4

Advances in Robotics in the Era of Industry 4.0

Contents

4.1 Introduction

- In factories, human workers are not effective any more on many reasons such as their capabilities and physical capacities affecting production performance, production cost, etc. Therefore, industrial robots which are machines with automated and embedded intelligence and capabilities are required to improve the manufacturing process.
- To achieve more accurate production at shorter time without any injuries in recent competitive industry have shifted the manufacturers' mind from human labour to robots. Nevertheless, a collaborative work of humans and robots is required for efficient and robust manufacturing.
- In the modern competitive industry, companies need to facilitate industrial robots not only due to safety reasons, to reduce labour force injuries during production, but also due to the need of faster and more accurate production considering economical gains.
- However, the recent robotic technology does not provide predictability of the outcome and performance of the manufacturing process in real-time, and does not help in autonomously managing and optimizing the cost and time of this process.
- Moreover, the robots are not able to monitor itself for health issues as part of their self-maintenance ability, and are not able to adapt to a new production process of a new product with different properties because they are designed and built based on the dedicated product, e.g. in automotive industry.

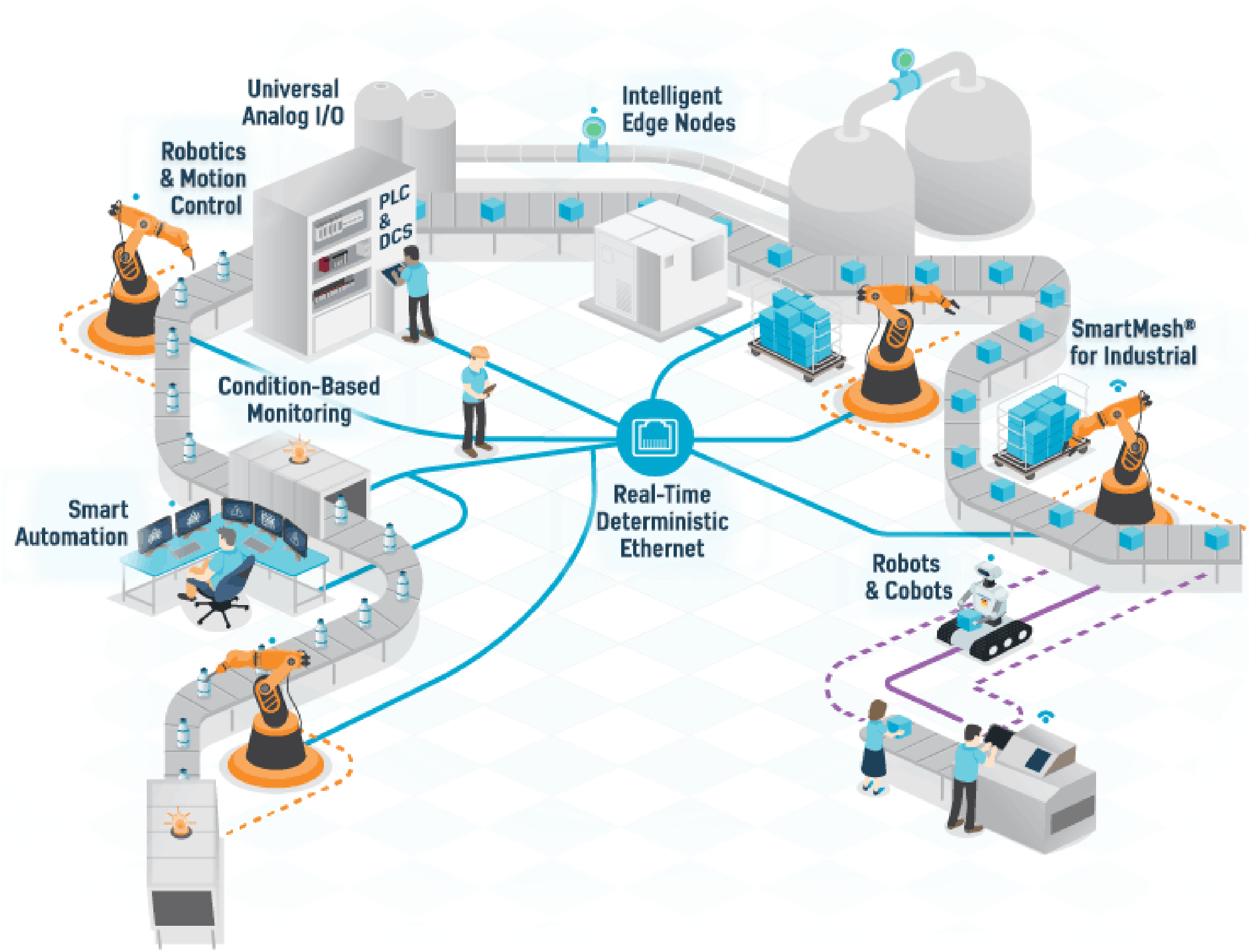


Fig.4.1 – Robotics in Industry 4.0

- The traditional industrial robots are placed in a designated space and programmed to repeatedly and continuously perform predefined/embedded the same sequence of actions for years and years. Therefore, they are designed, built and equipped for a given sequence of actions, which makes it difficult to reconfigure an industrial robot for a new production line.
- However, there are also problems of using robots in industry such as the lack of people having expertise and skills to exploit a robot, the hardness of reconfiguring a robot to adapt a new production process, morale on human workers, disabilities of collaborative work on the same space, etc. In addition, the cost of robots is still high even if it continues to decrease.
- The term, Industry 4.0 representing the new revolution on industry is based on smart aims to embed the data science into industry in order to generate smart factories for improvement on production/manufacturing.
- Moreover, many manufacturers think that the production process requires much more collaborative work between robots and humans where robots are intelligent industrial work assistants to humans.
- To provide such collaborative working, the safety problems for humans are to be solved , thus it is another reason for smart factories to guarantee the safety of humans by controlling the behavior of the robots since the risk of injuring humans may be possible due to collusions.
- Industrial robots in Industry 4.0 revolution are designed more efficiently and collaboratively with humans and with other robots over networking allowing them to be self-aware and self-adaptable on new products and manufacturing processes.
- Thus, the future of industry due to the recent technologies utilizing Internet of Things (IoT) such as for controlling and remotely monitoring on industrial robot, Cloud Computing, processing Big Data and advanced information analytics will provide smart factories with many such robots. In addition, the robots are able to autonomously detect degradation on product performance, and apply optimization to solve it.
- Industry 4.0 represents also an evolution from automated embedded system based manufacturing to Cyber-Physical System (CPS) based manufacturing, which is the recent challenge and requirement for manufacturing industries.
- CPS's are designed to be equipped with the smart capabilities like sensing, communicating, decision making and actuating to physical world, because such systems making the production decentralized combine the virtual and physical world together using a network in order to enable the robots and humans communicate with each other and share the industrial Big Data collected from the sensors.
