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# Role of Sensors in Intelligent Manufacturing Systems

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***Abstract* - Globalization, exchangeable market requirements and modern lifestyle trends establish tremendous challenge to manufacturing industries. Today, the competitiveness of any manufacturing industry is determined by its ability to respond quickly to the rapidly changing market and to produce high quality products at low costs. However, the product cost is no longer the predominant factor affecting the manufacturers' perception. Other competitive factors such as flexibility, quality, efficient delivery and customer satisfaction are also subject of consideration. Manufacturing industries have an ambition to achieve these capabilities through automation, robotics and other innovative concepts. Intelligent manufacturing systems (IMS) are means to accomplish the requirements such as reduction of inventories and market-response time to meet customer demands, flexibility to adapt to the changes in the market, reducing the cost of products and services to include more market shares as well as elimination of worker hand intervention. All IMS subsystems are equipped with highly effective sensors for perceiving inputs and acting accordingly. This paper defines the components of a simplified intelligent manufacturing systems (IMS) and illustrates the classification of the most frequently used kinds of sensors (tactile, proximity, vision). Correctly selected, installed and trained (programmed) sensor will significantly extend the operational capability of the system. Because CAx-technologies" (computer-aided technologies) are an integral part of every intelligent manufacturing this paper also presents uses of their integration.***

***Key words:* intelligent manufacturing system, Cax-technologies, tactile, proximity, vision sensors**

## I. INTRODUCTION

Automation is one of the major indicators of the change in manufacturing. Machines behaving themselves not only decrease the cost but also produce the products to be more compliant with the needs and specifications of the customers. Although technologies such as flexible manufacturing systems provide various advantages, automation itself is not enough to provide competitive advantage. In most of the modern manufacturing facilities, machines are capable of making decisions and exhibiting intelligent behaviour. That is to say that the manufacturing related activities starting from the design to product shipment are being carried out through intelligent manufacturing technologies. As traditionally known, manufacturing systems are the integrated combination of various functions such as design, process planning, production planning, quality assurance, storing and shipment etc. In each of these functions several activities are carried out. Manufacturing organizations have been facing a very challenging environment with dynamic and increasing complexity of activities. There is still a need for more flexible and dynamically changing systems to cope with the market requirements.

Intelligent manufacturing systems are capable of providng this flexibility with increasing performance. They can facilitate highly complex manufacturing systems as well as various degrees of functionality of products. As they can handle design changes as quickly as possible, they can easily adapt themselves to the changes in the market and satisfy customer requirements, which are most of the time too versatile. They can also embed new methodologies and technological progress without any problem. Since complexity and functionality of the products are increasing and companies need to sustain advantage in heavy competitive markets, it is not possible to make proper and effective decisions without the help and support of computer based manufacturing systems. Considering interrelated activities in various manufacturing units, the importance of intelligent systems becomes more obvious than ever before. Since they can foresee problems before they occur and provide respective remedies, intelligent manufacturing systems can be extremely useful in supporting the expected level of competitiveness. Another aspect of intelligent manufacturing is that, the traditional systems cannot be easily expanded in accordance with the technological achievements.

All IMS subsystems are including parts of so called machine intelligence (sensor equipment). Basics which are needed for realization of machine intelligence in manufacturing systems is so called monitoring, which is able to monitor internal stay of the system and also changing conditions coming from environment. Monitoring systems are using sensors which are located at some proper place of the system, usually such place is tool, machine or some manipulating device. Sensors are identifying parameters which are then used as input data of control system. Following to this data is realized some, technological, manipulating or other helping process [1].

