

SAIIE25 Proceedings, 9th - 11th of July 2013, Stellenbosch, South Africa © 2013 SAIIE**DISTRIBUTED MANUFACTURING SYSTEMS AND THE INTERNET OF THINGS: A CASE STUDY**P. Butala^{1*}, R. Vrabič² and G. Oosthuizen³¹Faculty of Mechanical Engineering
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toosthuizen@uj.ac.za**ABSTRACT**

In order to stay competitive in today's global market, manufacturing companies need to be flexible. To ensure flexible production, shorten processing times, and reduce time-to-market, companies are utilizing the distributed manufacturing system paradigm, wherein geographically distributed, local resources are used for product development and production. In this context, the Internet of Things (IoT) has emerged as a concept which uses existing communication technologies, such as local wireless networks and the Internet to ensure visibility of anything from anywhere and at any time. In the paper, a case study of applying the IoT to the manufacturing domain is discussed. A distributed agent-based system for virtual monitoring and control of 3-axis CNC milling machine tools is designed and developed. The machines' 3D models and process states are shown through a web interface in real-time. The potential and challenges of implementing this system and the basic building blocks for decentralized value creation are discussed.

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1 INTRODUCTION

Manufacturing of products and goods is probably the most important economic activity in the world. It is the backbone of modern industrialized society and a cornerstone of the world's economy [1]. Manufacturing concepts and systems have always been influenced by new developments, especially the ones from computer, information, and communication sciences. Computers have been an integral part of Computer Integrated Manufacturing (CIM) concept and CNC technology, and have changed product design and manufacturing through development of Computer Aided X (CAx) methods. Having a strong manufacturing base is important to any society or community, because it stimulates all the other sectors of the economy [2].

A world where physical objects are seamlessly integrated into the information network in order to become active participants in integrated systems is the core objective of the *Internet of Things* (IoT) movement. As illustrated in figure 1, with time more physical objects will be equipped with sensors and be able to communicate. These ubiquitous connections will result in an information network that promises to create new business models, improve business processes, and reduce costs and risks. Services are available to interact with these 'smart objects' over the Internet, query and change their state and any information associated with them, taking into account security and privacy issues. Even in the last two decades, the Internet has provided ubiquitous information exchange and communication possibilities and in turn enabled a truly global production of goods and services. Furthermore, the business side was affected as well - several new business models have emerged, using the Internet as an integral part of value creation.

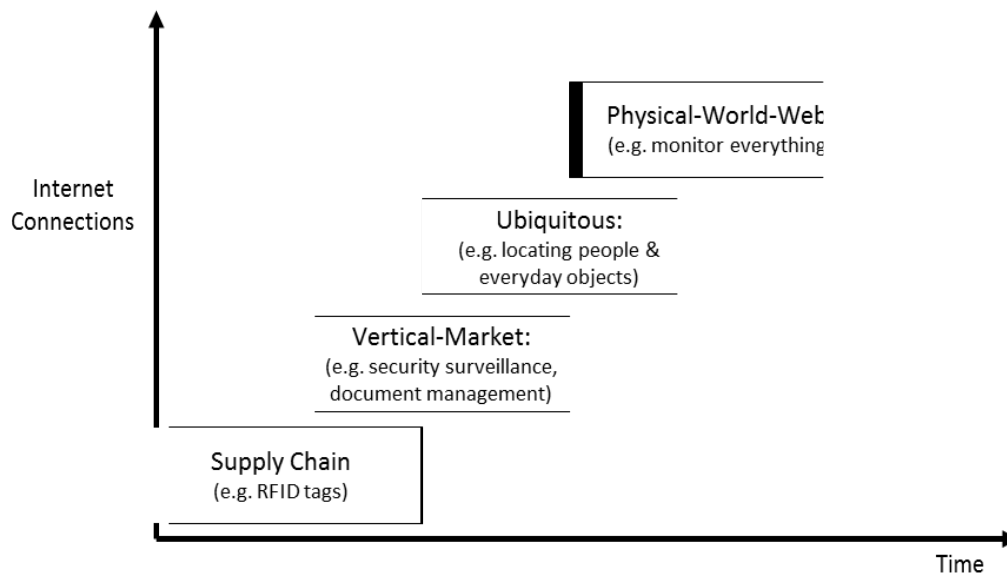


Figure 1: The Internet of Things (IoT) technology roadmap (Adapted from [3])

