The role of software agents in the life cycle of a product

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***Abstract*— This papers presents some ideas to use so-called software agents as a software representation of a product not only during manufacturing but also during the whole life cycle of the product. Software agents are autonomous entities capable of collecting useful information about products. By their design and capabilities software agents fit well in the concept of ubiquitous computing. We use these agents in our newly developed manufacturing process. This paper discusses further use of agent technology.**

***Index Terms*— Software agents, Green manufacturing, Product use logging, Ubiquitous computing**

I. Introduction

At the Utrecht University of Applied Sciences research is done in the field of micro system manufacturing. To meet new demands like short time-to-market and customer specific small quantity production we developed a new production approach based on so-called equiplets [1]. Equiplets are special production platforms that are cheap, agile and easy configurable. A set of these equiplets will be interconnected by a product transport system capable of moving the products along a production path that can be different for every product. This setup is called a production grid. The co-designed software for this production grid is based on autonomous software entities that are tied to the individual products [2]. Another group of these software entities is tied to the equiplets. These software entities or agents communicate with each other to control the production. Other implementations of agent-based control systems exist. In [3] agents tied to products during the production are introduced. So far agents can be used in the manufacturing phase of a product. These agents collect a lot of production information and thus carry important product information. Because this information could be helpful and useful during the use and also destruction or recycling of the product, it would be an interesting question to ask what advantages the use of agents in the whole life cycle of a product can have. This paper tries to give an overview of some of the possibilities.

II. Agents

Because this paper is about agents, this section will give a short introduction to agents and agent technology. There are many definitions of what an agent is. We use here a commonly accepted definition by Wooldridge and Jennings [4] *An agent is an encapsulated computer system that is situated in some environment and that is capable of flexible, autonomous action in that environment in order to meet its design objectives.* In figure 1 we depicted an agent in its environment. An agent is sensing the environment an can perform actions on the environment. As stated in the definition, the actions the agent performs depend on the design objectives.

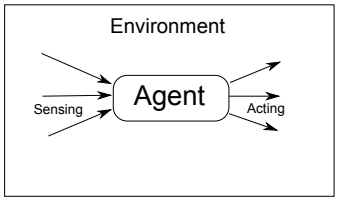

Fig. 1. An agent in its environment

A. Agent types

We will concentrate on some aspects that are important for our proposal to use these agents to guide a product during its manufacturing, distribution, use and eventually recycling or destruction. Literature and papers about agents introduce among others, two types of agents:

1) reactive agents
2) reasoning agents

A reactive agent senses the environment acts according to the information its get from this sensing. There is no internal state involved. A reasoning agent also senses its environment but does have an internal state. Depending on the sensing input and the internal state it will search for an action to perform, one could say it will reason for the action to perform. The sensing input will also change the internal state. A special type of reasoning agent is the so-called belief-desire-intention-agent or BDI-agent [5]. This type of agent has its backgrounds in the philosophy of Dennett and Bratman [6] [7]. An internal schematic of a BDI-agent can be seen in figure 2 [4].

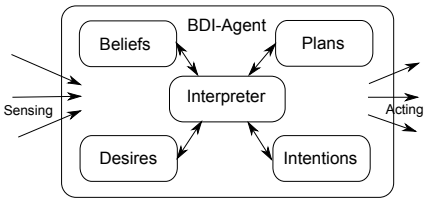

Fig. 2. BDI-agent

The beliefs, goals, desires and intentions could be viewed as the mental states of a BDI-agent.

- from the inputs of its sensors the agent builds a set of *beliefs*. Beliefs characterize what an agent imagines its environment state to be;
- *desires* describe agents preferences;
- *intentions* characterize the goals or desires the agent has selected to work on.

An agent is equipped with a set of *plans*. These plans have three components:

1) the postcondition or *goal* of the plan;
2) the precondition of the plan;
3) the course of action to carry out.

An agent will deliberately choose a plan to achieve its goals.

