KES Transactions on Sustainable Design and Manufacturing II
Sustainable Design and Manufacturing 2015 : pp.61-73 : Paper sdm15-028

The Assembly and Disassembly Process Guided by Software Agents

Leo van Moergestel[1], Erik Puik[1], Daniël Telgen[1], John-Jules Meyer [2]

[1]HU Utrecht University of Applied Sciences, Utrecht, The Netherlands
Leo.vanmoergestel@hu.nl
Erik.puik@hu.nl
Daniël.telgen@hu.nl
[2]Utrecht University, Utrecht, the Netherlands
J.J.C.Meyer@uu.nl

Abstract *A manufacturing process can be described by a sequence or combination of production steps. Based on this approach a manufacturing system has been developed that is capable to produce several different products in parallel. A batch size of one unit is possible and the production is pull-driven. The manufacturing system is based on agent technology and a special so-called product agent collects information about the assembly process. This agent will be connected to the actual product and can guide the disassembly process at the end of the products life. The agent will show the inverse steps to be taken to take a product apart. This approach can be used in the agent based manufacturing process described in this paper but the concept can also be used for other manufacturing systems. The paper discusses the possibilities as well as the restrictions of the method proposed here.*

1. Introduction

Individual end user requirements for products are becoming more important today. This trend is technically supported by internet technology, that enables the end user to select his or her preferences. It means that cost-effective small scale manufacturing will become more and more important. Another aspect is the fact that sustainability and reuse should be incorporated in the production process.
The manufacturing system introduced in this paper is based on multiagent technology. The following section explains this agent-based grid manufacturing concept as well as the concept of agent technology. Related work on agent technology in manufacturing, monitoring and recycling will be discussed next.

A more detailed explanation of the concept of production steps is the subject of the subsequent sections as well as the possibilities for disassembling and reuse of parts and subparts. The paper ends with a conclusion in combination with future research.

2. Agent-based grid manufacturing

In Puik [1] and Moergestel [2] a manufacturing system based on a grid of cheap and versatile production units, called equiplets, is described that is capable of agile multiparallel production. An important concept in this manufacturing system is an agent. There are many definitions of what an agent is. A common accepted definition by Wooldridge and Jennings [3] is:

Definition (agent). *An agent is an encapsulated computer system or computer program that is situated in some environment and that is capable of flexible, autonomous action in that environment in order to meet its design objectives or goals.*

A system where two or more agents are interacting is called a multiagent system or MAS. In Figure 1 the concept of a multiagent system is shown. In a multiagent system, agents can have a specific role and agents also have their goals.

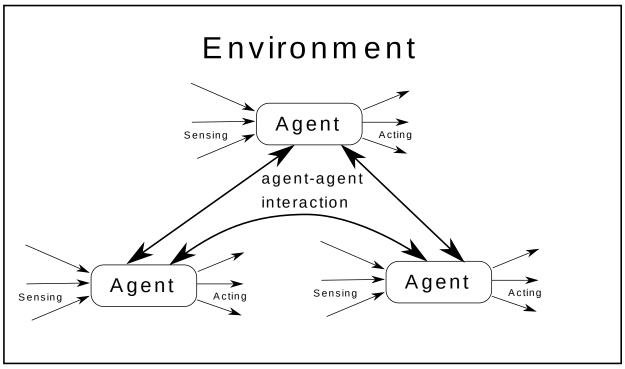

Figure 1: A multiagent system

The agent-based manufacturing system is a MAS where multiple agents work together to achieve a common goal: the manufacturing of products according to user specifications. The multiagent system is a distributed system consisting of agents, as cooperating autonomous entities, that have specific roles and responsibilities in the manufacturing system. The main roles in the system are

represented by two types of agents. The first type are agents representing a product to be made. These agents are referred to as product agents. A product agent knows *what* should be done to make a product but is not capable to perform the needed actions or production steps itself. These steps can be performed by cheap reconfigurable production machines, called equiplets. An equiplet agent represents an equiplet. This type of agent knows *how* to perform one or more production steps.
Every product to be made starts as a software entity or agent that is programmed to meet its goal: the production of a single product. In order to start the production, the product agent will search for equiplets offering the required production steps. The product agent will communicate with the equiplet agent about specific step parameters and will make a reservation on the equiplet for the production step to be performed. Multiple product agents can be active in this system working on the completion of possibly different products. In Figure 2 the situation for three product agents (X,Y,Z) and five equiplets (A,B,C,D,E) is shown. As can be seen in the figure, the production can start at a certain time and there is no need for steps taking the same amount of time.