- The autonomy of the robots is achieved by utilizing the novel components of the information technologies, since these enable the robots sensing and monitoring the production processes, working environment, and even the robots themselves; required for self-predicting, failure recovery, making goal-directed decisions, modelling and controlling the process, self-assessment, etc.
- One of the benefits of these systems is to make working with robots easier and safer for humans. Therefore, the developments of the sensor technology and networking are essential to provide such capability. Currently, several technical challenges for CPS's such as dealing with uncertainty and dynamics in the real-world, measuring the performance of the systems, lack of full competence on human-machine interaction, etc., most of which are also scientific challenges, are tackled and significant improvements are achieved.

4.2 Recent Technological Components of Robots

- The robotic technology, and its development highly depends not only on the cost of materials, but also on the advances of technological components for building a robot making it cheaper, having sensors with higher quality, faster and cheaper processors, the dependence on the open-source robotic software and applications, consuming less energy and being connected everywhere.
- Moreover, in robotics, there are many scientific challenges such as processing Big Data, dealing with uncertainty, perception in real environment, cognitive decision making in real time, etc.
- Thus, Industry 4.0 is based on these advances and also the scientific works in the academia to overcome the problems of slow and inefficient decision-making process of autonomous robots, difficulty of using the robots, adopting the robots into manufacturing process, etc. The proposed solutions both from academia and industry comprise the novel hardware and software components of the new age robots.

4.2.1 Advanced Sensor Technologies

- ***Sensor*** is a device which detects or measures a physical property and records, indicates, or otherwise responds to it.
- For industry 4.0 factories, the advances in the sensor technology has an important role, since these technologies are used in data processing, sharing and collecting. Moreover, networking which remains in the heart of the IoT and Cloud Computing to stream the data depends on the enhancements of wireless sensor technology.

Many sensors are used in robotics technology, few of them listed below.

Vision sensors use images captured by a camera to determine presence, orientation, and accuracy of parts. These sensors differ from image inspection "systems" in that the camera, light, and controller are contained in a single unit, which makes the unit's construction and operation simple.

Accelerometers and Tilt sensors measure speed variations, tilts, inclination and acceleration. The Accelerometer sensor provides bump and motion detection. The sensor works by measuring acceleration forces on the x, y, and z axis. By measuring the amount of acceleration (or lack there of) your robot can get a better understanding of its movements.

Temperature sensors are used for sensing the change in temperature of the surrounding. It is based on the principle of change in voltage difference for a change in temperature this change in voltage will provide the equivalent temperature value of the surrounding.

Touch sensor in robotics; *a touch sensor is commonly used in robots, enabling basic movement and the ability to detect touch in its surroundings (E.g. When the robot runs into something, the touch sensor can have it to stop moving)*

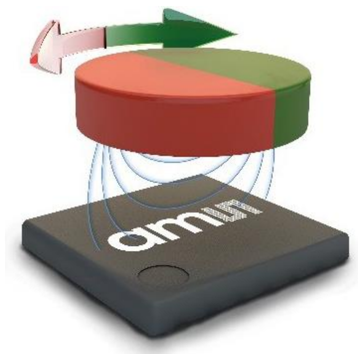
Pressure sensing is what allows a robot to tell when it collides with something, or when something pushes against it. Pressure sensors can be used to measure force, and in some cases, to determine the contour of an applied force.

