WIRELESS TECHNOLOGY AND ITS APPLICATION TO NEXT GENERATION OF MANUFACTURING SYSTEMS

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Abstract: Wireless technology has evolved radically into key technologies that allow its application to Next Generation Manufacturing Systems. However the impact in nowadays business has been limited therefore a revision of relevant issues and trends is a must to establish a coherent vision for future research. This paper summarizes the underlying principles and challenges for the application of wireless technology, and its impact on next generation of manufacturing systems.

Keywords: Manufacturing systems, sensor networks, wireless communication systems.

1. NEXT GENERATION MANUFACTURING SYSTEMS

Emerging economies, social and political transitions, and new ways of doing business are changing the world dramatically. These trends suggest that the competitive environment for manufacturing enterprises in 2020 will be significantly different than it is today. To be successful in this competitive climate, manufacturing enterprises of 2020 will require significantly improved technological capabilities. The acquisition of these capabilities represents the challenge facing manufacturing.

A new competitive environment for industrial products and services is emerging and is forcing a change in the way manufacturing enterprises are managed. Competitive advantages in the new global economy will belong to manufacturing enterprises, which are capable of responding rapidly to the demand of high quality, and highly customized products. Operating new competitive firms is becoming more difficult as product variety and options increase, product complexity increases, product life cycles shrink, and profit margins decrease. In addition, the capital costs of manufacturing technologies are extremely high. These factors impose high productivity levels for labor and manufacturing facilities. There is also the need to create the next generation manufacturing systems with higher levels of

flexibility, allowing these systems to respond to very dynamic market demands.

1.1 Next Generation Manufacturing Systems

The results of a study carried out in the United States for establishing the visionary manufacturing challenges for 2020 (National Research Council, 1997) defined the following six grand challenges for manufacturers that represent gaps between current practices and the vision of manufacturing 2020:

- Grand Challenge 1. Achieve concurrency in all operations.
- Grand Challenge 2. Integrate human and technical resources to enhance workforce performance and satisfaction.
- Grand Challenge 3. "Instantaneously" transform information gathered from a vast array of diverse sources into useful knowledge for making effective decisions.
- Grand Challenge 4. Reduce production waste and product environmental impact to "near zero".
- Grand Challenge 5. Reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities.
- Grand Challenge 6. Develop innovative manufacturing processes and products with a focus on decreasing dimensional scale.

Additionally to these grand challenges, the Next Generation Manufacturing Systems (NGMS) will be more strongly time-oriented while still focus on cost and quality. A NGMS will need to satisfy the following fundamental requirements:

- Enterprise Integration.
- Distributed Organization
- Heterogeneous Environments
- Interoperability
- Open and Dynamic Structure
- Cooperation
- Integration of humans with software and hardware
- Agility
- Scalability and,
- Fault tolerance.

All of these requirements have to be satisfied by new technologies that allow a company to integrate all its operations vertical and horizontal achieving Enterprise Integration. Enterprise Integration (EI) consists in connecting and communicating all the functional areas of an organizational to improve synergy within the enterprise to achieve its mission and vision in an effective and efficient manner. The integration concept of providing quickly the right information at the right place at the right time under the right format throughout the enterprise is therefore evolving. Enterprise Integration (Vernadat, 2002) now concerns:

- efficient business process management, integration and coordination;
- Team collaboration supported by Computer supported collaborative work (CSCW) for concurrent design and engineering activities;
- increased flexibility throughout the company;
- product life cycle management throughout the existence of a product
- interoperability of Information Technology solutions, systems and people to face environment variability in a cost-effective way.

Among all these issues, process management, integration and coordination remains the most challenging one because of its knowledge intensive nature (including hard problems dealing with semantic unification), and the need for sound negotiation mechanisms among executing agents.

