2

A Conceptual Framework for Industry 4.0

Contents

2.1 Introduction

- Industrial Revolution emerged many improvements in manufacturing and service systems. Many radical changes were appeared such as digital machines, automated manufacturing environment, and caused significant effects on the productivity.
- The main reasons and triggers of the radical changes are individualization of demand, resource efficiency and short product development periods. Thus, enormous developments such as Web 2.0, Apps, Smartphones, laptops, 3D-printers appeared and this situation creates a big potential in the development of economies.

2.1.1 Need of Conceptual Framework for Industry 4.0

- In recent years, manufacturing companies and service systems have been faced substantial challenges due to the necessity in the coordination and connection of disruptive concepts such as communication and networking (Industrial Internet), embedded systems (Cyber Physical Systems), adaptive robotics, cyber security, data analytics and artificial intelligence, and additive manufacturing. In parallel to the necessity of coordination mechanism, synergy aroused from the integration of the advancements in information technology, services and manufacturing forms a new concept, Industry 4.0, was first declared by German government during Hannover Fair in 2011.
- Additionally, electronic devices connection is a part of distributed systems to provide the accessibility of all related information in real time processing. On top of it, ability to derive the patterns from data at any time triggers more precise prediction of system behavior and provides autonomous control. All these circumstances influence the current business and manufacturing processes while new business models are being emerged. Hence, challenges for modern industrial enterprises are appeared as more complex value chains that require standardization of manufacturing and business processes and a closer relation between stakeholders.
- This transformation can be possible by providing adequate substructures supported by sensors, machines, workplaces and information technology systems that are communicating with each other first in a single enterprise and certainly with other communicative systems. These types of systems referred as cyber physical systems and coordination between these systems are provided by Internet based protocols and standards.
- Hence, the introduction of new digital technologies in industrial work systems and increasing implementation of Cyber Physical Systems are evoking new and unknown challenges and opportunities related to aspects of human work and organisation.
- To ensure human wellbeing and overall system productivity, there is a need for interdisciplinary methods and approaches for dealing with the challenges and taking advantage of the opportunities.
- Thus, in this study, the fundamental relevance between design principles and technologies is given and conceptual framework for Industry 4.0 is proposed concerning fundamentals of smart products and smart processes development.

2.2 Main Concepts and Components of Industry 4.0

- In recent years, Industry 4.0 has attracted great attention from both manufacturing companies and service systems.
- Mainly, Industry 4.0 is comprised of the integration of production facilities, supply chains and service systems to enable the establishment of value added networks. Thus, emerging technologies such as big data analytics, autonomous (adaptive) robots, cyber physical infrastructure, simulation, horizontal and vertical integration, Industrial Internet, cloud systems, additive manufacturing and augmented reality are necessary for a successful adaptation.
- The most important point is the widespread usage of Industrial Internet and alternative connections that ensure the networking of dispersed devices. As a consequence of the developments in Industrial Internet of Things, distributed systems such as wireless sensor networks, cloud systems, embedded systems, autonomous robots and additive manufacturing have been connected to each other.
- Additionally, adaptive robots and cyber physical systems provide an integrated, computer-based environment that should be supported by simulation and three-dimensional (3D) visualization and printing.
- Above all, entire system must involve data analytics and miscellaneous coordination tools to conduct a real time decision making and autonomy for manufacturing and service processes.
- While constructing the framework, network of sensors, real-time processing tools, role-based and autonomous devices are interpenetrated with each other for real-time collection of manufacturing and service system data.