Promising approaches to the search for a new manufacturing paradigm include networked, adaptive, and ubiquitous manufacturing systems (UMS). UMS is an emerging manufacturing paradigm, stemming from the concept of ubiquitous computing [3]. In turn, these developments are enabling manufacturing companies to be more flexible and use this flexibility as a competitive advantage. Although ambient intelligence and autonomous control are not part of the original concept of the IoT, equipping manufacturing technologies with minuscule sensors, actuators or transceivers could be transformative to current production systems. The ability to interact could be used to remotely monitor and control manufacturing processes based on immediate or present needs, thereby eliminating factors like running out of inventory and generating unwanted waste. Production systems will thus be more prepared to balance supply and demand fluctuations [3].



Ubiquitous availability of information is enabling seamless operation of distributed manufacturing systems. Together with the services of high speed postal providers, geographical distances are becoming less and less meaningful. Products are being ordered through the Internet, manufactured all around the globe, and delivered rapidly within days. Bug Labs for example, helps organizations innovate in the rapidly-growing IoT market. It's unique, cloud-based platform abstracts the raw functionalities (e.g. sensors, actuators, transceivers) of any hardware device and exposes them as web services. Bug's Blocks are snap-together modules, including a powerful Linux-based CPU, sensors, actuators and transceivers, which allow rapid prototyping, cost-effective deployment and field upgradability in a wide variety of use cases. Therefore, companies who understand and properly manage the arising complexity are translating these opportunities into business success.

IoT is widely considered as *the* future technological development of the century. It is a concept which foresees that everything will be connected to the Internet including everyday objects. Innovative growing applications include waste management, urban planning, continuous care and emergency response, intelligent shopping, smart product management, and home automation. This will drastically change the way humans interact with their environment. The underlying principle is that machines should be left to do what machines do best, such as collecting data, automating tedious tasks and analysis, while humans should be left to do what they do best: creative thinking and synthesis.

The use of IoT in manufacturing is envisioned as connecting every element of a manufacturing system to the Internet, including machine tools, work pieces, manufacturing environments, and humans. This will enable new ways of managing manufacturing complexity, by providing relevant, context sensitive information to the right people at the right time, enabling them to improve their decision making.

In this paper, a concept of *internetization* - making things appear online - of elements of manufacturing systems is presented. The paper attempts to answer how to do that in a sensible way, and gives an outlook of how this can influence the manufacturing of today and tomorrow in different regions of the world.

The concept is discussed within the context of Ubiquitous Manufacturing Systems (UMS), an emerging paradigm, based on the principles of ubiquitous computing, wherein IoT is seen as the concept, underlying the Information and Communication (ICT) infrastructure for UMS.

A case study, illustrating the core components of the concept is developed. A CNC machine tool is mapped from real world to the digital and virtual ones.

2 THE INTERNET OF THINGS

The term Internet of Things encompasses a vision that everything will be connected to the Internet at some point in the future. However, the precise definition of the term is still not agreed upon. Ashton's original definition from 1999 [4] emphasizes the gap between the physical and the digital, and envisions the IoT as a bridge between the two:

Today computers—and, therefore, the Internet—are almost wholly dependent on human beings for information. Nearly all of the roughly 50 petabytes (a petabyte is 1,024 terabytes) of data available on the Internet were first captured and created by human beings—by typing, pressing a record button, taking a digital picture or scanning a bar code. Conventional diagrams of the Internet ... leave out the most numerous and important routers of all - people. The problem is, people have limited time, attention and accuracy - all of which means they are not very good at capturing data about things in the real world. And that's a big deal. We're physical, and so is our environment ... You can't eat bits, burn them to stay warm or put them in your gas tank. Ideas and information are important, but things matter much more. Yet today's

information technology is so dependent on data originated by people that our computers know more about ideas than things. If we had computers that knew everything there was to know about things - using data they gathered without any help from us - we would be able to track and count everything, and greatly reduce waste, loss and cost. We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best. The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so.

