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# A Multi-Agent System Architecture for Self-Configuration

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**Abstract.** Due to constant globalisation new trends on the market are coming up. One of the trends is the customisation of products for the customer and shorter product life cycles. To overcome the trends industries identified as key element self-reconfigurable production systems. A change to a running system means loss of time, money and manpower. A reconfigurable production system can automatically adapt to changes in terms of changing a machine or a product. The methodology behind is adapted from the office world and is called plug and produce. However, a production system has different requirements which need to be met. Due to a lack of homogeneity of industrial controllers in terms of communication and reconfigurability, as well as the interaction with the end user, the multi-agent technology was identified as a superior communicator. We present a new multi-layered multi-agent architecture where the necessary agent types are introduced to fulfil the requirements for plug and produce. One scenario is shown where the architecture is employed to enable plug and produce capabilities and allow the system to adapt itself.

**Keywords:** *Plug and Produce, Multi Agent System, Self\*, Robotic Systems*

## 1 Introduction

Throughout the globalisation, European markets are becoming more dynamic and applying new trends in industries. Therefore, vendors must now deal with more competitors than before. The available products will increase, which in turn will reduce the product life cycles. One way to remain competitive is to supply product variants instead of new technologies, because of the high development costs and time constrains to offer a new product. Another trend to push the selling of products is the customisation of products which is well known from the auto

mobile industry. The customer can first choose from a catalogue his favourite equipment and then assemble a personalised car.

The main challenge for European SMEs (small and medium enterprises) is to respond quickly to market changes. A new manufacturing system must cope with it by adjusting and reconfiguring itself with minimum human intervention. New manufacturing processes should be introduced easily to the production line with a minimised downtime. The production should adapt in layout and configuration to different types of products. After a machine failure the production line should recover quickly either by replacing devices or by redirecting the workflow and spreading the tasks to different machines.

The described production issues can be addressed by using a technique called plug and produce [1-3] (otherwise known as plug and work [4-6] or plug and operate [7-9]). The concept enables to plug and unplug a device (like a robot, machine, sensor etc.) with less effort in terms of reconfiguration, reprogramming and communication linking. The concept is adapted from plug and play from the office world. In the literature there are a few approaches showing that plug and play cannot easily be converted to plug and produce. In a manufacturing system one needs to deal with complex machines, which are not standardised and often have mechanical interference or share the same workspace. That increases the complexity of adding. The range of capabilities are too different, a component can be simple like a sensor or complex as a robot. On top of this the plug and produce concept must still provide real time behaviour for the system and fulfil bus system timing and bandwidth requirement. Also an important condition for the industrial-level is robustness and the health and safety regulations which must match the company's policy [10].

In the literature review different approaches of how and why researchers have investigated plug and produce can be found. One motivation is to reduce the integration effort when a production layout has changed [11]. A method is developed to standardise software components and machines. Important data about machines are stored in a database to automatically plan if a new machine layout is required. While in [12] the integration time is reduced with a method to automatically calibrate robots and allocate workspace based on the task when a new tool is installed. Another approach involves changing the machines of a production line e.g. parts of robots. In [13] a robotic system is proposed to build and program from parts out of a CAD catalogue which includes the functionalities and limits. The drawback of this approach is the dependency on specialised hardware to realise the integration and information about the parts which can be difficult to get from different vendors.

Another approach is to minimise the integration effort by introducing a control architecture that contains commands for machine parts, like manipulator etc. [14]. If a part is plugged in commands are shown to the operator to make the programming less complex for less trained persons. In [15] a concept to store configurations and functions in EDDL (electronic device description language) is presented. The system needs to be configured only once and it can be reused from the central

data management. However, these approaches lack of a dynamic adaptation to a changing environment and complex demonstration scenarios.

In [1] the procedure of plug and produce is presented and used in combination with autonomous and cooperative systems, called holons or agents. The system is located in the computer network and checks the condition of the machines frequently. This allows a high level management of the assembly machines and an experiment shows that a replacement of a machine can be realised in a shorter time. In [16] the experiments and products to assemble are extended. The automatic calibration of the robotic system is included and controlled by the agent system.

The interested reader is directed to [17, 18] for a general introduction to multi-agent systems (MAS).

An extension to the management of plug and produce by the agents is described in [19], where an agent-based control system with diagnostic possibilities is presented. Based on Hidden Markov Models the authors introduce several layers for diagnostic of the system. Whereas a lower layer monitors the control hardware, a higher level does diagnostics and classifies types of failure. This system is able to collect and detect failures more often. Based on this, further work could include automatic failure recover and decision-making support for the user.

As we have seen, there is a need for customised products and a quickly response to changes on the market. The literature review identified plug and produce as a key element [1] to integrate new devices in order to configure machines with minimum reconfiguration effort. In combination with multi-agent technology properties like autonomy, openness and communication features, this will extend the plug and produce concept to deal with workflow changes and automatic task assignment [2].