An ***Infra Red*** receiver captures the reflected light and the voltage are measured based on the amount of light received. Infrared sensors are used in a wide range of applications including here proximity robotic applications for distance and object detection, or color detection and tracking.

Smoke, flame and temperature measurement sensors were used in the system to detect the fire event in fire fighting robot.

The humidity sensing component is a moisture holding substrate with electrodes applied to the surface.

Magnetic position sensors are precise and contact-less devices that measure the changes in the angle of a magnetic field as seen by the sensor.

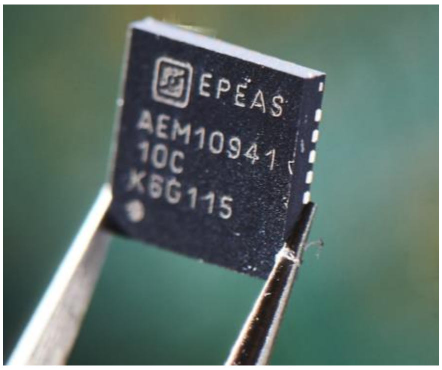


A presence sensor is a sensor able to detect the presence of nearby objects without any physical contact. 2D and 3D vision stereo cameras, Light Detection and Ranging (LIDAR) sensors, Ultrasonic sensors are used in presence sensor.

The Gesture sensor is an interactive sensor that integrates 3D gesture recognition and motion tracking.

A force torque (FT) sensor is an electronic device that is designed to monitor, detect, record and regulate linear and rotational forces exerted upon it.

Environmental sensors that can detect VOCs (Volatile Organic Compounds) in regards to air quality, temperature and humidity sensors, pressure sensors, and even sensors that can detect the presence of lighting. These sensors not only help to ensure a robot can continue to operate effectively and safely, but also make humans in the robot's local area aware of unsafe environmental conditions.



Power management sensors are being integrated into today's autonomous robots to aid in extending a robot's operating time between charges, and for ensuring that batteries don't overheat when being charged or drained.

4.2.2 Internet of Robotic Things

- Internet of Robotic Things" (IoRT) can be defined as an emerging scientific discipline that simply adds a layer of robotic systems to existing smart IoT devices and sensors.
- The concept of the Internet of Robotic Things (IoRT), where intelligent devices can monitor events, fuse sensor data from a variety of sources, use local and distributed intelligence to determine a best course of action, and then act to control or manipulate objects the physical world, and in some cases while physically moving through that world.
- The vision behind this concept is to empower a robot with intelligence to execute critical tasks by itself. Internet of Robotic Things is a concept where IoT data helps machines interact with each other and take required actions. Robots that communicate with other robots and take appropriate decisions on their own.