1.2. Technical trends

The following technological areas (National Research Council, 1997) have been defined to be core for the success of next generation manufacturing:

- Adaptable, integrated equipment, processes, and systems that can be readily reconfigured
- Manufacturing processes that minimize waste production and energy consumption
- Innovative processes to design and manufacture new materials and components
- Biotechnology for manufacturing
- System synthesis, modeling, and simulation for all manufacturing operations
- Technologies that can convert information into knowledge for effective decision making
- Product and process design methods that address a broad range of product requirements
- Enhanced human-machine interfaces
- Educational and training methods that would enable the rapid assimilation of knowledge
- Software for intelligent systems for collaboration

All of these areas are strongly related to the concepts of Enterprise Integration, and therefore it is important to foster the application of EI concepts to support the generation of new technological solutions.

Recent advances in information and communication technologies have allowed manufacturing enterprise to move from highly data-driven environments to a more cooperative information/knowledge-driven environment. Enterprise knowledge sharing (know-how), common best practices use, and open source/web based applications are enabling to achieve the concept of integrated enterprise and hence the implementation of networked enterprises.

2. WIRELESS TECHNOLOGY: STATE OF THE ART

The wireless technology has been developed from the 1920's when it was used like another alternative to send telegrams, later like radio (also known like walkie-talkie), to develop services of digital communication that are offered nowadays. In the last years the use of wireless technology has seen a fast growth, due to the increase of requirements (Morel, *et al.*, 2003) of telecommunications, data transfer and IT devices in companies, the educative area and homes. These requirements are mentioned by Novel Networks:

- Great communication speed
- Shared access to files, data/knowledge bases
- Exchange of picture, voice – multimedia applications
- On line/real-time access
- Access for anybody, from anywhere, at any time, -mobility
- Reliable secure exchange of information
- Intelligent user interfaces
- Easy and cheap installation

But all of these requirements have not been implemented in one type of network; nevertheless there are networks that fulfill some of these characteristics depending on the application. Within the wireless technology, different platforms exist (Intelligent Manufacturing Systems, 1994; National Research Council, 1997) that are currently in use and their usage are limited depending on the application. A structured overview of the different wireless technologies based on (Mezgár, 2004) is shown in Table 1:

Table 1. Main characteristics of wireless networks

Wireless network type	Operation frequency	Data rate	Operation range	Main characteristics
Satellite	2170–2200 MHz	Different (9.6 kbps - 2 Mbps)	Satellite coverage	Relative high cost, availability
WWAN				
GSM (2-2.5 G)	824-1880 MHz	9.6 - 384 kbps (EDGE)	Cellular coverage	Reach, quality, low cost
3G/UMTS	1755-2200 MHz	2.4 Mbps	Cellular coverage	Speed, big attachments
iMode (3G/ FOMA)	800 MHz	64 - 384kpbs (W-CDMA)	Cellular coverage	Always on, easy to use
WWLAN				
IEEE 802.11a	5 GHz	54 Mbps	30m	Speed, limited range
IEEE 802.11b	2.4 GHz	11 Mbps	100 m	Medium data rate
IEEE 802.11g	2.4 GHz	54 Mbps	100-150m	Speed, flexibility
WPAN				
Bluetooth	2.4 GHz	720 kbps	10 m	Cost, convenience
UWB	1.5 – 4 GHz	50-100 Mbps	100-150 m	Low cost, low power
ZigBee	2.4 GHz, 915 - 868 Mhz	250 Kbps	1-75 m	Reliable, low power, cost effective
Infrared	300 GHz	9.6 kbps-4Mbps	0.2-2 m	Non interfere, low cost

Nevertheless each one of these platforms differs from the others; each one having singular characteristics of transmission and reception, inherent properties to its design, in which they were made to fulfill some specific objective (bandwidth, transmission frequency, transmission distances) and they are commonly used nowadays.