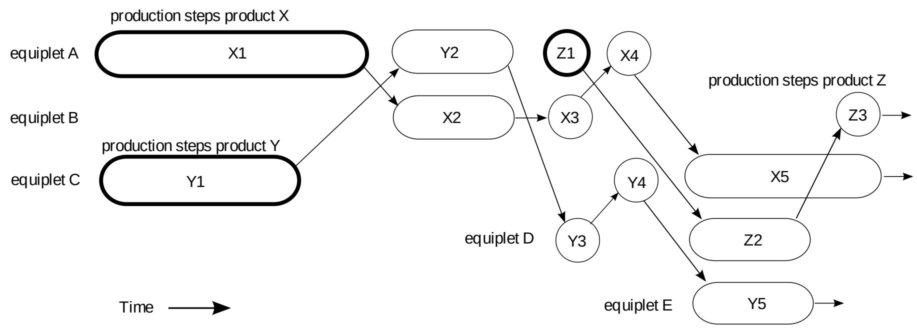

Figure 2: The manufacturing of different products in parallel

In this model every single product is guided through the production environment by the already introduced product agent. While being responsible for the manufacturing of the product, the product agent will also collect for every step relevant production information of this product. When the product is finished, the agent has all the manufacturing details and is still available for further use containing valuable data about the product. The next step in this approach is to investigate and study the roles of this product agent in the other phases of the life cycle of the product. In the next section related work will be discussed. A more detailed and elaborate description of the agent-based manufacturing system can be found in [4]. Details about the scheduling and planning system can be found in [5].

3. Related work

In the field of agent-based production there are several important publications. Important work in this field has already been done. Paolucci and Sacile [6] give an extensive overview of what has been done. Their work focuses on simulation as well as production scheduling and control. The main purpose to use agents is agile production and making complex production tasks possible by using a multi-agent system. The focus is not on reuse, and sustainability. Bussmann e.a. [7] introduce the concept of a product agent, in their terms workpiece agents, during the production. These agents do not however perform individual product logging and only play a role in the production phase. In our approach the product logging is the basis of the other roles of the product agent in other parts of the life cycle.
Burgess [8] describes Cfengine that uses agent technology in monitoring computer systems and ICT network infrastructure. In Cfengine, agents will monitor the status and health of software parts of a complex network infrastructure. These agents are developed and introduced in the use phase of this infrastructure and focus on the condition of the software subsystems. In our approach this monitoring function for hardware and software is the role of the same agent that started as an agent during the manufacturing and already collected valuable information that can be useful to the end-user. Unlike Cfengine that is designed for computers and networks, our approach does not focus on certain types of products.
By using the product agent again in the final phase of the life-cycle, component reuse and smart disassembly is a very important aspect when it comes to recycling of rare or expensive building material.
Research in the field of recycling is overwhelming. We only mention here an agent based solution. Kovacs [9] proposes agent technology in car-recycling. This work focusses on exchange of information between enterprises that recycle and destruct used cars. There is however not a notion of a product agent in their approach.
Another difference with our approach is that it focusses only on cars.

4. The implementation of the agent-based manufacturing

To involve the end user in the production process, a web interface is an integral part of the manufacturing system. This web interface, consisting of a web server and a web browser at the client side, enables the end user to specify the product to be made and it will also create the product agent to make this product. Figure 3 shows the actual global scheme of the manufacturing system.