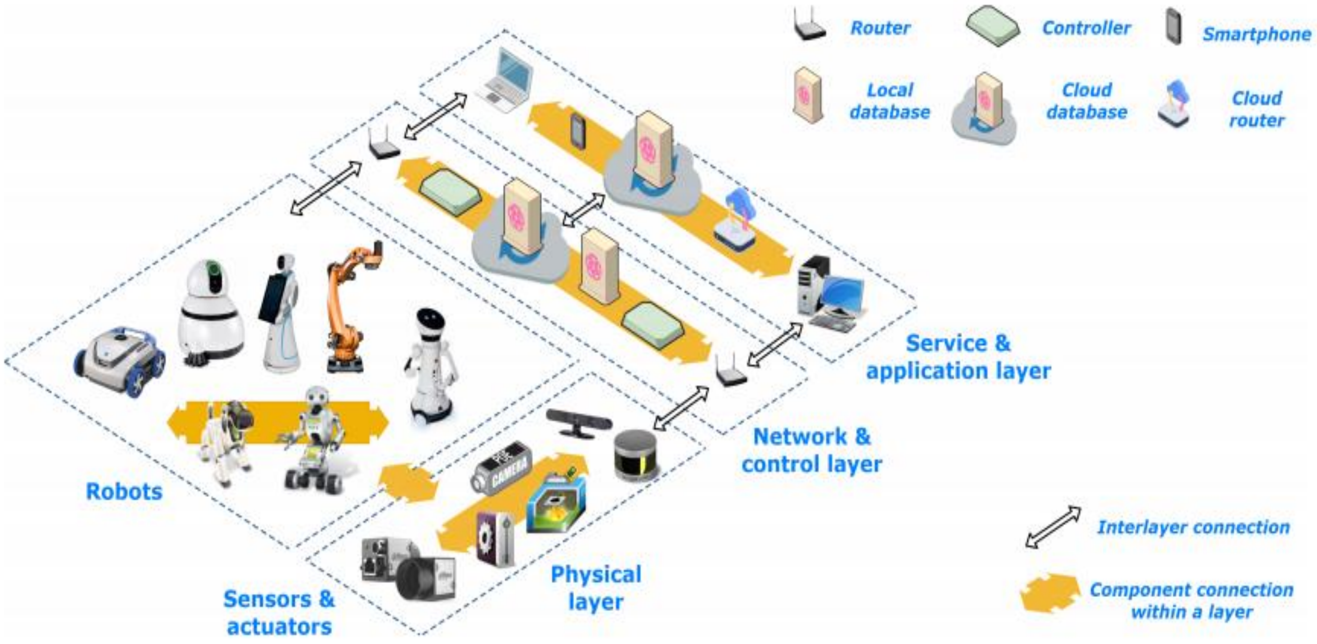


Fig.4.2 – Internet of Robotic Things architecture

- The facilities of IoT for manufacturing enable the communication and interaction among devices, machines and humans in order to obtain, process, analyze, collect and share the knowledge about environment, materials, machines, and processes during production. Ray proposed an architecture of Internet of Robotic Things divided into five layers:

1) the hardware/robotic things layer consisting of various physical things such as robots, sensors, devices, vehicles, etc., to send the information to the network layer,
2) the network layer providing different kinds of networking options such as Wi-Fi, Bluetooth, broadband global area network, etc.,
3) the internet layer, which has an important role to provide the whole communication,
4) infrastructure layer providing a framework including the approaches of IoT based robotic cloud, Big Data, middleware and business process, and
5) the application layer.

Internet of Robotic Things can be the perfect choice for industries that deal with heavy duty work or repetitive manual jobs. Let's check out a few potential use ***cases*** through which industries can benefit from this newly emerged concept.

- Robots at warehouses can inspect product quality, check for product damages, and also help with put-aways. Without humans playing any role, robots can analyze the surroundings with the IoT data and respond to situations as needed.
- A robot can effectively play the role of a guidance officer and help customers with parking space availability. By checking the parking lots, robots can assist customers with the right place to park their vehicles.
- Robots can automate the labor-intensive and life-threatening jobs at a construction site. Right from scaffolding to loading and unloading heavy construction equipment, robots can take care of every on-site task responsibly. With the help of intelligent robots, construction engineers and managers can ensure enhanced worker health and safety.

4.2.3 Cloud Robotics

- ***Cloud robotics*** is the use of remote computing resources to enable greater memory, computational power, collective learning and interconnectivity for robotics applications.
- When computational or storage demands exceed the on-board capacity of a robot, they are offloaded to the cloud, where the massive resources of a datacenter can supplement their limited local resources. Cloud robotics also represent a significant advance for robot learning.
- With a Wi-Fi connection to cloud-based resources, a robot can access a vast library of known objects to identify things in its environment. Object recognition helps a robot to better perform tasks like sorting, cleaning and using appliances.
- Relying on the cloud for resources also means that the robot itself can be simpler, eliminating costly compute power and the associated cooling and electrical power draw. Due to this offloading, cloud connected robots have lower battery requirements and are overall lighter and less expensive. Cloud robotics are typically used for tasks that don't require real-time execution, preserving local resources for applications with demanding time constraints.
- The connection to the cloud eliminates the need for a robot to learn a task any other connected robot has: It can download the necessary information instead of having to feel out or observe how to do a task. This interconnectedness can help robots work together more smoothly too, coordinating their tasks automatically.

Fig.4.3 – Cloud Robotics and Automation

Applications of Cloud robotics

- **Autonomous mobile robots:** Google's self-driving cars are cloud robots. The cars use the network to access Google's enormous database of maps and satellite and environment model (like Streetview) and combines it with streaming data from GPS, cameras, and 3D sensors to monitor its own position within centimetres, and with past and current traffic patterns to avoid collisions. Each car can learn something about environments, roads, or driving, or conditions, and it sends the information to the Google cloud, where it can be used to improve the performance of other cars.

- **Cloud medical robots:** a medical cloud (also called a healthcare cluster) consists of various services such as a disease archive, electronic medical records, a patient health management system, practice services, analytics services, clinic solutions, expert systems, etc. A robot can connect to the cloud to provide clinical service to patients, as well as deliver assistance to doctors (e.g. a co-surgery robot). Moreover, it also provides a collaboration service by sharing information between doctors and care givers about clinical treatment.
- **Assistive robots:** A domestic robot can be employed for healthcare and life monitoring for elderly people. The system collects the health status of users and exchange information with cloud expert system or doctors to facilitate elderly peoples life, especially for those with chronic diseases. For example, the robots are able to provide support to prevent the elderly from falling down, emergency healthy support such as heart disease, blooding disease. Care givers of elderly people can also get notification when in emergency from the robot through network.
- **Industrial robots:** In manufacturing, cloud based robot systems could learn to handle tasks such as threading wires or cables, or aligning gaskets from a professional knowledge base. A group of robots can share information for some collaborative tasks. Even more, a consumer is able to place customised product orders to manufacturing robots directly with online ordering systems. Another potential paradigm is shopping-delivery robot systems. Once an order is placed, a warehouse robot dispatches the item to an autonomous car or autonomous drone to deliver it to its recipient.