There is no architecture available to enable plug and produce capabilities with standard technology. To provide a basis for the complex structures and communication of the reconfigurable production system, we propose a multi layered multi-agent architecture for plug and produce. This architecture will extend an existing setup to provide self-reconfiguring capabilities. We will show the benefits of this contribution by implementing the architecture on a real industrial demonstrator.

## 2 The Multi-Agent Architecture

This section introduces the production environment in which agents will be deployed. Agents are defined and specified as part of the architectural design. The plug and produce system is designed as a multilayered multi-agent system, where each layer is represented as a graph of agents [20] [21]. The benefits of a layered multi-agent architecture are visible, for example, in resource bounded agents with a clear methodology and a modular structure [22].

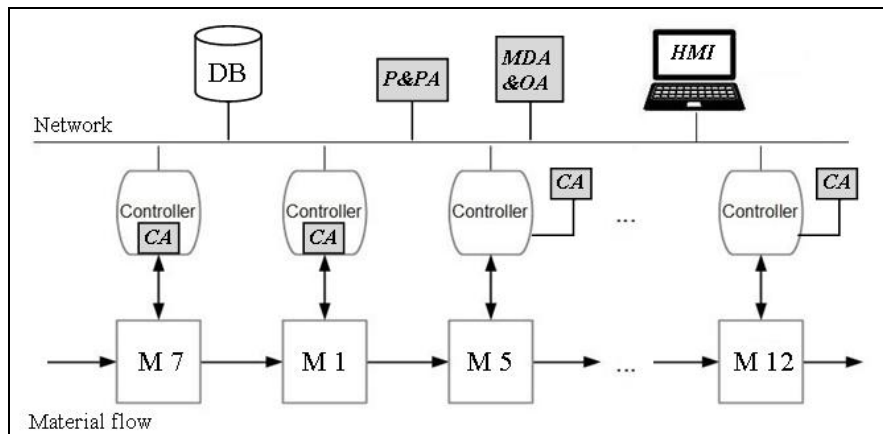
In Figure 1 a generic production system which is able to produce a final product is shown. The architecture is an extension to the traditional system. The parts in grey indicate necessary additions to host the agent system in order to enable plug and produce capabilities. Attached to each controller is a machine. The order

of machines is given by the product. In case of changing the production system layout the PLC and the machine will be moved together.

The architecture in Figure 1 is based on the three layers of a traditional production system:

1. **HMI layer:** this layer interacts with the end user by receiving input from the operator and delivering information to the agents. The goal of this interaction is to control and supervise the production system.
2. **Control layer:** this layer controls the production system by monitoring the production process through sensors and by commanding the execution of actions through actuators.
3. **Production system layer:** this layer contains the production system where machines and the material handling devices operate to produce the desired product

In the following, the agent types are described. The *Component Agent* (CA) can be deployed either on a PLC or on a small processing unit which will then be connected to the PLC (both shown in Figure 1). The latter enables the use of legacy systems. The *Plug and Produce Management Agent* (P&PA) manage the plug and produce activities by monitoring the component agents and interfacing with the HMI. These agents are dormant during the operation of a production system, yet aware of component agents plugged in. However, they become active whenever a plug and produce activity is initiated. Once a module is plugged in and detected by the P&PA, the configuration for this device will be uploaded from the database (DB) to the relevant controller.



**Figure 1: Generic production system without and with the agent system**

Afterwards the *Monitoring, Data Analysis and Optimisation Agent* (MDA&OA) become active to police the system. Additionally, they are used to

monitor performance indicators and perform data analysis for process optimisation. Monitoring information can be displayed on the HMI to be used directly by the operator or written to a database to perform an analysis separately.

The management of the machines is done by the agents through the existing communication link. The process control activities are left to the control layer to avoid collisions with machines. If the agent system fails plug and produce capabilities are disabled but the production system continues to operate. This level of robustness is necessary for industrial implementation because of the reduced risk of stopping the production which normally is connected to high costs.

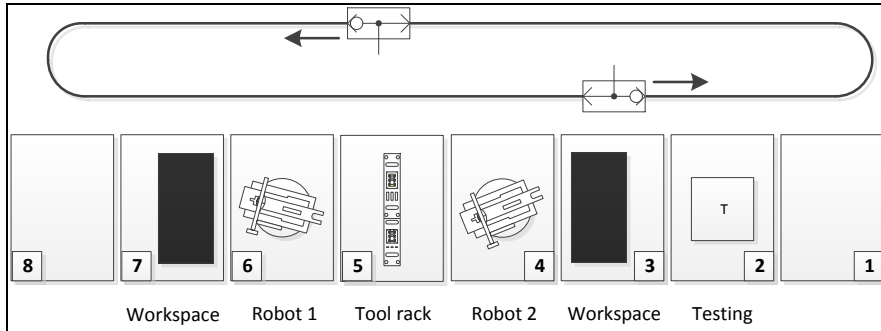
### 3 Implementation

In order to demonstrate our idea we use a real industrial production cell from Feintool Automation, shown in Figure 2, which is suitable to address all our research questions. This type of cell is used, for example, in some European factories to assemble photovoltaic panels. The production cell contains two robots, tool changing equipment (not displayed in the figure) and a testing station with an adaptable hexapod. At the bottom there are eight boxes with industrial used PLCs inside, one for each workspace. A shuttle system is serving all workstations.