## III. CAX SYSTEM IN THE IMS

CAD/CAM represents the first real integration between CAx systems, mainly between CAD and CAM systems. System CAD/CAM integrates modelling component and his construction design, technological design documentation in the form NC programs and operation control of production into a single computer system. The benefits this integration system is his ability to solve complex and difficult tasks. Integration parts of CAD/CAM system is product model and the internal database system. The term CAD/CAM represents technology which use numerical computer to perform certain functions in before-production stages and in the production itself. This technology represents the integration of the preparation and production processes in all industrial activities. Computer Integrated Manufacturing (CIM) represents the integration of traditional production and engineering technologies with the computer technology, which enable the automation all activities from product design to their expedition (design of products, creation of technological procedures, production planning, operative control, manufacturing of products, quality control, assembly, packaging, expedition, etc.), with goal to bring down of the material and energy pretension, to increase of work productivity, to bring down of supplies, to shorten of development and production time, to increase of time and power utilize of production devices and it increase of products quality [2].

## III. INTELLIGENT MANUFACTURING SYSTEM

Short manufacturing cycle times, shorter supplier times, adaptation to the changing situations in a short time frame, consistent knowledge flow, etc. provide advantages to global economic competition for which most of the manufacturing organizations need to sustain. Intelligent manufacturing systems are proven to be an effective tool for assuring these advantageous. IMS consist of the following components Fig. 1:

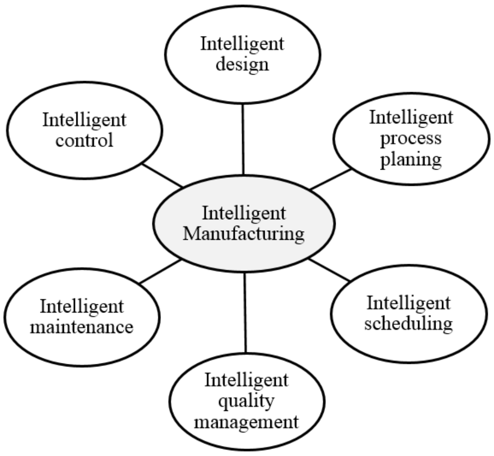


Fig. 1. Intellignet manufacturing content [3]

***Intelligent design.*** A firm's products or services are typically the primary source and focus of contact with its customers, and the development of new designs plays a key role in establishing and maintaining a competitive position for most firms.

***Intelligent process planning.*** Process planning provides a detailed description of manufacturing capabilities and requirements for transforming a stock of raw material into a completed product [4]. Intelligent process planning include Computer-Aided Process Planning (CAPP) and facility and location layout. A CAPP system contains a large amount of knowledge that includes rules about arranging machine operations and facts about the machine shop.

***Intelligent quality management***. More organisations are involving customers in the early stages of design to assure quality and a market for their products. There are two approaches to quality assurance [5]: reactive quality assurance and proactive quality assurance. Reactive tools include sampling plans, lot acceptance determination, scrap or rework analysis etc. Proactive strategy requires an emphasis on physical cause-effect knowledge, risk analysis, experience and judgement.

***Intelligent maintenance and diagnosis.*** The goal of fault diagnosis is to detect the faults and their causes early enough, so that failure of the overall system can be avoided.

Maintenance management and planning is a fundamental component of successful manufacturing operations. Scheduling preventive maintenance activities is an important aspect of maintenance management and it is particularly challenging for large and complex systems with many thousands of components.

***Intelligent scheduling.*** Scheduling is a resource allocation problem subject to allocation and sequencing constraints. It is an optimisation problem. The objective in optimisation is to allocate a limited amount of resources to a set of tasks such that cost functions are optimised.

***Intelligent control.*** The basic objective of control is to provide the appropriate input signal to a given physical process to yield the desired response. It is a complex process that continues to require human intelligence to ensure proper operation.

## IV. SENSORY SYSTEM

Sensors are used as integral components of the robot's position feedback control system. They are also used to acquire data from the surrounding environment needed by the robot to perform its tasks. A sensor converts one type of external physical effects (i.e. force, temperature, sound, image, etc.) into electrical signals and measures that physical effect after calibrating the sensors. Sensors can be classified into three main groups; tactile proximity and vision.

### *A. Tactile sensors*

The tactile sensors for geometric recognition of the objects in the environment were designed due to the development of the robotic engineering. The main tendency in the sphere of tactile sensors creation is to simulate the tactile properties of human skin. Matrix type tactile devices meet this tendency to the upmost degree as each matrix cell, which is in essence a microelectronic force (strain or torque) sensor gives definite information making it possible to form a full image about an object shape.