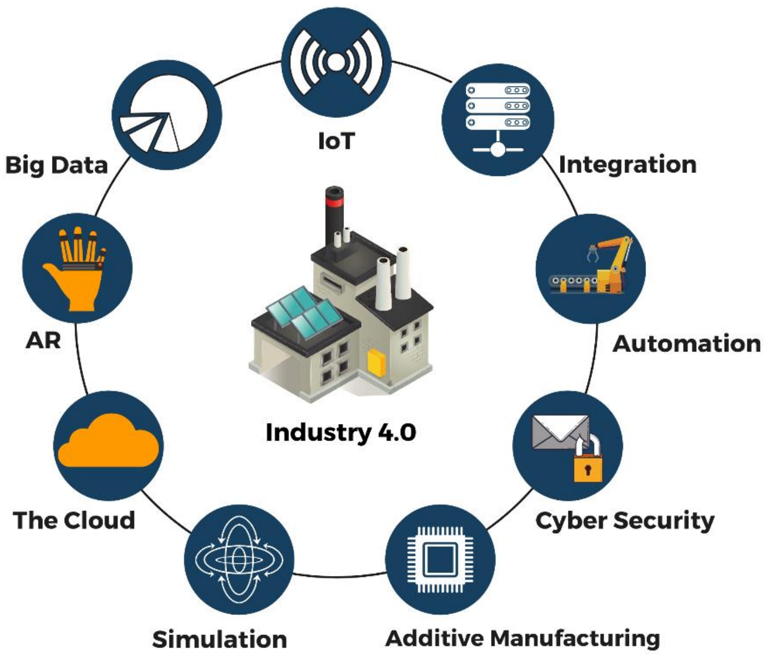

Fig.2.1 – Key Fundamental Technologies of Industry 4.0

2.2.1 State of Art

- For successful system adaptation to Industry 4.0, three features should be taken into account:
    1) Horizontal integration via value chains,
    2) Vertical integration and networking of manufacturing or service systems, and
    3) End to-end engineering of the overall value chain.
- Vertical integration requires the intelligent cross-linking and digitalization of business units in different hierarchal levels within the organization. Therefore, vertical integration enables preferably transformation to smart factory in a highly flexible way and provides the production

of small lot sizes and more customized products with acceptable levels of profitability. For instance, smart machines create a self-automated ecosystem that can be dynamically subordinated to affect the production of different product types; and a huge amount of data is processed to operate the manufacturing processes easily.

- On the other hand, horizontal integration obtains entire value creation between organizations for enriching product life cycle using information systems, efficient financial management and material flow.
- The horizontal and vertical integration enable real time data sharing, productivity in resource allocation, coherent working business units and accurate planning which is crucial for connected devices in the term, Industry 4.0.
- Finally, end-to-end engineering assists product development processes by digital integration of supportive technologies considering customer requirements, product design, maintenance, and recycling.

2.2.2 Supportive Technologies

For successful implementation of Industry 4.0 transformation, fundamental and supportive technologies are required to be the part of the entire system. In this section, detailed information of these technologies is given for better understanding of the proposed framework.

2.2.2.1 Adaptive Robotics

- As a consequence of the combination of microprocessors and AI methodologies, the products, machines and services become smarter in terms of having not only the abilities of computing, communication, and control, but also having autonomy and sociality.
- In this regard, adaptive and flexible robots combined with the usage of artificial intelligence provide easier manufacturing of different products by recognizing the lower segments of each parts.
- This segmentation proposes to provide decreasing production costs, reducing production time and waiting time in operations. Additionally, adaptive robots are useful in manufacturing systems especially in design, manufacturing and assembly phases.
- One of the sub technologies underlying adaptive robots can be given from co-evolutionary robots that are energetically autonomous and have scenario based thinking and reaction focused working principle.
- **Real life examples** can be given as:
    1) a robot called **Yumi** which is created for ABB manufacturing operations. Yumi has flexible handling, parts-feeding mechanism, camera based part location detection system and state-of-the-art motion control for the adaptation of ABB production processes as reported in ABB Contact (2014).

Fig.2.2 – Yumi Robot

2) Another example can be given as **Kuka KR Quantec robot** that has task-distributing screws and other production material by delivering the ordered KANBAN boxes coming from the central warehouse rack. The "**workerbot**", created from pi4, has a humanoid anatomy with two arms, a rotating upper body and supported by camera and image processing systems. This combined mechanism enables memory based activity identification using independent recognition of the previous positions and characteristics of production parts.

Fig.2.3 – Kuka Robot

- The general **characteristics** of these applications are given in the following:
  1) Networked via Ethernet or Wi-Fi for high speed data transmission
  2) Easy integration in existing machinery communication systems
  3) Optical and image processing of part positioning
  4) Integrated robot controller
  5) Memory based or case based learning mechanism.