3. APPLICATION OF WIRELESS TECHNOLOGY IN NGMS

Nowadays, manufacturing enterprises in general have adopted five or four functional levels to realize their function. A de-facto standard has already emerged, by the petition of various standardization bodies such as ISO and NIST (National Institute of Standards and Technology), together with various European projects within ESPRIT (BSI PD 6526:1990). This de-facto standard had partitioned the factory into five hierarchical levels: Facility (Factory), Shop (Area), Cell, Work station and Equipment (Chen and Doumeingts, 2003; Chen and Vernadat, 2004).

2.1 Concerning Wireless Sensors Networks (WSN)

There is a wide range of applications where the WSN are extensively used, and its development in other applications is in growth. There are applications from building automation, to military equipment, chemistry process industry, environmental research, and even surgical procedures. Each application has its requirements (Zhao and Guibas, 2004), which must be accomplished to make it work, reason why certain factors are due to consider:

- The number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network
- Sensor nodes are densely deployed
- Sensor nodes are prone to failures
- The topology of a sensor network changes very frequently
- Sensor nodes mainly use broadcast communication paradigm whereas most ad hoc networks are based on point-to-point communications.
- Sensor nodes are limited in power, computational capacities, and memory.
- Sensor nodes may not have global identification (ID) because of the large amount of overhead and large number of sensors.

Sensor networks may consist of many different types of sensors such as seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic and radar, which are able to monitor a wide variety of ambient conditions that include the following:

- Temperature
- Humidity
- Vehicular movement
- Lightning condition
- Pressure

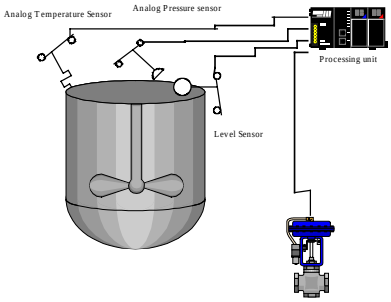
- Noise levels
- Proximity
- Mechanical stress levels on attached objects
- The current characteristics such as speed, direction, and size of an object

The sensor nodes can be used to sense continuously, for detection of events, identification of events, location, and local control of actuators.

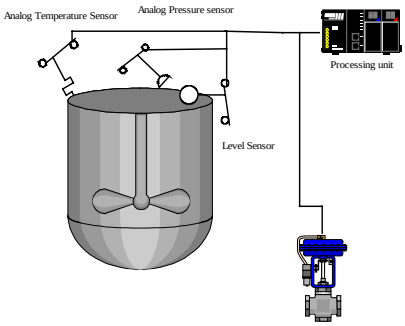
The WSN can be used as a wired sensor network, (Figure 1), the mains advantages are:

- Mobility.
- Fast reconfiguration

Currently, the factory are changing the wired sensor by the networked sensor for example the used of different technologies (profibus, profinet, CAN, ASi, etc.).



Wired Sensors



Networked Sensor.

Fig. 1. Wired Sensors vs Networked Sensor. Cabling structure differences between two types of network.

An individual machine has sensors for verifying initial conditions, security procedures. In the manufacturing process WSN can sense light, temperature, sound, acceleration, etc., without wired the sensor, this technology can give mobility, achieve fast device mounting, interchanging and redundant/non-redundant feedback of variables. (Figure 2).

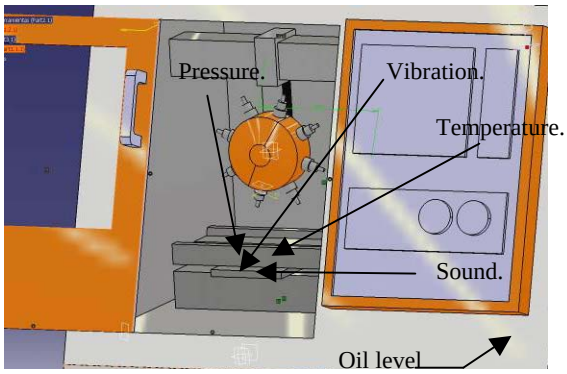


Fig. 2. WSN opportunities. The WSN can sense physical variables in manufacturing process.

