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MULTI-ROBOT SYSTEMS: FROM FINITE AUTOMATA TO MULTI-AGENT SYSTEMS

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Abstract: An attempt to connect finite automata theory with multi-agent systems is presented. The purpose is to obtain an accurate way to plan and control the robot activities within a multi-robot system. The proposed model is an adapted Moore machine, which is to be used with a contract net protocol agent coordination procedure. The considered architecture was tested in an educational flexible manufacturing system with two industrial robots.

Keywords: Robotics, multi-robot systems, multi-agent systems, robot programming, finite automata, flexible manufacturing systems.

1. INTRODUCTION; MULTI-ROBOT AND MULTI-AGENT SYSTEMS – CONNECTED FIELDS

The field of Multi-Robot Systems (MRS) is an active research area, involving several directions, among which the most important are Robotics, Control Theory and Artificial Intelligence. The present contribution is a further attempt to bring together in a synergic way elements from the above mentioned fields. The research was supported by an experimental area consisting of an educational Flexible Manufacturing System (FMS) developed around two industrial robots (Pănescu *et al*., 2001). The respective system allowed various scenarios and methodologies to be tested. The one presented here refers to considering the two robots as forming an MRS that can be involved in various assembly tasks. The two robots are able to carry out tasks of part handling between several storage devices, to feed a machine tool that can process the parts before their assembling and execute the proper assembly phase using some fixture devices on an assembly table (Pănescu *et al*., 2006).

As regards the high level decision part of the MRS, this was considered under the form of a Multi-Agent System (MAS) - see Fig. 1. This approach can bring about certain advantages, as an increased autonomy

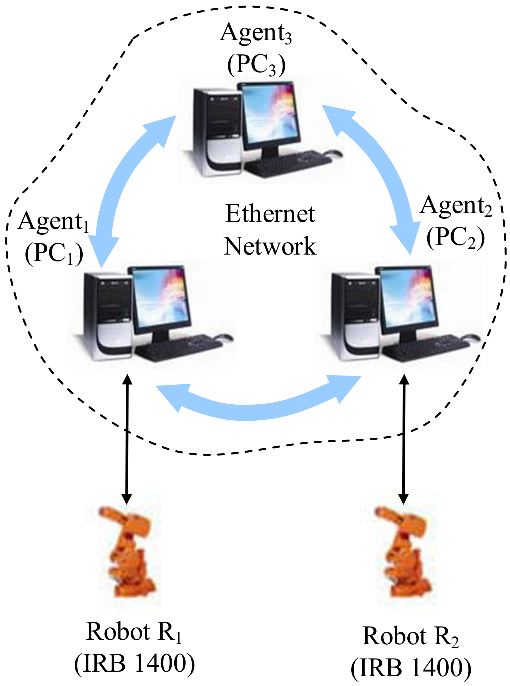

Fig. 1. The MRS software architecture

[1]IRB 1400 and IRB 2400 are industrial robots produced by ABB Robotics, Sweden.

and flexibility for the whole manufacturing system, and improved solutions for the real-time decision making process. The architecture is obtained by coupling each robot with an agent; the respective software module runs on a distinct computer (PC) as the robot controllers imply certain programming constraints. If necessary, some additional agents can be considered. In the presented solution, because the robot controllers are able to transmit the necessary command information to the other devices implied in manufacturing (start/stop commands, processing programs for the machine tool, speed for the conveyor, tasks to be solved by the computer vision system), only one additional agent was involved. This has as major role to manage the production goals received from the user. Thus the main software architecture resulted as presented in Fig. 1. At the low level, several software modules are implied (not represented in Fig. 1): the robot programs accomplishing specific operations (the necessary paths planning and execution, the grasping/un-grasping procedures, the issuing of controls towards the other devices), the machine tool and computer vision programs.

An important point for an MAS is the coordination procedure. One of the most used is the contract net protocol (Huhns and Stephens, 2001). This supposes that when an agent is faced with a goal that it cannot solve by alone, it will announce the respective goal to the other agents and wait for their bids. The agent making known a goal is named the manager, while the others are the contractors. The manager has to choose the best received offer and announce the respective contractor. This coordination mechanism as well as some other aspects of the MRS operation are often coupled with heuristics approaches, without a formal description and support. The next paragraph tries to make the connection between the agent based operation of an MRS and the finite automata theory, some implementation details being then provided. The contribution ends with a few conclusions.

2. A FORMAL APPROACH TO MODEL THE ROBOTS OF AN MRS

An MRS is specified by some entities, namely: the world, which is the environment where the MRS is evolving, including the robots and some other things that may be classified in two categories, depending on how they can produce changes in the environment or not. Always the robots of the MRS must be in the category of the items that can influence the environment. In fact the purpose of the MRS is to transform the environment in a certain way. With respect to this a robot is characterized by the set of actions it is able to perform. Meanwhile, robot actions are made on purpose, namely in accordance with the goal or goals of the MRS. Besides these, a robot has inputs from its environment – perceiving information, provided by its sensorial system. In the decision process a robot may be in the case to use in addition to the sensorial information some data on the history of the environment evolution, which is the state information.

The above points can determine the connection to be made between a robot of an MRS and an automaton. Such a methodology has been already reported (Quottrup *et al*., 2004; Van de Ven, 2005). The new ideas here refer to some additional adaptations and the use of the respective formalism in order to further link MRS and MAS. The robots of an MRS can be compared with the agents within an MAS, having a lot of common points. The only notable difference refers to the embodiment that in the case of robots is much complicated, involving a specific mecatronics combination. By making use of this analogy one point is to transfer various agent architectures towards robots. Without entering in the details of agent structures, these can be classified in three main categories: reactive, deliberative (logic-based) and mixed ones (Wooldridge, 2001). The robots of an MRS are the best included in the last category. Thus, the robots can be considered as possessing a reactive component – they have to interact with the environment and provide a reply to the changes detected by their sensors. Moreover, the robots have to consider the states the environment is passing through in order to properly correlate these with the goals and future actions in their plans.

Based on the above mentioned assertions, it results the necessity to model the robots of an MRS as possessing both reactive and state based components. The proposal is to assign each robot a set of behaviours, like in a reactive architecture, but to enhance their high level decision system so that it should be able to use not only the information on the present sensorial context, but also the state information. Thinking from the agent theory point of view, this means the combination between a state based agent and a reactive one. The framework for such an approach could be provided by the automata theory, as further explained.

A finite automaton (here a Moore type automaton is to be used) can be defined as the 6-tuple (Carrol and Long, 1989):

$$M = (\mathbf{Q}, q_0, \Sigma, \Gamma, \delta, \Phi) \quad (1)$$

where $\mathbf{Q}$ is the finite set of states, q_0 is the initial state ($q_0 \in \mathbf{Q}$), Σ and Γ are the finite input alphabet and respectively output alphabet, δ is a partial function (named the transition function) that maps $\mathbf{Q} \times \Sigma$ to $\mathbf{Q}$, and Φ is a function (output function) that maps $\mathbf{Q}$ in Γ. Several adaptations are needed in order to make a robot of an MRS have an automaton based operation. The first important point is the decision on the state set. As already explained the proposed method is supposed to make use of the behaviours from agent theory. A behaviour must be appropriately launched according to the robot present goals and the sensorial information on the environment. For the industrial robots, behaviours refer to specific activities, mainly on part manipulation tasks, i.e. movement procedures containing a certain path and respectively grasping or un-grasping operations. For example, the considered robots should have behaviours on: part picking up