2.2.2.2 Embedded Systems (Cyber Physical Infrastructure)

- Embedded systems, named as Cyber-Physical Systems (CPS), can be explained as supportive technology for the organization and coordination of networking systems between its physical infrastructure and computational capabilities.
- In this respect, physical and digital tools should be integrated and connected with other devices in order to achieve decentralized actions.
- In other words, embedded systems generally integrate physical reality with respect to innovative functionalities including computing and communication infrastructure.
- In general, an embedded system obtains two main functional requirements:
  1) The advanced level of networking to provide both real-time data processing from the physical infrastructure and information feedback from the digital structure; and
  2) Intelligent data processing, decision-making and computational capability that support the physical infrastructure.

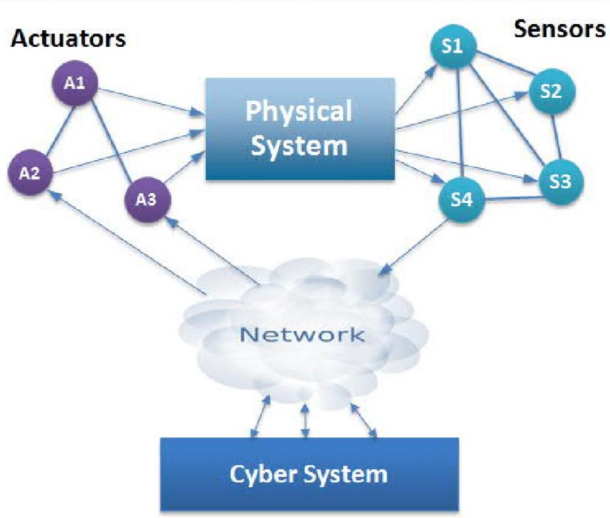

Fig.2.4 – Architecture of Cyber Physical Systems

- For this purpose, embedded systems consist of RTLS technologies, sensors, actuators, controllers and networked system that data or information is being transformed and transferred from every device.
- In addition to that, information acquisition can be derived from data processing and data acquisition in terms of applying computational intelligence supported by learning strategies such as case based reasoning.
- **Real life examples** can be given as:
    1) A specific example for embedded systems can be observed in Beckhoff maintenance tool: Process parameters (stress, productive time etc.) of mechanical components can be recorded digitally while making some adjustments such as technical experiments in online or offline platforms.
    2) In addition to that case, cyber-physical research and learning platform "CP Factory" from Festo provides educational institutions and companies with access to the technology and applications of Industry 4.0. The main part of the (physical) mechanism is supported by an intelligent module for the communication of process data—the "CPS Gate". The "CPS Gate" operates within the factory's workstations as the "backbone" module for controlling the processes.
    3) Schunk linear motor drives with each prioritized order in the assembly lines repeatedly for decentralized quality assurance and documentation of quality criteria.
- The embedded systems have some **properties** mentioned as follows:
    1) Increased operational safety through the detection of safety-critical status prior to their importance level,
    2) Sensorless or with sensor switching condition monitoring,
    3) Control and monitoring using feedback loops,
    4) Systematical and targeted integration of storage and analysis of data directly and interactively on the local control, in private networks or in the public cloud system,
    5) Flexible and reconfigurable parts and machines.

2.2.2.3 Additive Manufacturing

- Additive Manufacturing is a set of emerging technologies that produces three dimensional objects directly from digital models through an additive process, particularly by storing and joining the products with proper polymers, ceramics, or metals.
- In details, additive manufacturing is initiated by forming computer-aided design (CAD) and modeling that arranges a set of digital features of the product and submit descriptions of the items to industrial machines. The machines perform the transmitted descriptions as blueprints to form the item by adding material layers. The layers, which are measured in microns, are added by numerous of times until a three-dimensional object arises.
- Raw materials can be in the form of a liquid, powder, or sheet and are especially comprised of plastics, other polymers, metals, or ceramics.