The definition explicitly outlines the potential benefits, relevant for the manufacturing environment: reducing waste, loss, and cost. The rationale is that decision making can be improved by providing precise and relevant information in real time. Other definitions, such as the one from Cisco Internet Business Solutions Group [5] simply define the IoT as:

IoT is the point in time when more “things or objects” were connected to the Internet than people.

Although this definition is very straightforward, it specifies that existing Information and Communication technologies (ICT) - the existing Internet - are the basis for the IoT. The whole idea is to literally have everything imaginable connected to a network as a computer that uses standard protocols (such as TCP/IP) to communicate. More accurately, a computer can be attached to any physical thing, acting as a sort of an agent - representing it in the digital world as illustrated in figure 2. In this view, digitalisation of the thing means simply creating its digital representation. This representation can then be involved in different kinds of computations, from data aggregation to simulation, which do not have a physical basis, and we therefore consider them virtual. The physical world can be connected to an organisation's execution system or enterprise resource planning (ERP) systems for multiple plant connectivity from the physical devices to enterprise level. Manufacturing organisations use these connected devices to get a virtual representation that can support strategic level decision making by detecting unusual patterns and initiating the appropriate measures.

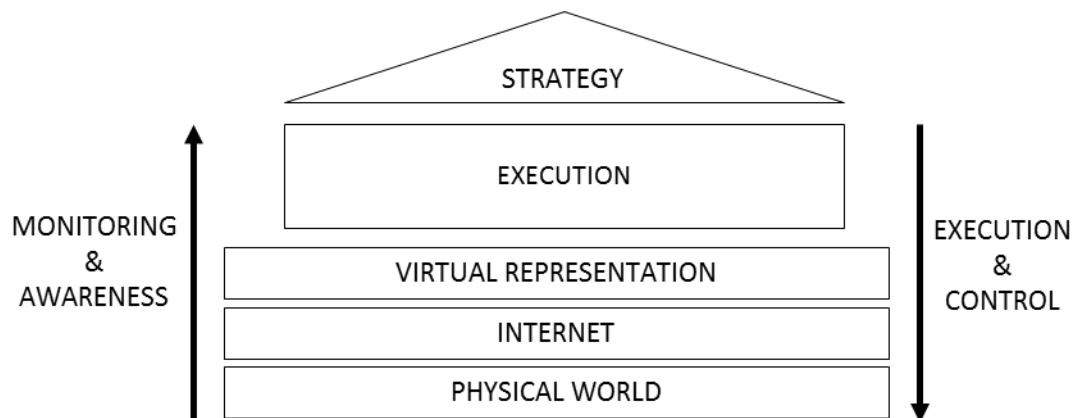


Figure 2: Connecting the physical world for consistent execution of strategy

Connecting a range of devices and systems together, by putting sensors in the physical world to monitor and control processes, can assist organisations with preventive maintenance. Still, it is not only about connecting devices, but about modelling and understanding changes of all the things to create a competitive advantage. Numerous technologies can be put in place at organisations to monitor and control these changes, of which Ethernet, wireless and cellular networks play a significant role. Using wireless networks to collect data and determinism to control decisions enables intelligent, anticipatory tracking of challenges.

From the above, it can be concluded that the IoT is a concept, and that it is based on existing ICT technologies, such as agent-based systems, web technologies, IPv6, computing technologies (grid, cloud), radio-frequency identification (RFID), near field communication,

only applied on a much bigger scale. Vendors are integrating RFID technology into existing sensor products, to log data economically and efficiently, which are wirelessly transmitted to a higher level (ERP) system when activated by a programmable logic controller. All of this forms part of the Industry 4.0 industrial revolution of seeking ways to help industry achieve greater flexibility and robustness while dealing with greater complexity.