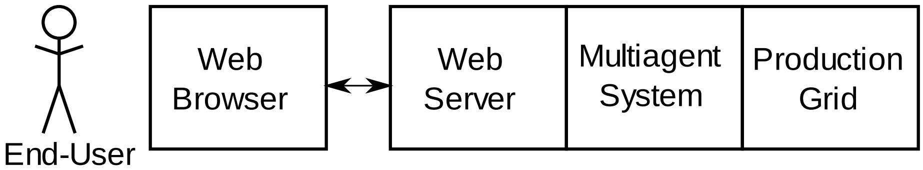

Figure 3: Overview of the main components of the manufacturing system

The webserver is connected to the multiagent system, and will spawn a new product agent when a request for a product arrives from the end-user. This multiagent system is connected to the actual production grid, where the production hardware, the aforementioned equiplets, are available. A more detailed scheme is shown in Figure 4.

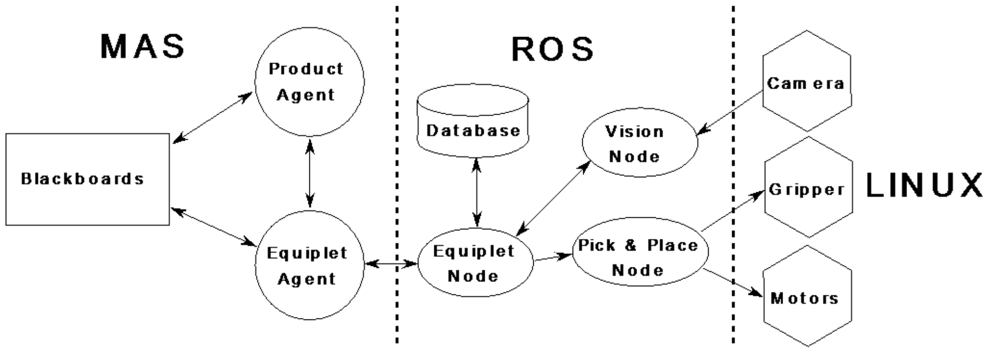

Figure 4: The internal architecture of a part of the manufacturing system

In this figure the MAS and its agents also contains so-called blackboards. Blackboards are software implementations of inter-agent communication systems. Agents can read and write information on a blackboard and all agents can access the information. The software on the equiplet is based on the robot operating system ROS [10] running on a Linux platform that contains the drivers to control the actual hardware. In this case an equiplet having a gripper, a camera and motors to control the position of the gripper.

5. Advantages and disadvantages of the concept

The concept described here has several advantages.

1. It is an agile, scalable and robust system. The manufacturing can be adapted to new situations by adding equiplets with the required production steps. By adding more equiplets, the capacity of the manufacturing system can be raised and by using duplication of the equiplets, the system does not rely on a single equiplet.
2. A single product can be made in parallel with other products, so a batch size of one unit is possible. Because the manufacturing is remotely driven by internet technology, this concept can be called in cloud-terms “Manufacturing As A Service (MAAS)”.
3. The production is on demand. A product will only be made if the end user is asking for it. There will be no overproduction and waste of resources. This is one of the concepts of lean manufacturing [11].
4. Every product has its own unique manufacturing history contained in the knowledgebase of the product agent.
5. This type of production can also be used in the situation where automated machinery like equiplets, are replaced by human operators, that will be instructed by the product agents.

There are also disadvantages

1. The load of the equipment (in our case equiplets) should be kept under a certain maximum. In [12] it is shown that above an average load of 80% of the equiplets in the grid, the number of products simultaneously present in the grid becomes too high resulting in problems related to the transport of products between the equiplets and the inter-agent communication.
2. The transport of products within the grid is much more complicated than the situation in a production line, where a transport belt might be sufficient. In [12] a transport system based on automated guided vehicles (AGV) is proposed.
3. The logistics for transporting parts and raw material to the equiplets should be realized. This problem has been solved by using a so-called building box system [12]. All components and raw material for a product or part of a product are placed in a container that is located on an AGV.

6. The production step

To investigate the possibilities for disassembling a product, this section will provide a more detailed discussion of the production step.