Tactile sensors are classified depending on their operating principle and physical nature. According to the operating principle tactile sensors can be resistive, capacitive, inductive, optical, magnetic, piezoelectric, ultrasonic, and electromagnetic, Fig. 2. According to the physical nature they can be flexible, elastic, rigid and so on.

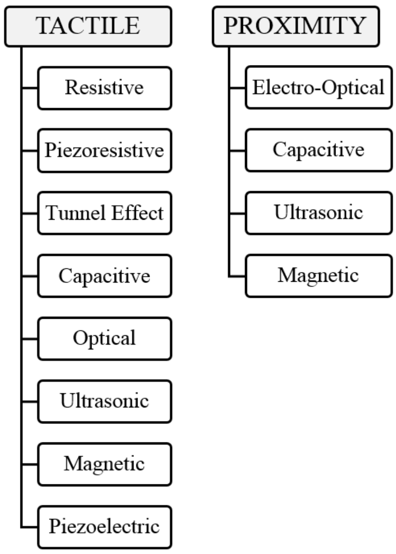


Fig. 2. Classification of the tactile and proximity sensors

The description of different types of tactile sensors is given below:

***Resistive sensors*** usually consist of two conductive layers separated either with air or with non-conductive material. They operate on the resistive principle. They can be of two types: a) resistance depends on the point of force application; b) resistance depends on the amount of the force applied. Resistive sensors are sensitive and cheap but they are energy-consuming. Another drawback of this sensor type is that they can define only one contact point.

***Piezoresistive sensors*** are made of materials whose resistance changes with force /pressure. Force sensing resistors based on the piezoelectric effect are widely used in devices defining the positions. They are widely used due to their low cost, simple electronics and high sensitivity. Their drawbacks are: they require high-technological manual or series assembly, possess non-linear response and hysteresis, are manufactured on the comparatively rigid base plate.

Tactile sensors made of composite materials are based on the ***Quantum Tunnel Composites*** effect (QTC). Composite materials consist of metal particles and a non-conductive rubber adhesive element. QTC has the unique capability of transformation from a virtually perfect insulator to a conductor when a force is applied to it: compression, deformation, twisting and stretching of the material. The insulator - conductor transition has an exponential dependence.

***Capacitive tactile sensors*** consist of a plate capacitor in which the distance between the plates or its effective area changes when applying the force by changing the position. Distance change results into the change of a capacitor electric capacitance. This type of sensors can be very small in size which permits to build up a sensor array [6], and to make measurement in dynamics. They have high sensitivity, spatial resolution and quick response, high interference immunity and can be placed on the fingers of a robot of any construction.

***Optical tactile sensors*** are based on changes in material optical properties under the influence of a force applied to the material. Optical sensors can measure force as low as 0,001N with the spatial resolution 5 mm [7]. Optical tactile sensors are immune to electromagnetic interference, are flexible, sensitive and fast but at times they are bulky.

***Acoustic ultrasonic sensing*** is yet another technology which has been used for the development of tactile sensors. The main component of an ultrasonic sensor is an electro-acoustic transducer and a piezoelectric ceramic element is often used in this function. As the same transducer is used to transmit and receive the signals, to define the objects in the nearest zone the quick damping of acoustic energy is required. This can be achieved by using acoustic absorbers and decoupling between the transducer and the body. The body design permits to receive a narrow acoustic streaming which gives a powerful directional signal. The advantages of such sensors are quick dynamic response and high resolution.

***Magnetic tactile sensors*** are based on the principle of the density measurement of the stream cause by the applied force. The flux measurement can be made by either a Hall Effect, or a magneto resistive device. The tactile sensors based on magnetic principle have a number of advantages that include high sensitivity and dynamic range, no measurable mechanical hysteresis, a linear response, and physical robustness. Major drawback of magnetic based tactile sensor is that they cannot be used in magnetic medium.