B. Multiagent systems

A multi-agent system (MAS) consists of two or more interacting autonomous agents [8] [9]. Such a system is designed to achieve some global goal. The agents in a multi-agent system should cooperate, coordinate and negotiate to achieve their objectives. When we consider the use of a multi-agent system we should specify abstract concepts such as:

- *role*: what is the role of a certain agent in a multi-agent system. Perhaps an agent has more than one role;
- *permission*: what are the constraints the agent is tied to;
- *responsibility*: i.e. the responsibility an agent has in achieving the global goal;
- *interaction*: agents interact with each other and the environment

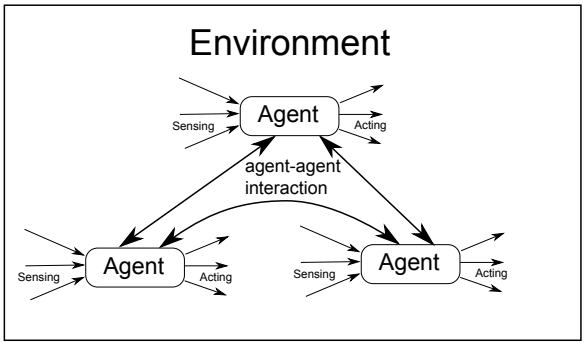

Fig. 3. Multi-agent system

For Multiagent system both modeling and development tools have been proposed [10] [11] as well as special multiagent programming languages like Jade, Jason and 2APL [12].

III. The product life cycle

In figure 4 a global overview of the phases in the life cycle of a product is depicted.

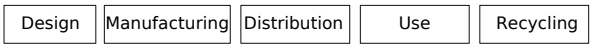

Fig. 4. Lifecycle of a product

The role of information and computer technology is different in all phases, resulting in different approaches at different phases that have no interconnection or interrelation. However in most phases information about previous phases can become very important as we shall show in the next sections. The reason why an agent is proposed is based on some important characteristics of agents:

- by its design and nature an agent should be autonomous. This feature is a basic property of an agent;
- an agent should communicate with its environment in the broadest sense: this means humans and systems. In a multiagent system agents, communication between agents is facilitated;
- an agent can react on events, coming from the environment as well as from other agents;
- because of the interaction with the environment and the capability to react according to events an agent could adapt itself to new and even unforeseen situations;
- as mentioned earlier, an agent can reason i.e. it can deliberately choose a plan to achieve its goals;
- because an advanced agent can reason about a situation in can be pro-active;
- some types of agents can move around from platform to platform. These are the so-called mobile agents;
- an advanced type of agent can learn from its environment and also from the effects of its actions and reactions;
- in most multiagent systems agents should be cooperative.

When agent-based product guidance is used, two possibilities arise:

1) one single agent is developed to guide the product during its whole life cycle;
2) a multi agent approach is used, where different agents operate at different phases but where information exchange between these agents is possible.

It depends on the situation which solution fits the best. If the different phases of the life cycle require for example

completely different agent architectures, a multiagent solution seems adequate. If on the other hand a 'one agent fits all' solution is possible, one could choose for this option. Without pretending to give an exhaustive overview, we will now describe some advantages of using agents in the life cycle of a product.

A. Design and manufacturing

In our view the design of a product will be greatly influenced by the individual end user requirements. This means that cost-effective small scale manufacturing will become more and more important. In [1] and [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. In this model every single product is guided through the production environment by a so-called product agent. This agent is responsible for the manufacturing of the product as well as for collecting relevant production information of this product. This is normally a function of the so-called Manufacturing Execution System (MES) [13]. The result is that every product has its own production journal in contrast to one journal for a whole batch of products. To make a smooth transition from design to production possible and a short time-to-market, the product agent is designed as a co-design for the product. Though this is all based on our own special production environment we expect this approach to be useful in other production environments as well.

Another multiagent-based production system is developed by Jennings and Bussmann [3]. This system focuses on reliability and minimizing downtime in a production line. This approach is used in the production of cylinder-heads in car manufacturing.

B. Product distribution

Product agents can negotiate with logistic systems to reach their final destination. Logistic applications based on multi agents systems already exist [14]. Information of product handling and external conditions, like temperature, shocks etc. can be measured by cheap wireless sensors and collected by the guidance agent during the transport or after arrival at the destination. The handling and external conditions during transport can be important during product use, especially for product quality, maintenance and repair.

C. Product use

The role of the product agent during the use of the product could focus on several topics. The first question one should ask is: who will benefit from these agents, i.e. who are the stakeholders. In a win win situation both the end user as well as the manufacturer could benefit from the information. If a product is a potential hazard (in case of misuse) for the environment. The environment could also be a winner if the agent is capable to minimize the effects of misuse or even prevent it.