Definition (Production step). *A production step is an action or group of coordinated or coherent actions on a product, to bring the product a step further to its final* *realization. The state of the product before and after the step is stable, meaning that the time it takes to do the next step is irrelevant and that the product can be transported or temporarily stored between two steps.*

For a production step the symbol σ will be used in this paper. Combining steps results in two basic combinations: a fixed sequence of steps denoted by a tuple notation: $<\sigma_1,\sigma_2, ...>$ and a combination where the order of steps is irrelevant, denoted by the set notation $\{\sigma_1,\sigma_2, ...\}$.
These basic combinations lead to the overview of step combinations given in Figure 5.

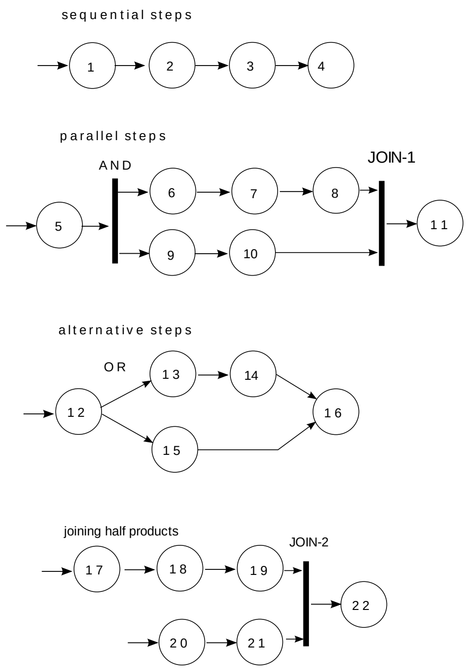

Figure 5: Possible combinations of steps

The combination of steps or product paths in Figure 5 can be written in sets and tuples resulting in:

- Single path: $<\sigma_1, \sigma_2, \sigma_3, \sigma_4>$
- Parallel steps: $<\sigma_5, \{<\sigma_6, \sigma_7, \sigma_8>,<\sigma_9, \sigma_{10}>\}, \sigma_{11}>$
- Alternative steps: $<\sigma_{12}, \{<\sigma_{13}, \sigma_{14}>$ V $<\sigma_{15}>\}, \sigma_{16}>$ (V stands for logical OR)
- Joining half products: $<\{<\sigma_{17}, \sigma_{18}, \sigma_{19}>,<\sigma_{20}, \sigma_{21}>\}, \sigma_{22}>$

In these possible step combinations, there is the AND concept, where one could choose which branch to complete first (Figure 5). Because we start with a single production step and thus a single path we deal only with a single (uncompleted) product after step 5, so we cannot use real parallelism in this case. The single product cannot be split to follow two different paths simultaneously. Because we want to treat the join as a special situation for real parallel manufacturing as will be the case of Joining half products, we re-map this AND construction to a choice of branches (OR) as can be seen in Figure 6.

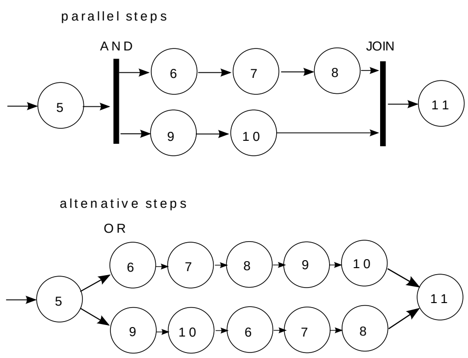

Figure 6: converting an AND to an OR

In the tuple/set notation this can be written as:

$$<\sigma_5, \{<\sigma_6, \sigma_7, \sigma_8>, <\sigma_9, \sigma_{10}>\}, \sigma_{11}> \; => \; <\sigma_5, \{<\sigma_6, \sigma_7, \sigma_8, \sigma_9, \sigma_{10}> \vee <\sigma_9, \sigma_{10}, \sigma_6, \sigma_7, \sigma_8>\}, \sigma_{11}>$$

In the case of joining half products, real parallel processing can be used, where the two subparts are made in parallel and joined to realize the final product.
Production steps used in our agent-based production model can be classified according to the following descriptions:

1. Steps that alter the shape of a product by chemical, mechanical or physical action. Drilling, moulding, cutting and milling are examples of mechanical shaping.
2. Steps that add one or more components to the product by inserting, gluing, welding soldering, or another way of attaching. This includes steps that combine half-products, constructed by a separate step path.
3. Steps that inspect and/or test a product made so far.