- **Inspection and Traceability**

WSN can track a product in the process or in the workshop and must to be able to make inspections and corrections of the information to feedback about a product to a control computer so it can make decisions as to regarding on the information it has just received, what to do, locate it, or how to treat that product (Figure 3), also this system can give information about: the place where the part is in, process failures, and quality process, and eliminating the need for manual pallets scanning.

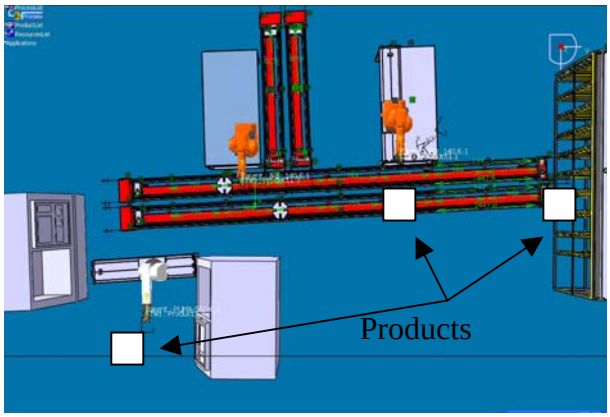
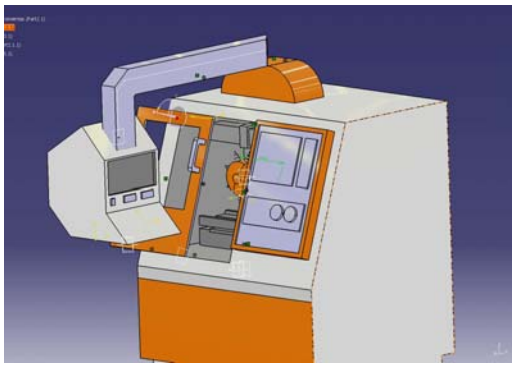


Fig. 3. WSN can tracking products in process inside factory warehouse.

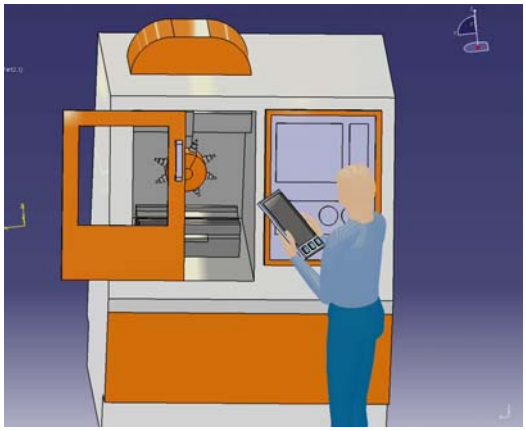
- **Controls (PLCs, CNCs)**

WN can be used in multiple wireless cells joined by a wireless local area network (WLAN) also the PLC slave can communicate with the PLC.

With wireless tablet PC, we can take control of the machine (HMI), and this system eliminates the big HMI. (Figure 4 a, b)



a)



b)

Fig. 4. Types of CNC controls. The Machine is controlled by HMI a) wired b) Tablet PC or handheld

- **Shop Floor Management and Manufacturing Execution Systems**

WSN can track products in the process the network captures the product name or number. It starts with processing the information of the product such as part name, special treatments, and instructions on what to do with the product, in other words, the product genealogy. Then the process is modified according to this information. It may change feed speeds, position, velocities of manipulators, etc.. The different cells can interchange information for manufacturing the correct part or element.. WN are useful to communicate the shop floor and the lower levels (Industrial Network) with the WON (wireless office network) for total integration and monitoring of the facilities.

The WN link between these two networks is useful because it provides all the required information of the warehouse and the raw material and supplies, besides that there can be a WS counting how many products are in stock and how many have been already delivered. All these information is helpful to know the overall production which is managed by the Industrial network, and also the info of the WON about the client requirements in order to be able to optimize the production and start drafting and designing better models for production, optimizing or implementing marketing plans to improve sales and ponder maintenance costing when a specific amount of products have already being produced.