4.2.4 Cognitive Architecture for Cyber-Physical Robotics

- Cognitive robotics is a subfield of robotics concerned with endowing a robot with intelligent behavior by providing it with a processing architecture that will allow it to learn and reason about how to behave in response to complex goals in a complex world.
- Cyber Physical System(CPS)s are the embedded systems equipped with physical systems and environments through the combinations of computational modules.
- The application areas of the systems cover not only smart machines and factories, but also smart transportation, smart buildings, smart cities, smart medical technologies, etc., thus, the integration of such systems with the technologies like IoT, Big Data analytic, Cloud Computing and wireless sensor networking is the core of the Industry 4.0 revolution. The main components of the system infra-structure are actuators to interact with these world, the sensors for sensing the physical environment, and information processing, therefore, the advances on these related technologies will determine the development of the CPS's.

A 5C architecture including 5 levels, which are

(1) ***Connection*** as the level to manage data acquisition systems such as sensors, data sources and transferring protocols,

(2) ***Conversion***, where the data is processed and transformed into valuable and usable knowledge,

(3) ***Cyber*** as central information hub in order to establish cyber space using the information acquired from every source,

(4) ***Cognition*** for optimization of the decisions and

(5) ***Configuration*** as supervisory control to endow machine self-configure and self-adaptive, is designed to integrate cyber-physical systems with smart machines to be used the manufacturing industry. Thus, such systems are the core of a smart factory due to the incorporation of IoT and Big Data with physical industrial world.