The ***piezoelectric sensor*** operation is based on the property of some crystals to generate charges when compressing or stretching. The example of such crystals is quartz, segnetoceramics, and others. The pressure measured is perceived by a membrane and sent to piezosensitive plates. The voltage is read from the metal fillings. Temperature sensitivity of piezoelectric materials is a major cause of concern in their use as tactile sensors.

*B. Proximity sensors*

Proximity sensors should be able to measure the position and orientation (pose) of an object’s surface. Proximity sensors have employed various transduction media, including sound waves, magnetic fields, electric fields, and light. Such sensors are relatively small in size, have a large range of operation, and impose almost no restrictions on the object’s material. Brief descriptions of the proximity sensors, shown on Fig. 2 are given below.

***Electro-Optical Sensors.*** Many proximity sensors use light, directly scattered from a target surface, to determine the distance and orientation of the target object from the gripper. The mechanism by which light is reflected can be explained by a model that specifies four different reflection phenomena. According to this model, light reflects from the surface primarily as a result of one or more of the following interactions: 1. Single surface reflection, 2. Multiple surface reflection 3. Reflection after penetration, 4. Corner reflection. Common measurement techniques used in optical proximity sensing utilize one or more of the reflected components to determine the pose of the object in relation to the transducer.

***Capacitive sensors*** generate and measure changes in an electric field caused by either a dielectric or conducting object in their proximity. There are basically two types of capacitive proximity sensor. One type uses the principle of a parallel plate capacitor, the other uses the principle of fringing capacitances [8]. Proximity capacitive sensors have the following general advantages: low energy consumption and simple structure. The major disadvantages, however, are that they are influenced by external signals and a calibration-per-surface technique must be carried out, since their operation directly depends on the object's material.

***Ultrasonic Sensors.*** The basic principle underlying ultrasonic ranging sensors is the measurement of the time required for a sound wave to travel from the emitter to the object's surface and return to the detector. By using several such emitters and detectors, one can obtain information about the distance and orientation of the surface. One of the major disadvantages of ultrasonic proximity sensors is that they are relatively large in size.

***Magnetic Sensors.*** A magnetic-type sensor creates an alternating magnetic field, whose variation provides information about the object's position. The main problems with magnetic sensors are their high size/range ratio and difficulty in providing reliable distance measurements in varying magnetic environments.

### *C. Vision sensors*

Robotic vision may be defined as the process of extracting, characteristing and interpreting information from images of a 3-dimensional world [9]. Robotic vision (also termed as "Computer vision" or "Machine vision") is an important sensor technology with potential applications in many industrial operations. Robotic vision is primarily targetted at manipulation and interpretation of image and use of this information in robot operation control. Robotic vision requires two aspects to be addressed: Provision for visual input; Processing required to productively utilise the visual information in a computer-based system.

The basic purpose of robot vision system is to identify an object and determine its location (position and orientation). The vision system must be capable of handling multiple views to deal with the multiple stable states. The system must be able to work in an industrial environment including factory illumination and be insensitive to normal light variation.

The operation of robot vision consists of the following three functions: 1.Sensing and digitizing, 2. Image processing and analysis, 3. Application. The digitized image is subjected to image processing and analysis for data reduction and interpretation of the image. This function may be further subdivided as: Preprocessing, Segmentation, Description, Recognition and Interpretation.

A general vision system consists of a light source, an image sensor, an image digitizer, a system control computer and some form of output. The image sensor of a machine vision system is defined as an electro optical device that converts an optical image to a video signal. The image sensor is usually a vacum tube TV camera or a solid state sensing device.

## V. CONCLUSION

Properly designing or choosing and using sensors is an essential part of robotics and sensors of all types are used in many different kinds of robots for different tasks. Most importantly, the sensors have increased the performance of robots to a large extent. It also allows the robots to perform several functions like a human being. This paper gives a brief description of the state-of-the-art in tactile, proximity and vision sensors for robotics and their merits and demerits, bacause to choose an apropriate sensor for a particular need it is necessary to consider a number of different characteristics. In certain situations, different types of sensors may be available for the same purpose.

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