1) Collecting information: A product agent can log information about the use of the product as well as the use of the subsystems of the product. Testing the health of the product and its subsystems can also be done by the agent. These actions should be transparent for the end user. If a product needs resources like fuel or electric power, the agent can advice about this. An agent can advice a product to wait for operation until the cost of electric power is low i.e. during the night.

2) Maintenance and repair: Based on the logging information about the product use and the use of the subsystems, an agent can suggest maintenance and repair or replacement of parts. Repairing a product is easier if information about its construction is available. Also the use of a product or the information about transport during distribution can give a clue for repair. An agent can also identify a broken or malfunctioning part or subsystem.

An important aspect of complex modern products are updates or in case of a late discovered manufacturing problem, callbacks. Information about updates or callbacks can be send to the product agent that can alert the end user in case it discovers that it fits the callback or update criteria. This is a better solution for a callback than globally advertising the problem and alert all users of a certain product when only a subgroup is involved.

3) Miscellaneous: Use of product agents could result in transparency of the status of a product after maintenance by a third party. The agent can report to the end user what happened during repair so there is a possibility to check claimed repairs. Of course the agent should be isolated from the system during repair to prevent tampering with it. Recovery, tracking and tracing in case of theft are also possible by using this technique.

D. Product recycling

Complex products will have a lot of working subsystems at the moment the end user decides it has come to the end of its life cycle. This is normally the case when a certain part or subsystem is broken. The rest is still functional, because in a lot of complex products the mean times between failure (MTBF) of the subsystems are quite different. The product agent is aware of these subsystems or components and depending on the economical value and the remaining expected lifetime these components can be reused. This could be an important aspect of 'green manufacturing'. An important issue here is that designers should also take in account the phase of destruction or recycling. Disassembly and reuse of subsystems should be a feature of a product for this approach to be successful.

IV. PRODUCT TYPES

This approach of having an agent for a product could be used on different kind of products, but one should investigate

if the final product has intelligence and hardware to communicate with the agent. Some products have this by nature (computers, cell-phones); for other products (cars) it should be a small investment.

A. Where do these agents reside?

The biggest challenge for implementing the approach of a guidance agent will be in the usage phase. This is where the product is under control of the end user and not as during the production under control of the manufacturer. In the latter case an agent based infrastructure can be implemented for the production system or production line. The same is true for transport and even disassembly of the product. In case of the usage phase, the agents should reside in a system that is connected to the product, but should be available at the moment the product itself is broken. This is comparable to the case of the so-called black box in airplanes. There are several possibilities, depending on the type of product:

- The agent runs on its own separate hardware that is closely tied to the product;
- The agent runs on the hardware of the product but stores information on a special place on the product itself. This information can be recovered after breakdown;
- Remote with a continuous connection;
- Remote on a 'connect when necessary' basis.

The last two options require a stub or entry point for the remote agent to make contact with the product system. The connection with the environment could be established by wired or wireless sensors or sensor networks as well as computer subsystems in the product. Interaction with humans in the environment could be established by a messaging system or human computer interface (HCI).

V. Related work

Agents for distribution, logistic applications and product manufacturing already exist [15]. In most situations agents represent human operators or negotiators. Jennings and Bussmann [3] introduce the concept of a product agent, in their terms workpiece agents, during the production. These agents do not however perform individual product logging. The use of a product is also studied by observing and/or interviewing end users [16] [17]. Some software applications do connect with their originating company to report the use by end users. We propose an agent for every product that is worthwhile without trapping in the pitfalls as described by Wooldridge [18]. One of the things they mention in their paper is: *agents may make it easier to solve certain classes of problems, (and there are good arguments for supposing that this is the case), but they do not make the impossible possible*. Another wise advise they give in their paper is to first investigate existing agent architectures for your situation instead of designing a completely new architecture from scratch.

VI. Conclusion

The use of software agents in product manufacturing is not new though not yet widely accepted., Their possibilities however can be extended to the whole life cycle of a product. This gives new opportunities to agile manufacturing and re-use of subsystems. This approach can also be used in other fields like health care (an agent for every patient) or supporting students (an agent-based student guidance system for a school or university). For these applications normally a central database is used. However in case of downtime all information is unavailable. By using an agent-based system, we have a more flexible, scalable, distributed and adapting software solution that is made to work autonomously and can stay in close contact with the product. The idea that ubiquitous computing will be the next step in the ICT revolution could be a good breeding ground for the ubiquitous agent approach. Agent technology could be a cornerstone in this concept.

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