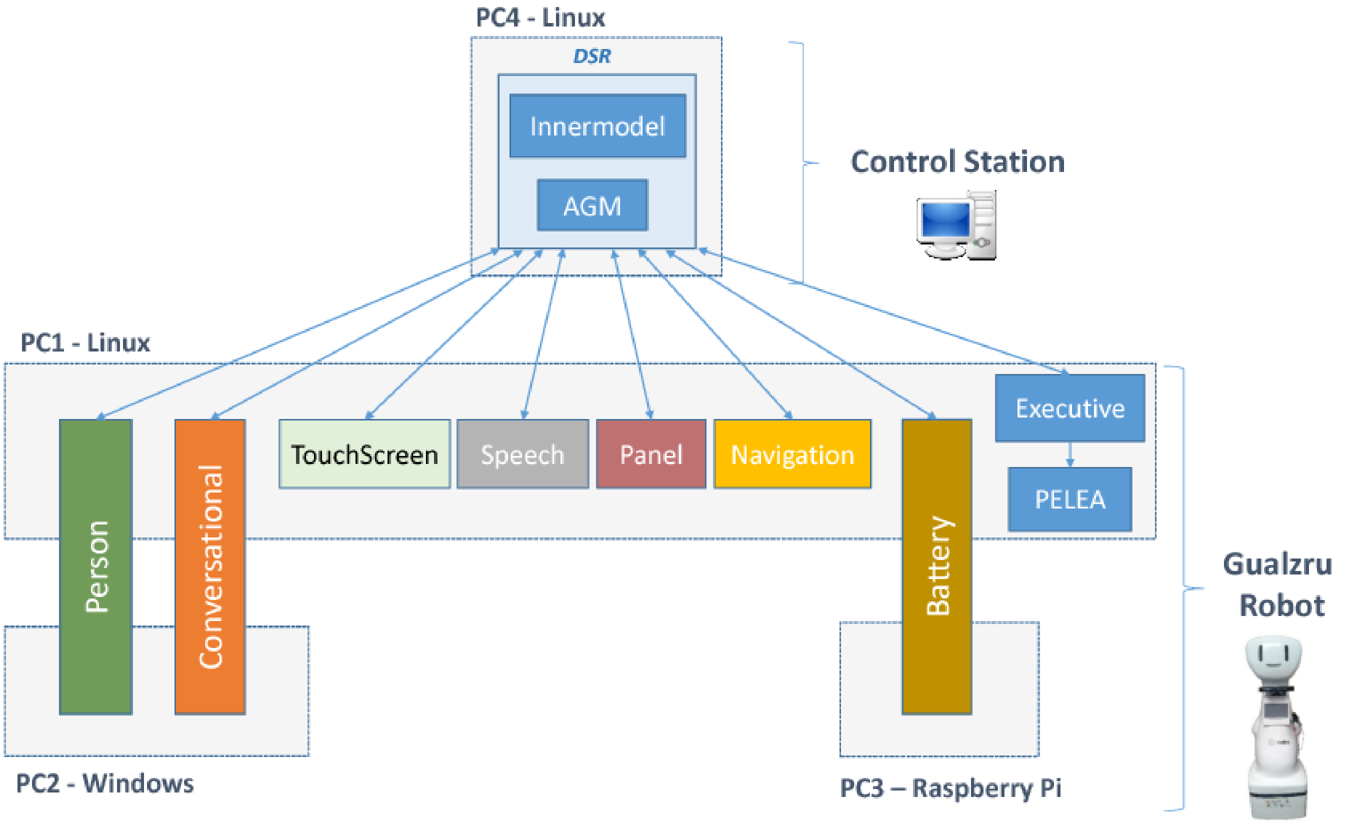


Fig.4.4 – Cognitive architecture of robotic salesman

- There are many CPS studies in industrial tasks like in where an integrated cyber-physical system is proposed by building cloud-based services of monitoring, planning of production processes, machining and assembly in decentralized environment, for remotely accessing and controlling an equipment used in production such as Computer Numerical Control (CNC) machines and robots.
- The CPS software plays the most important role on the development of this kind of system; related issues like the analysis, design, development, verification and validation, and quality assurance of CPS software need to be taken into account.
- In addition, A CPS in human robot collaboration also called Collaborative Robotic CPS (CRCPS) covers three main integrated entities;
  - (1) Human Component (HC) connected through different adaptor technologies, e.g. accurate human position tracking technology,
  - (2) the Physical Component (PC) and
  - (3) the Computational Component (CC).
- A CRCPS is developed considering safety and protection measures in order to increase productivity. Such a system is able to utilize a variety of sensors and actuators, and is intended to provide the interaction between HC, CC and PC, for example a vision system for detection, tracking and gesture recognition of human workers.

4.3 Industrial Robotic Applications

- Industrial robots with various intelligent and sensory capabilities are utilized in the manufacturing processes. In an Industry 4.0 factory, the robots endowed with the advanced capabilities owing to the information, networking and sensor technologies are able to collaboratively work with human workers and cooperatively with the other robots in an assembly line.

- The collaborative and cooperative working applications of the robots, the maintenance practices and assembly line applications using the robots shape the factories of the future.

4.3.1 Manufacturing

- Conventional manufacturing industry was transformed into manufacturing by intelligent systems in order to improve production performance and economical benefit in many advanced countries.
- The machines like industrial robots instead of humans were already utilized a few decades ago in order to enable faster and more accurate production than using human workers. However, in recent industries, manufacturing is not sufficient due to disabilities of robots and the hardness of implementations of current technological development.
- Due to the benefits of the information and sensory technologies, the enhancement of the interaction between the robotic machines and the human workers as well as the robots themselves will improve the manufacturing quality.

4.3.1.1 Human-Robot Collaborative Manufacturing

- In the recent industrial manufacturing, the requirement of industrial robots and human workers for collaborative works over a communication network is growing, and such communication is achieved due to the advances of the aspects of Industry 4.0.
- Moreover, it is also believed that integrating the industrial robots into human working spaces makes the production process more economical, and enables many collaborative applications in the factories.
- However, the robots and humans are not much capable of smoothly working together in the same working space because of safety issues. Even if the robots are designed to be cautious around human workers, it is aimed to achieve a more flexible and agile moving capability for a robot, which is highly required to provide more efficiency in working collaboratively with the humans.