- In this respect, additive manufacturing is comprised of two levels as software of obtaining 3D objects and material acquisition side.
- For instance, additive manufacturing processes outperform than conventional manufacturing mechanisms for some products including shaping initially impossible geometries such as pyramidal lattice truss structures. Obviously, printing mechanism reduces material waste by utilizing only the required materials.

Fig.2.5 – Arburg 3D Printer

- Besides that, networked system comprised of ordering, selection of injection molding is also necessary to monitor the process variables and parameters on a particular interface.
- **Real life examples:**
    1) ARBURG GmbH deals with individualized high volume plastic products. An ALLROUNDER injection moulding machine and a freeformer for additive manufacturing are linked by means of a seven-axis robot to 3D plastic lettering using additive processes.
    2) Addidas created 3D printed shoes, the designs of which were created based on big data. They united with Carbon, an innovative tech company, to create a groundbreaking computational design with Digital Light Synthesis. Liquid, light and oxygen form the three elements of the 3D printing process. The end result is a unique lattice structure. They examined 17 years of athlete data and over 5 million lattice variations to create it.

2.2.2.4 Cloud Technologies

- Cloud based operating is another essential topic for the contribution of networked system integration in Industry 4.0 transformation.
- The term "cloud" includes both cloud computing and cloud based manufacturing and design.
- Cloud manufacturing implies the coordinated and linked production that stands "available on-demand" manufacturing. Demand based manufacturing uses the collection of distributed manufacturing resources to create and operate reconfigurable cyber-physical manufacturing processes.
- Here, main purpose is enhancing efficiency by reducing product lifecycle costs, and enabling the optimal resource utilization by coping with variable-demand customer focused works.

- As a consequence of the advancements in cloud technologies such as decreasing amount of reaction times, manufacturing data will increasingly be practiced in the cloud systems that provide more data-driven decision making for both service and production systems.
- On the other hand, privacy and security issues aroused from system lacks are needed to be considered and secondly, extra storage needs, payment options and physical location should be carefully decided in advance.

Fig.2.6 – Cloud Service Providers

- **For example:**
  1) GE Digital proposed "Brilliant Manufacturing Suite", which uses smart analytics to evaluate operational data and factory's overall equipment effectiveness is increased by 20% or more.
  2) Besides that, M&M Software's industrial cloud service platform is based on real time data analytics and consists of a universal core system of individual web portals. The mentioned system can be remotely operated on both a PC using a browser and on mobile devices.
- The **requirements of cloud based processing** are listed as follows:
  1) Data driven applications are worked on cloud-based infrastructure, and every supply chain element and user is connected through the cloud system.
  2) Real time data analytics for notifications and abnormalities using independent cloud database function.
  3) Take full advantage of big data to optimize system performance according to external and sudden changes.
  4) Users need a connected device to see the necessary information on cloud, and they have authorized access to available applications and data worldwide.
  5) Proactive application function as an automatic shift log or tool change log, perform adaptive feed control, detect collisions, monitor processes, and much more besides.

2.2.2.5 *Virtualization Technologies (Virtual Reality (VR) and Augmented Reality (AR)):*

- Virtualization technologies are based on AR and VR tools that are entitled the integration of computer-supported reflection of a real-world environment with additional and valuable information.

Fig.2.7 – Repair/Maintenance using Augmented Reality technology

- The visualization technologies have four functional requirements:
  1) scene capturing,
  2) scene identification,
  3) scene processing,
  4) scene visualization.
- Thus, hardware such as handheld devices, stationary visualization systems, spatial visualization systems, head mounted displays, smart glasses and smart lenses are utilized for implementation.
- Today, visualization technologies are mainly applied in diversified fields such as video gaming, tourism and recently, this topic has started to be considered within the context of constructing quality management systems, assembly line planning and organizing logistics and supply chain actions for smart factories.
- Specific **examples** can be given from BMW Connected Drive that enables navigation information and assists driver assistance systems, Q-Warrior helmet for military purposes, Liver explorer for medical practitioners and Recon Jet for leisure activities.
- **Applications:**
  1) Particularly, AR and VR systems are adapted to computer aided quality assessment for the estimation of scale, tracking the product position and visualizing current state of the product by a graphical user interface.