Since the technologies already exist, the challenge is mainly of conceptual and practical nature, the question being: How can we use the existing technologies to make elements of manufacturing systems appear on the Internet, and furthermore, what can we do with that afterwards.

3 INTERNETIZATION OF MANUFACTURING - THE CONCEPT

In recent years, researchers have been searching intently for new manufacturing concepts that would replace the obsolete principles of scientific management postulated by F. W. Taylor a century ago and would create new fundamentals for the next generation manufacturing systems. Rising complexity of products, production systems and organisational structures [6] on one side and turbulent market fluctuations are setting new expectations to the manufacturing sector. In order to face these challenges a shift of the existent manufacturing paradigm is needed. Several innovative concepts emerged like the Fractal factory [7], Bionic manufacturing systems [8] and Holonic Manufacturing systems [9]. Other promising approaches to the search for a new manufacturing paradigm include networked, adaptive, and ubiquitous manufacturing systems (UMS). Peklenik [10] studies the concept of Distributed Manufacturing Systems (DMS) in terms of a Complex Adaptive Manufacturing System (CAMS), which is structured as a network of many agents acting in parallel, in series or both ways.

These new manufacturing structures are accompanied by a number of questions regarding their design, development, operations, and other life cycle phases, which have to be addressed and investigated in the framework of current research and development.

The UMS concept stems from the concept of ubiquitous computing, which is based on the observation that the number of computers (computing capable devices) per person is rapidly growing. In UMS, manufacturing organisations are connected into a global network, and reconfiguration takes place within the network. A definition of ubiquity in the manufacturing sense is provided by Weber, 1928 [11]:

Ubiquity naturally does not mean that a commodity is present or producible at every mathematical point of the country or region. It means that the commodity is so extensively available within the region that, wherever a place of consumption is located, there are ... opportunities for producing it in the vicinity. Ubiquity is therefore not a mathematical, but a practical and approximate, term.

This definition (albeit put forth in 1928) still encompasses the essence of the concept. Two notions are of utmost importance. Firstly, “extensive availability” implies a redundancy of resources. Having the “opportunity for producing a commodity in the vicinity” assumes that there are resources waiting to be utilised. Secondly, “availability within the region” and “vicinity” imply the presence of the geographical element of distance.

Since the definition had been put forth, advancements in the area of ICT have rendered geographical distance virtually non-existent in the informational sense. Furthermore, logistics services companies have greatly reduced the time and cost of physical transport and, in turn, contributed to the depreciation of the impact of geographical distance. This is why UMS are viewed as an extension of the Global Manufacturing concept, which aims to transcend national borders to leverage capabilities and resources worldwide.

Moreover, UMS build on the grounds of the Virtual Manufacturing concept [12]. This second influence stems from the fact that virtuality is a requirement for ubiquity. If ubiquity is



understood as “omnipresence”, then virtuality, “not physically existing as such but made (by software) to appear to do so” [13] is a mechanism that enables it.

Virtuality is also identified as an enabling factor for the creation of virtual organisations within business networks. The term “Virtual Breeding Environment” (VBE) is used to describe a long-term organisation that presents an adequate environment for the establishment of cooperation agreements, common infrastructures, common ontologies, and mutual trust [14].

A core part of a VBE is its ICT infrastructure, which facilitates the creation, operation, and eventual disintegration of the virtual organisations it contains. As these are distributed in nature, it is most appropriate that the infrastructure be distributed as well.

We propose that the IoT concept is used to facilitate the infrastructure. In other words, every object or thing should be represented on the Internet and be able to interact with others. Agent-based software technologies have turned up a promising approach for the development of such systems.

Agents are a branch of distributed artificial intelligence. Each individual agent in a Multi-Agent System (MAS) works autonomously in order to achieve its own goals. A MAS thus represents a loosely coupled network. However, one of the key capabilities of agents is that they can cooperate through communication and thus solve problems that are beyond their individual capabilities [15].