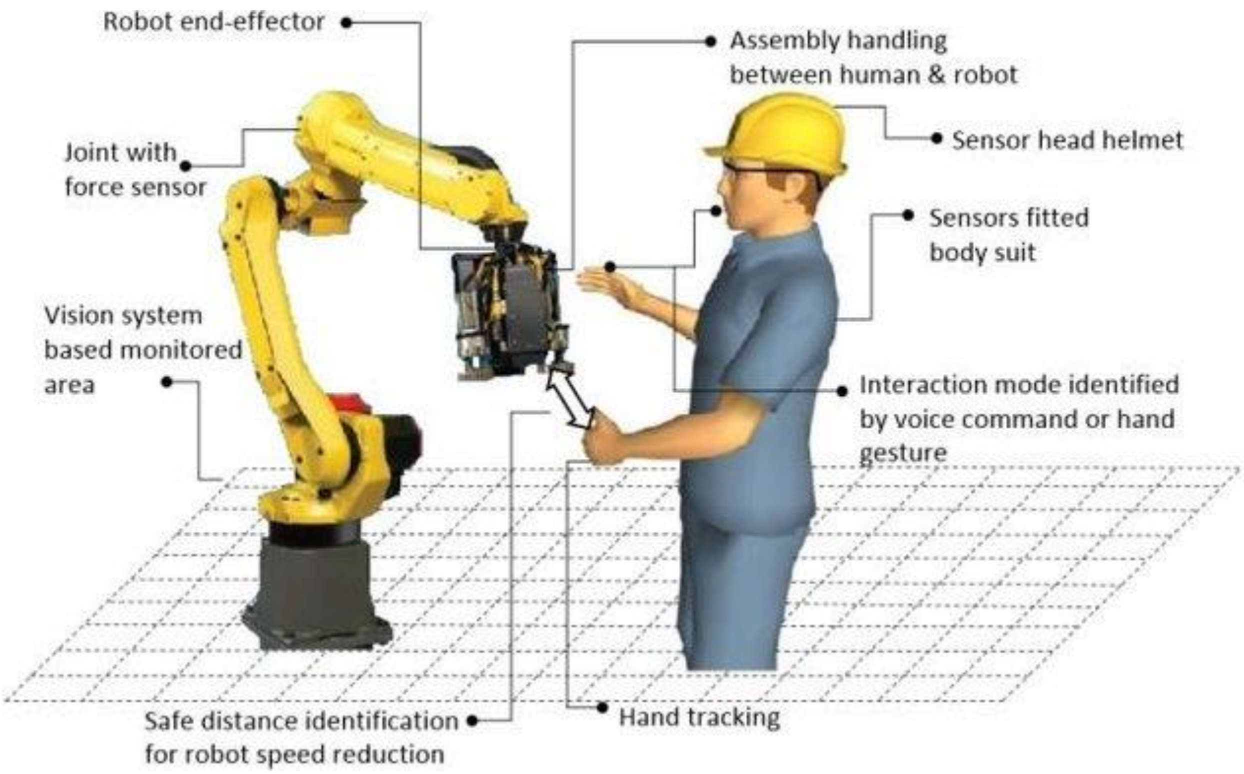


Fig.4.5 – Human robot collaborative work

- The collaborative robots are still not maturely developed to work for complex tasks in the same space with humans in assembly lines and distribution centers.
- In addition, there are many studies aiming for the collaboration of humans and robots while considering the safety of the human workers in which a human-robot interaction system is proposed to guarantee the safety by tracking and estimating the proximity of the workers to the robots, and by activating the strategies considering the proximity.
- In colaboration mechanism variety of sensors and actuators are used to estimating the safety distance based on different sensors for human position monitoring, cost, risk, collaboration category, performance level, etc.
- The sensors are selected considering the safety concepts, such as force monitoring, speed and distance monitoring, and the complete isolation. Also, in this study, the collaboration is formalized taking into account the number of sensors, the data rate from the sensors to calculate the key performance indicators, and considering the speed of the human workers in the same working space approaching to collision with the robot, and finally the robot's follow-up time to stop completely by calculating the safe distance in order to provide the safety of human workers.