7. Reversing steps

In this section we will consider properties of production steps regarding to the possibility to undo a step. This is needed in case we want to take a product apart at the end of its life. In its simplest form a sequence of steps like $<\sigma_1,\sigma_2,\sigma_3>$ can be reversed by $<\sigma_{3i},\sigma_{2i},\sigma_{1i}>$, where σ_{ni} is the inverse of σ_n. However this is not possible in all cases. For every step one of the following four possibilities exist:

1. A step can be undone by reverting it: for example, a component that is placed at a certain position can be removed or a screw can be untightened and removed as well as the part that was hold by that screw.
2. A step can be skipped in the reverse assembly process. Example if two parts are welded, it might be possible to cut the parts apart, but this might not be necessary for disassembling a product. If a step was drilling a hole in a part, filling that hole is normally not needed to disassemble the product.
3. A step can be reversed by a sequence of steps. The sequence of reversed steps should be defined in combination with the original production step.
4. A step cannot easily be undone, due to the nature of the step. Mixing materials (especially fluids), or chemical reactions are not always easily reversed.

Another consideration is how far a product should be disassembled. Most products consist of subparts. These subparts can be reused. In complex products, containing the product agent itself, the product agent monitors the usage of subparts, during the use-phase of the product. The possibilities for reuse and expected lifetime of subparts play an important role in the decision how far the disassembly process should be worked out. Actually two questions arise here:

1. Do we want to reuse subparts?
2. Do we want to reuse material?

In both cases it is also important where the product will go at the end of its life. In case it is returned to the manufacturer, it will be in an environment where the usage of subparts is well defined. Also the expected lifetime is well known, or if it is not, the use of product agents can help in this situation. If many product agents report the mean time between failure of subparts, the manufacturer can build a reliable knowledge base for all subparts used. If material should be reused, the product agent should point to places within the product itself where rare or interesting material is used and available. This method as described in [13] can use a web-based interface for human instruction, or a computer readable format like XML.

8. Possibilities for mass production

In the situation of mass production, the concept of a product agent can also be applied to disassemble and reuse subparts. In that case, the information about taking a product apart, can be supplied globally for all products by using Internet technology. If the product agent had been embedded in the product, after manufacturing (in this case the product agent might not be involved in the manufacturing process itself), the agent can monitor the usage of the product and its subparts. It can then be useful in the process of disassembling the product and advice for reuse of subparts or materials [13].

Manufacturing can be stepwise, but not every step can be easily reversed. Careful selection of alternatives to accomplish a certain step could select the step that is reversible. If this can be done for all steps, the product can be taken apart and the components can be recycled.

The type of manufacturing that can take advantage of the proposed model are the manufacturing systems that put components or subparts together to realise the final product. This ‘putting together’ should be easily reversible. The most preferred situation is that the final product can embed the product agent and connect this agent to the subparts of the product so it can monitor the usage of the system as a whole as well as its subparts. An example of a product made this way, is a device that can be used for playing streaming audio from the internet, a so-called internet radio.

9. Example of production steps and reverting it

A production step should be specified in detail. The equiplet has to know exactly what should be done. Normally a step specifies an action on one or more objects. An example of drilling a hole is given here:

```
Step (Identifier)
  Action: Drill
  Object: Block
EndStep
```

To give more details, the action as well as the object should be specified. The object is confined to a boundingbox. This bounding box will put the object in a Cartesian coordinate system, so points on the object can be specified. In this case a point of interest will be the centre of the place where the drill will enter the object, the drilling point. This leads to:

```
Drill
  Size: x mm
  Material: wood
  Drilling point: x,y,z
  Angle: 0 deg Z-axis
  Depth: x mm
  Fixate: yes, point or surfaces to fixate during drillig
EndDrill
```

Given this information, an equiplet agent can decide if this step is feasible, taken into account its capabilities. In the planning phase this information is used to inform the product agent about the feasibility of the step as wel as the duration. The actual specification is done in the eXtensible Markup Language (XML) that is widely used in computer science for specifying structured data in a computer and human readable form. The inverse action can in this case be skipped as stated earlier in this paper. The disassembly process should continue with the inverse of the step before the drilling action.