Applications of MAS in manufacturing are numerous [15, 16]; however, the focus in this paper is on their support role in the interoperability of networked systems, where coordination, collaboration, and cooperation all play an important part. Accordingly, agents are seen by the paper as an underlying principle for the creation of the IoT and as an enabling technology, rather than in their problem solving sense which is more common in the area of artificial intelligence.

Some of the properties of MAS make them especially suitable to form the basis of an ICT infrastructure. MAS are distributed in nature, scalable, robust, and fault-tolerant. Nevertheless, other desired properties such as reconfigurability and flexibility are application specific and have to be implemented by the software creator as the logic and/or the architecture of the MAS.

The infrastructure consists of three layers, a physical, a digital, and a virtual one. The Elementary Work System (EWS) [17] is taken as the primary concept in system structuring. The EWS concept originates in the cybernetic approach towards the modelling of manufacturing systems. EWS is defined as the smallest structure capable of carrying out a process. The concept’s greatest power is that any manufacturing system can be described as a set of EWS.

The universal structure of the EWS is adopted as the basis for the definition of UMS elements. In accordance with the concept, these elements are processes, inputs, outputs, process implementation devices (i.e. machine tools), human subjects, and environments. If a manufacturing process is to be carried out, all of these elements have to be involved. For example, even in completely automated line production, human subjects have to set references and are involved in line supervision.

In general, elements can be tangible or intangible and must be connected when a process is to be performed. Therefore, they have to exist on the same layer of the information infrastructure. A three-layer approach presented in figure 3 is proposed.

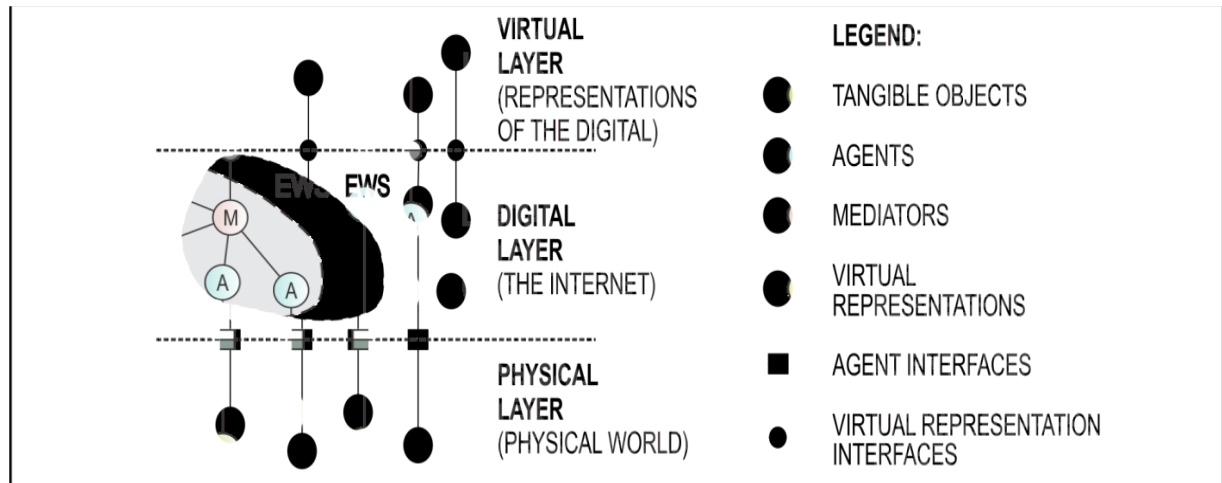


Figure 3: ICT infrastructure conceptual layers.

The physical layer contains tangible objects such as blanks, products, machine tools, and human subjects. These objects are represented on the Internet by software agents on the digital layer. Agents and elements communicate through agent interfaces, which are implemented in software. Additionally, agents of intangible elements such as NC programs or process plans exist on the digital layer.

Agents can themselves be represented on the virtual layer, allowing them to participate in a virtual world. The virtual layer can provide the means for subjects not present in the network to communicate with the agents of the digital layer (i.e. through social networks). In addition, the virtual layer can be used to connect multiple networks with incompatible digital layers due to different rule sets, ontological definitions, or communication protocols. Agents manage their virtual representation through virtual representation interfaces.