- **Interoperability of ERPs, MES and PLCs.**

The main problem with ERP or MES is “bad information” WN can send information automatically to ERP database without human intervention. With mobiles PCs (laptops), or handheld, the personal can get information about status of machines, critical alarms, and check the work in process (WIP), verify operations instantly, track sales etc, this system can help for Kanban/Just-in-Time strategies.

- **Interoperability of Supply Chain Systems (Supply Chain Management)**

WN can manage the inventories in the warehouse; give information about purchased raw material, selling of goods, etc using a PDA, handheld, PC with Internet connection or a cellular phone. This information can be sent by satellite or by Wireless Wide Area Network. (WWAN) and Internet WNS (Vernadat, 1996) can be considered a WEB-based technology.

2.2 Concerning Wireless Personal Area Network (WPAN)

Warehouse workers are increasingly demanding mobile scanners or pen-based computing tablets to access data in real-time. These devices are linked to mainframes or servers that usually have a software application running on such as inventory collection, order fulfillment, and shipping/receiving applications. By connecting to inventory records and purchase orders, companies reduce the inefficiencies of transferring numbers through paper forms.

Wireless LANs connected to automated handheld computers on manufacturing or factory floors are a viable alternative to wired LANs. Laying cable in these environments proved cost prohibitive, or not feasible because of the size of the warehouse. Also changes in assembly lines are frequent and many employees do not work in any fixed location for one straight month. In this study, we have seen that workers and management in the manufacturing environment need instantaneous access to accurate information so they can improve track orders, production runs, and production quantities in real time.

Wireless LANs aid production, maintenance, and troubleshooting (repair) process at production bays of a foundry, production lines of an automotive manufacturer, and the outside work area of an aircraft manufacturer. The use of production planning and control software combined with wireless LAN technology illustrates the positive effect of this specific

IT on an organization. A typical medium-sized to large manufacturing firm must stock, control and ensure the availability of thousands of items (end products, parts, and raw material). Further, production of the parts and raw material must be coordinated to ensure that the firm meets order commitments and production plans. Using manufacturing software with automated inventory status reporting, order processing, production scheduling, and invoicing features, made possible for companies to control system complexity. But in this study, we found that having a wireless LAN connected to this software enabled operators to go beyond second-guessing the age of the information coming over the wire. It appeared in real-time or nearly real time. This combination of hardware and software reduced the control and coordination and associated costs.

3. POTENTIAL PITFALLS OF THE APPLICATIONS

The main reasons could be:

- The cost involved
- Complexity of technology
- Reliability of technology
- Limited end-user applications
- Lack of technical expertise
- Project size and duration:
- Management support:

Nevertheless, the enthusiasm of the technologists and research community remains intact and the future look bright for the potential application of wireless technology in manufacturing.

4. CONCLUSIONS

Wireless technology is still developing and currently mostly relies on: advanced computer networks, worldwide web and Internet, platforms integration as well as data exchange formats. However, system interoperability is still very weakly addressed compared to real needs.

A big problem is that wireless technology is almost totally ignored by SME's (Small and Medium Enterprises) and there is still a long way to go before SME's will master this technology.

It is the author's opinion that these technologies would better penetrate and serve any kind of enterprises if:

- There was a standard vision on what wireless technology really is and if there was an international consensus on the underlying concepts for the benefit of business users.
- There were de facto standards that will make companies feel secure on their investments.
- There were real commercially applications available taking into account the needs of industry.
- There were design patterns of components available as (commercial) building blocks to design, build, and implement large-scale systems.
- There were commercially available integration platforms and integrating infrastructures (in the form of packages of computer services) for plug-and-play solutions.

These are some of the challenges to be urgently solved in the coming years to build more wireless applications in manufacturing.

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