A pick and place step has an inverse action, the removal of a part. In more detail:

```
Step (Identifier)
  Action: PickAndPlace
  Object1: Box
  Object2: Ball
EndStep

PickAndPlace
  Gripper: vacuum pincer type x
  GrippingPoint: x,y (refers to bounding box object2)
  Origin: x,y (refers to position in workspace)
  Destination: x,y (refers to position object 1)
EndPickAndPlace
```

Reversing this action is easily done by exchanging the information about `Origin` and `Destination`.

For complex products the description of product steps consist of a tree-shaped model as shown in the last picture of Figure 5, ending in a single sequence of one or more production steps at the end and sequences of parallel steps for making the subparts. To use the method the tree should we followed from the end (the last step) to the branches. At every branch, a subpart is available that could be reused or also disassembled.

10. Conclusion

The model proposed in this paper, fits in the concept of the Internet of Things (IoT). The embedded or remote software entity will provide details about the disassembly of the product as well as pinpointing interesting or rare materials.
The concept can also be applied to other manufacturing paradigms like mass-production. In that case all products are similar and the required information should be available on the internet. This information can be combined with local information in case the product has an embedded product agent keeping track of the usage of subparts during the use phase of the product.

References

[1] Puik, E., Moergestel L.J.M. van: Agile multi-parallel manufacturing using a grid of equiplets. Proceedings of the International Precision Assembly Seminar (IPAS 2010), pp. 271-282 (2010)
[2] Moergestel L.J.M. van, Meyer, J.J.Ch., Puik, E., Telgen, D.H., Decentralized autonomous-agent-based infrastructure for agile multiparallel manufacturing. Proceedings ISADS 2011, pp. 281-288, Kobe, Japan (2011)
[3] Wooldridge, M., Jennings, N.: Intelligent agents: Theory and practice. The knowledge Engineering Review, 10(2), pp. 115-152 (1995)
[4] Moergestel, L.J.M. van, Puik, E., Telgen, D.H., Meyer, J.J.Ch., Implementation of an Agent-Based Manufacturing Grid, Accepted for publication in the Proceedings of the ISADS 2015, (2015)
[5] Moergestel, L.J.M. van, Puik, E., Telgen, D.H., Meyer, J.J.Ch., Production scheduling in an agile agent-based production grid. Proceedings of the Intelligent Agent Technology (IAT), pp. 293-298, (2012)
[6] Paolucci, M., Sacile, R., Agent-based manufacturing and control systems, CRC Press, Boca Raton, Fla., (2005)
[7] Bussmann, N.R., Jennings, N.R., Wooldridge, M., Multiagnet Systems for Manufacturing Control, Springer-Verlag, Berlin Heidelberg (2004)
[8] Burgess, M., Cfengine as a component of computer immune-systems, Proceedings of the Norwegian Informatics Conference, (1998)
[9] Kovacs, G., Heidegger, G., Car recycling sme network with agent-based solutions. European research consortium for informatics and mathematics (2008)

[10] Quigley, M., e.a., ROS: an open source robot operating system. Open Source Software workshop of the ICRA (2009)

[11] Shingo, A Study of the Toyota Production System, Productivity Press, (1998)

[12] Moergestel, L.J.M. van, Erik Puik, Daniel Telgen, Mathijs Kuijl, Bas Alblas, Jaap Koelewijn, John-Jules Meyer, A Simulation Model for Transport in a Grid-based Manufacturing System, Proceedings Intelli Conference, (2014)

[13] Moergestel, L.J.M. van, Puik, E., Telgen, D.H., Folmer, H., Grünbauer, M., Proost, R., Veringa, H., Meyer, J.J.Ch.: Enhancing products by embedding agents, Agents and Artificial Intelligence, Revised selected papers ICAART 2013 conference, Communications in Computer and Information Science, vol. 449, pp. 115-130. Springer (2014)