism, which has to be integrated with the planning process. In [17] a comparison is made between the planning theory and DisCSP. Some similarities are remarked, namely the way agents own plans and respectively variables in a distributed manner, and they try to solve conflicts through negotiation. The resulted idea, the one being considered in our approach too, is to use plans as values for agents' variables within the framework of DisCSP.

DisCSP was used for resource allocation problems, even in HMSs [16,18]. Besides the method of this paper, there is also the possibility to integrate optimality search within DisCSP by using the approach of distributed constraint optimization problems (DCOPs) [19]. In [20] different DCOP methods are discussed, and the difficulties on obtaining a certain quality for the solution determined through an asynchronous communication between agents are underlined. An improved DCOP scheme is proposed, and this relies on bounds imposed for the accepted costs; our method does not need this additional specification.

As about the use of CNP [21] in manufacturing control architectures, this was an extended one. It offers a simple and general mechanism for solving coordination of manufacturing entities, and thus it was included in manufacturing planning, scheduling, reconfiguration and control schemes [22–25]. However, CNP in its original form can conduct to several drawbacks with respect to the optimality and completeness of provided results and thus different extensions of CNP were proposed; some of these improvements are reviewed in [25]. They regard the tuning of CNP in accordance with the type of relations between agents (cooperative/competitive), the adding of a centralized component within the coordination protocol and the possibility of improving the way contractors can make bids that exceed their capacities, so that no solution to be lost. The last of these extensions was considered in this paper too, but now the focus was on augmenting CNP through its link with DisCSP.

According to our knowledge, there is no result about using both CNP and DisCSP in the same coordination scheme, as proposed in this paper. A remark about this is made in [19], namely on the usefulness of DisCSP for solving problems in which agents' tasks, resulted from a global goal, are a priori determined. If this is not the case, then the use of CNP is suggested, without any details given about the possible combination of CNP with DisCSP.