4.3.1.2 Cooperating Robots in Manufacturing

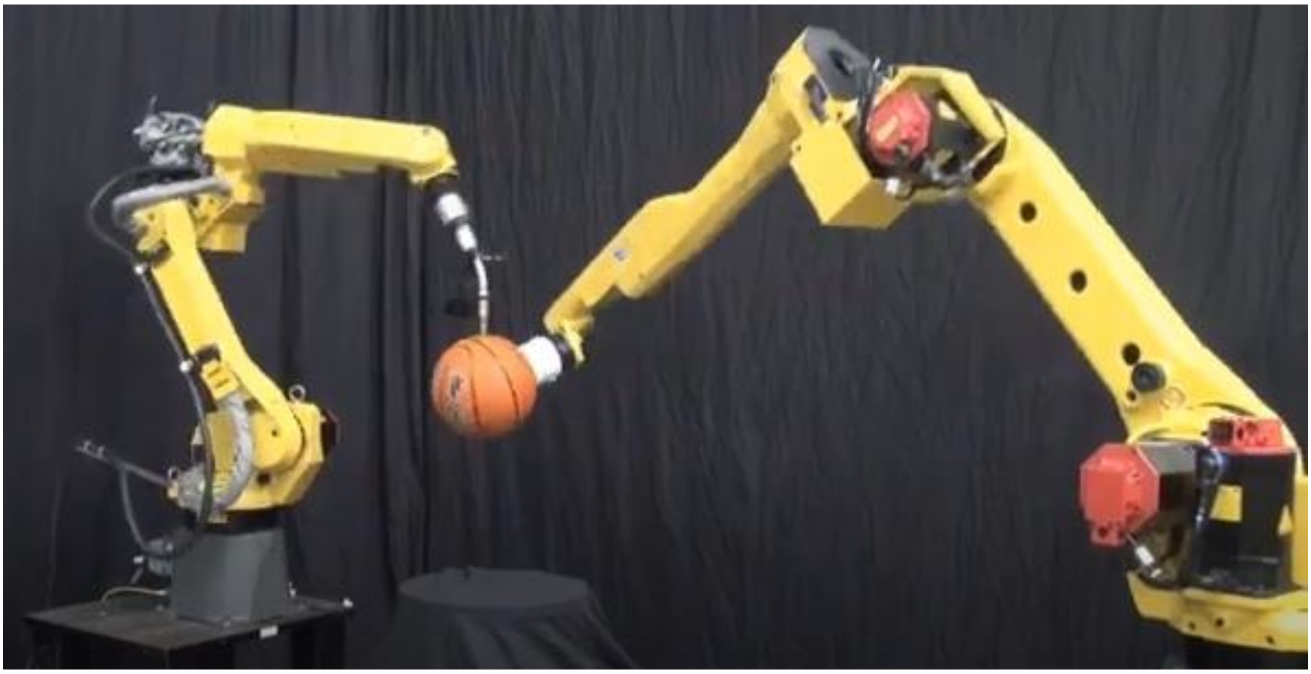


Fig.4.6 – Cooperative working of two industrial robots

- In the cooperative working of two industrial robotic arms, one is used for the sensory task, which is to scan the work pieces like pins and to inform the other one handling the task, by creating point clouds and modifying it during the motion.
- In smart factory platform experiments robots used for industrial tasks, having wireless connection and a private cloud. A number of serial robots for loading tasks and Cartesian robots for machining and testing tasks, and a railway like conveying system were used.
- A serial robot serves two Cartesian ones equipped with manipulators to achieve different tasks. The serial ones put the products on Cartesian ones, which are brought from the conveying system, and vice versa. These are also able to autonomously control their position and velocity, and able to avoid collisions. Moreover, the robots are equipped with smart controllers and devices required to make them the components of the smart factory.

- The software provides the capabilities for cloud computing and Big Data analytic, and virtualizes the network of servers as a supercomputer of the platform, where the robots constitute the clients. By using this network architecture, the smart factory is constructed where the robots can communicate with each other, the massive data obtained from tasks and experiences can be collected and transferred to cloud, and over the cloud, the big data can be transferred to other robots.
- Also, a ROS based framework for cyber-physical production systems is proposed in order to develop and improve the coordination strategies for cooperating robots considering network delays, localization inaccuracies, and availability of embedded computational power. Such a framework makes the robots more adaptive and cooperative since it combines collision detection and avoidance using local decisions based on observations from the environment.

4.3.2 Maintenance

- In factories, maintenance of a production process is one of the most essential planning items to diagnose the health problems of the machines and to reduce the downtime of the process due to these problems.
- Humans are still responsible for this task in the recent technology, but several systems are proposed to enable the machines having self-maintenance ability.
- For instance, Prognostics and Health management (PHM) is a discipline for machines and robots to assess the health of systems in order to diagnose anomalies using sensors, and in order to predict the performance over the life of the machines. The development of IoT provides opportunities for the discipline PHM to be used efficiently in manufacturing, such as the speed of decision-making, improved reliability and accountability over a cloud, enhanced liability and workforce competency.
- To track and to assess its own health and overall production performance degradation, self-awareness and self-maintenance are required abilities for the robots.
- By processing the information from Big Data, industrial robots are able to manage their health and maintenance. In a recent study, it is shown how robot skills for manufacturing and new tasks can be derived by transferring information from factory worker’s knowledge in order to develop self-asserting ability.
- For the robot maintenance and fault diagnosis, the vibration on an industrial robot is measured using accelerometers and evaluated by applying Fast Fourier Transformfor the analysis of the auditory spectrum of vibration. Also, the tooth failures of the gears on an industrial robot such as scuffing, cracking, macro- and micro-pitting, wear, bending fatigue, and fracture are diagnosed using Discrete Wavelet Transform and Artificial Neural Networks.

4.3.3 Assembly

- Conventional modern assembly lines are highly automated, but not dynamically adaptive to new production requirements. However, it is notoriously difficult to make the robots easily reconfigured and reprogrammed to the changes in production lines.
- Manufacturers feel the need of an assembling process, in which the humans and robots work together, and the optimization of the production process and reduction of the downtime are achieved autonomously by monitoring the assembly tasks and making decisions. Such intelligent systems are possible in the Industry 4.0 factories.

- Adapting new production paradigms and reconfiguring automation, tasks in assembly line during production is another requirement for the industrial robots in a smart factory.
- Within the framework of Industry 4.0, study explains how assembly works will change by focusing on the non-routine and neglected works in core assembly tasks, and what the roles of humans and robots will be in an assembly task considering their interactive capabilities to ensure high performance, quality, and a smooth material flow.
- Also, it is needed to utilize the Industry 4.0 technologies, such as IoT, in the development of robots for all kind tasks of an assembly line such as the assembly conveyor tasks in which the robot is developed to be able to achieve manufacturing task for synchronizing the industrial mobile robot with the moving object used in this process.
- In this study, there are two systems to achieve the synchronization, to control the mobile platform, to localize the object, on which three LEDs need to be mounted, as well as the mobile platform by relying on an optical sensor to estimate the position of each LED.
- A number of distributed and collaborative CPSs are designed and utilized to create a feature-based manufacturing process as a cyber-physical robot application. This process is used for equipment control of robots and matching resources and tasks in order to achieve assembly tasks by combining assembly features of products and event-driven function blocks.
- The features consist of the coordination and control of a set of robot motions and actions such as signal processing, program logic, decision-making, and communication. Thanks to the CPSs, manipulations of the components of a product are related and the assembly method is applied to the product considering the assembly features in this assembly task scenario.

4.4 References

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