Communication within the network can take place between elements or their representatives on the same conceptual level, or between an element and its representatives via an interface. Such structure offers parallel communication, integration of different networks, and more options for potential users to participate in the network. The network hence becomes open and flexible.

The agents of the digital layer do not form a hierarchy. No agent has authority over others. Therefore, in order to manage work within a network, mediator agents (or mediators) are introduced. Mediators create organisational connections between elements and can be seen as the basis of the digital infrastructure.

Mediators facilitate a market mechanism of supply and demand following the business-to-manufacturing-network concept [18]. The market can function as a sort of a self-regulating system. The mediators act autonomously but have to comply with the rules set by the network.

In summary, to facilitate the IoT in manufacturing, elements of manufacturing systems need to be represented on the internet. We propose that this is done through software agents, representing the elements in the digital world. On top of that, the agents are responsible for virtual representations of the elements, interacting in different virtual environments.

4 CASE STUDY

The proposed ICT infrastructure is implemented in a case study of an experimental network at the University of Ljubljana also intended for the potential implementation in a global manufacturing network that is built upon a UMS test-bed [12, 19].

The test-bed was developed to support research in the fields of new manufacturing structures design and control, teleservices, dynamic reconfigurability, and semiotic-based

information systems [20]. In this case study, the test-bed is used for the proposed ICT infrastructure concept validation as shown in figure 4.

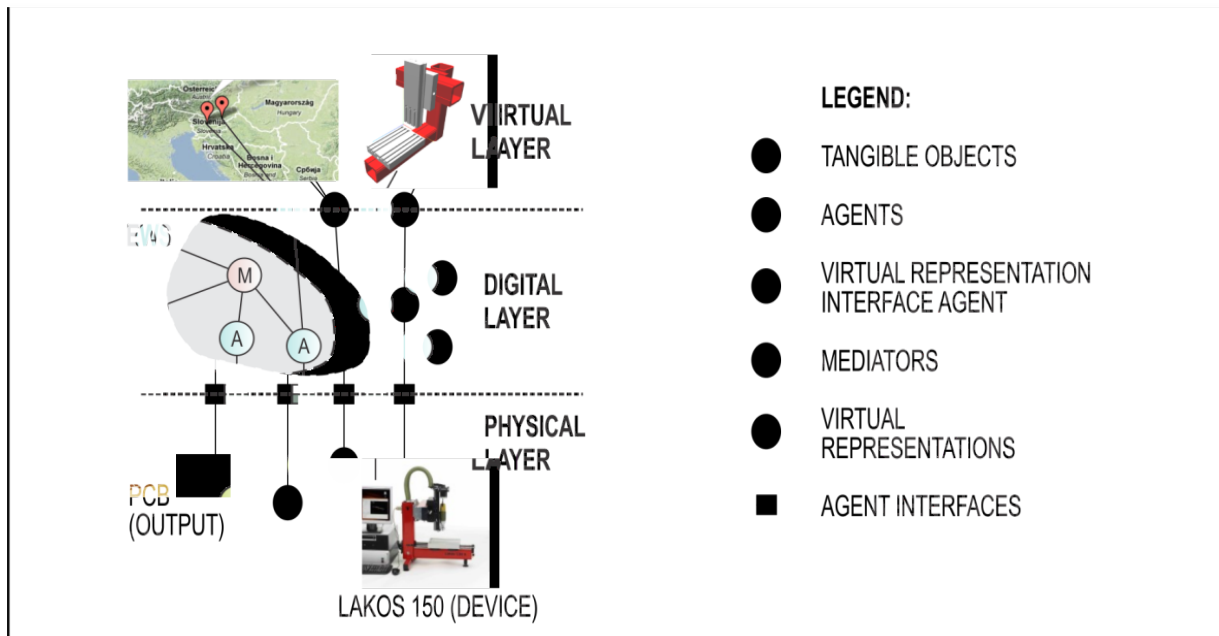


Figure 4: EAC installation at the University of Ljubljana.