**Figure 2: Testbed for plug and produce**

Figure 3 is the top view of Figure 2 after setting up.



**Figure 3: Demonstrator setup for plug and produce**

We are currently working on the following use case to demonstrate plug and produce and self-reconfiguration.

For this scenario the robots need to have both access to the same tool changing rack to be able to assemble the full product.

Firstly, robot 1 is deactivated. Robot 2 assembles and tests the product and is monitored by the MDA&O agent type. Performance data is displayed on the HMI. The operator decides to plug in robot 1 to produce in time. As soon as robot 1 is plugged in, the P&PA detects a new machine and loads the corresponding configuration from the DB. After integration the responsible agents become dormant again. The MDA&O agents are notified about the changes and execute the optimisation algorithm. When a better configuration is found the operator is asked to confirm the change on the HMI. On this demonstrator the configuration of the shuttle system will be modified to serve robot 1. Also, depending on the robot capabilities (e.g. speed, energy consumption, precision) both robots will share assembly tasks in order to achieve the best result.

In Figure 4 is an example of assembly of three items of a product. The assembly consists of three steps (1,2,3) which can be performed by either robot. The parts are carried on a pallet which can be moved by the robots. In the figure one robot is labelled as A, the other is marked as B. A2 stands for the second assembly step by the first robot. The parts and the final products are transported by a shuttle system indicated by the letter 'S'. A testing procedure is carried out at the end of each assembly and labelled by the letter 'T'. It is assumed, for the sake of simplicity of the drawing, that all tasks take the same amount of time.

As you can see in the table at the top of Figure 4 the shuttle needs to go two steps towards robot A which is in this case located after robot B. After the three assembly steps are performed by robot A, the product is tested and transported away by the transport system. Then the next shuttle with product parts comes to start again the process for the next product.

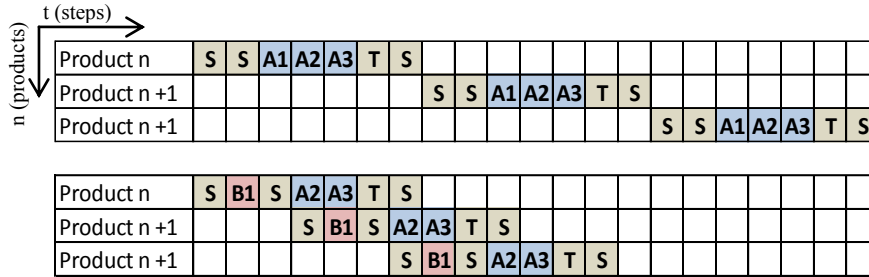


Figure 4: Task sequence diagram to produce three of the same products

The table at the bottom of Figure 4 visualises the task sequence for two robots. Now the shuttle goes first to robot B in order to perform the first assembly step. The way and number of steps from the shuttle does not change so the shuttle goes to robot A to finish the product. Once the robot A takes the pallet from the shuttle, the pallet is empty and ready to serve robot B in order to work in parallel. With three products and the given setup this would bring a saving of 62 % of time compared to the former case.

## 5 Conclusions

One way to reduce the effort of reconfiguration tasks is to implement self\* techniques for machines [23], e.g. to be self-aware of the machine status or self-organise the order of jobs. One technology identified by the literature is the multi-agent system where multiple agents communicate to reach an agreement that satisfies their individual goals [17, 24]. The reasons why multi-agent technology is not fully accepted in manufacturing are listed in [2]. Our work will focus on the main barriers for an industrial take-up of multi-agent systems to implement plug and produce. In various European projects (e.g. EUPASS, IDEAS) the hardware was modified in order to host the agent system. We use standard technology to host the agent system. This allows the operator to get support by the vendor and the availability is secured in opposition to modified controller. Another barrier we focus on is the integration of legacy systems, with the objective of avoiding high investments to replace hardware. The architecture will be deployed on existing hardware or little processing units which host the agents and work as a middleman.

Another barrier for industry is the potential unpredictability of actions performed by self-interested agents to reach their goal. Our contribution is an extension to the traditional production control, in the sense that if the agent system fails the plug and produce capabilities will stop but the production system will continue to operate. Such a fault-tolerant system will be supported by our architecture by separating the production line into layers. This behaviour will reduce the risk for industries to have the whole production stopped because of a failure.



We will extend the architecture and validate it on the testbed with different use case scenarios. Furthermore, we will develop a generic methodology for plug and produce to enable the self-reconfiguration of the system.

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