The test-bed is composed of several Experimental Autonomous Cells (EAC) interconnected in a manufacturing network. Each EAC is composed of two desktop CNC engraving machines LAKOS 150 and the supporting infrastructure such as controller computers and web cameras. The CNC machines are capable of performing 2D or 3D engraving, milling, and drilling operations on small work pieces made of light materials. Their controller is based on open architecture principles and open source, and allows for the machine to be integrated with the experimental test-bed.

An important part of the cell is the human subject that operates it. There are many potential operators for a single machine. Because of the educational purpose of the machine, the number can vary significantly.

Virtual representations of outputs are generated by part designers and collected in a parts library. After part design is completed, a process engineer prepares a process procedure, which is also virtually represented and stored in the library. In the case of EAC cells, the environment is the research laboratory.

EAC are viewed as geographically connected units, but their components are not necessarily connected in the logical sense. This is because, in accordance with the proposed model, the basic elements are not cells but rather their components.

Each component is represented on the digital layer by an agent, and the components together form a MAS. Agents are developed using the Jade software library [21] which supports the FIPA standard [22]. Interoperability of the MAS is thus provided. This also allows for an easy inclusion of new elements and contributes to the robustness and fault-tolerance through mechanisms such as agent life-cycle management and agent container replication.

From the MAS standpoint, the system is organised as follows: The whole network corresponds to the agent platform. The agent containers that make up the platform are situated each on its own computational device. Finally, each EAC component is represented by one agent.

In the case study, several virtual layers are developed. Firstly, a Google Maps ® user interface is developed, on which agents' geographical location is presented. The primary objective of this virtual layer is to enable human subjects to monitor the system through an

intuitive interface. Secondly, a 3D representation interface is developed, showing the 3D models of the machine tools in real time along with information about the process which they are performing. The virtual layers are implemented through virtual profile interfaces, which are themselves agents. The architecture of the system is shown in figure 5.

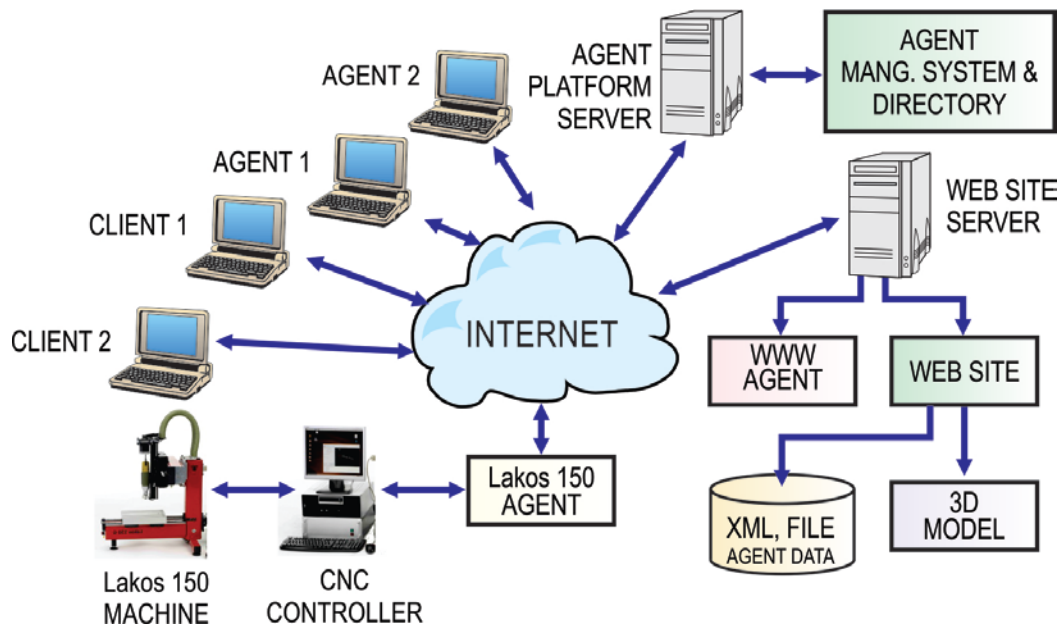


Figure 5: The architecture of the case system.

The user interfaces of the virtual representations - the Google Maps ® and the 3D model interface - are shown in figure 6. Monitoring and controlling distributed process technologies are possible with this virtual representation.

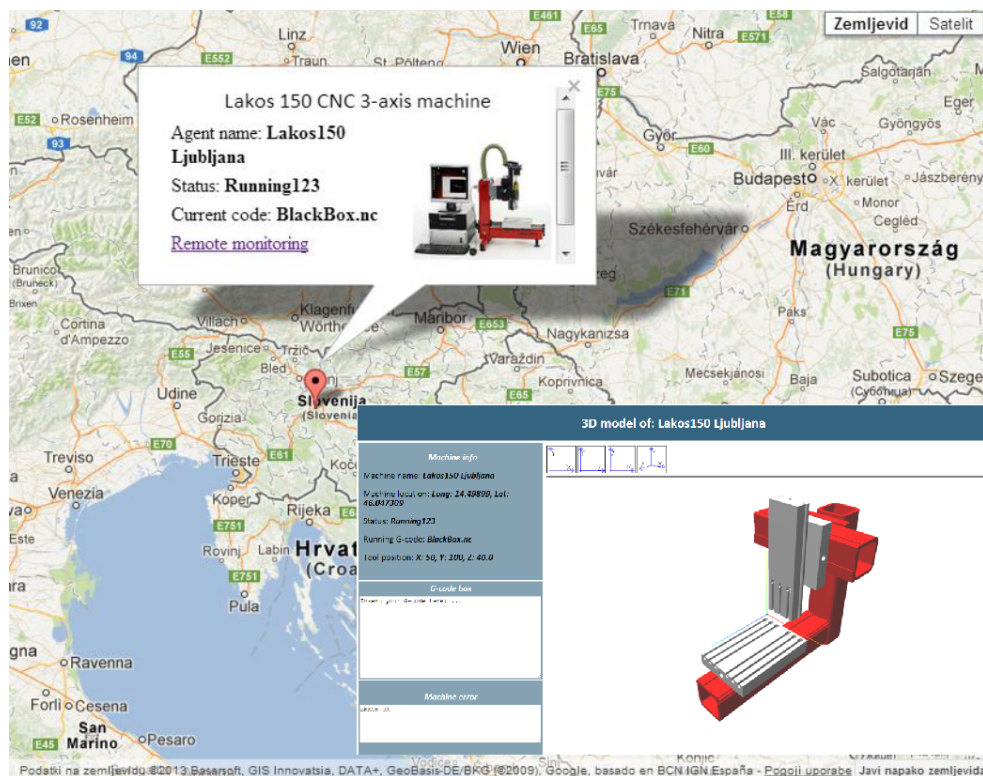


Figure 6: The virtual representation of the machine tool, showing its geographical location of a Google Map ®, and its 3D representation - synchronised with the physical system in real time.



5 CONCLUSION

The paper discusses the Internet of Things, its role in manufacturing and new possibilities which it will bring for distributed manufacturing systems - i.e. manufacturing systems utilizing local resources for product development and production. The use of IoT in manufacturing is envisioned as connecting every element of a manufacturing system to the Internet in order to provide context sensitive information to the right people at the right time, enabling them to improve their decision making. We suggest that in order to facilitate the IoT in manufacturing, the Information and Communication Technology infrastructure must also be distributed and propose an agent-based model.

A three-layer architecture is proposed: a physical layer where tangible object exist, a digital one where software agents representing tangible and intangible objects are organised to do work, and a virtual one that serves primarily as an interface with external stakeholders such as network users and other networks.

The case study presents an implementation of the concept. A network of experimental autonomous cells serves as a test-bed for the implementation. The virtual layers of the case study give external users an insight into the state of the network. A 3D virtual representation of the Lakos 150 machine tool allows for remote monitoring and control in real time.

Future work will focus on a broader implementation of the base ICT infrastructure within the network and on further development of the concept, particularly the mechanisms that enable work to be done.

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