2) In shop floor implementation of visualization technologies, video based glasses (Oculus Rift), optical glasses (C wear) and Android based devices, video based tablet and spatial projector are utilized.
3) In logistics, especially considering warehouse operations, transportation optimization, last mile delivery, customer services and maintenance.
4) In this virtual world, operators can interact with machines or other devices by using them on a cyber-representation and change parameters in order to interpret the operational and maintenance instructions.
5) The most remarkable future implementation of visualization systems is the requirement of tailor made solutions for human and robot collaboration and more user-friendly devices for better experience.

- The visualization technologies have some properties mentioned as follows:
    1) Optimal user support through augmented reality and gamification.
    2) Significantly more convenient and user-friendly interface design.
    3) The mobile projection providing holistic and latency-free support.

2.2.2.6 Simulation

- Before the application of a new paradigm, system should be tested and reflections should be carefully considered. Thus, diversified types of simulation including discrete event and 3D motion simulation can be performed in various cases to improve the product or process planning.
- **Applications:**
    1) Simulation can be adapted in product development, test and optimization, production process development and optimization and facility design and improvement.
    2) It handles assembly line balancing and machining planning that requires to calculate operating cycle times of robots and enables design and manufacturing concurrency.

Fig.2.8 – Simulated Aircraft

- In the perspective of Industry 4.0, simulation can be evaluated as a supportive tool to follow the reflections gathered from various parameter changes and enables the visualization in decision-making. Therefore, simulation tools can be used with other fundamental technologies of Industry 4.0.
- For instance, simulation based CAD integration ensures the working of multiple and dissimilar CAD systems by changing critical parameters. Additionally, simulation can reflect what-if scenarios to improve the robustness of processes. Especially for smart factories, virtual simulation enables the evaluation of autonomous planning rules in accordance with system robustness.

2.2.2.7 *Data Analytics and Artificial Intelligence*

- **Origin of Big Data:** Big data comes from sensors, video/audio devices, networks, log files, transactional applications, web, and social media — much of it generated in real time and at a very large scale.
- Too much data makes it difficult to identify the relevant information.
- The **main challenge** lies into accurately process the collected data so that the right information for the desired purpose can be provided at an appropriate time.

Fig.2.9 – Big-data filter

- **Big data analytics** is the use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes.
- Employment of such techniques can aid in unraveling of hidden patterns, trends of market, and preferences of the customer, unknown correlations and the related useful information.
- They make it possible to identify the performance of an individual component and its operating restrictions in order to prevent future production issues and take preventative action.
- Around 15–20% increased return on investment could be achieved by the industries with the implementation of Data Analytics techniques.
- In consequence of the manufacturing companies start to adopt advanced information and knowledge technologies to facilitate their information flow, a huge amount of real-time data related to manufacturing is accumulated from multiple sources.
- The collected data which is occurred during R&D, production, operations and maintenance processes is increasing at exponential speed.
- For instance, data mining techniques have to be used where data is gathered from various sensors. This information assists the evaluation of current state and configuration of different machinery, environmental and other counterpart conditions that can affect the production as seen in smart factories.
- The analysis of all such data may bring significant competitive advantage to the companies that they are able to be meaningfully evaluate the entire processes.
- Big data acquisition and integration phase includes data gathering from RFID readers, smart sensors and RFID tags etc. Big data processing and storage configures real time and non-real time data as a form of structured and unstructured data by cleaning, transforming and integration.

2.2.2.8 Communication and Networking (Industrial Internet)

- Communication and networking can be described as a link between physical and distributed systems that are individually defined.
- Using communication tools and devices, machines can interact to achieve given targets, focus on embedding intelligent sensors in real-world environments and processes.
- Industrial Internet of Things (IIoT) relies on both smart objects and smart networks and also enables physical objects integration to the network in manufacturing and service processes. In other words, major aim of IIoT is to provide computers and machines to see and sense the real world applications that can provide connectivity from anytime, anywhere for anyone for anything.
- On the other hand, the **main issue** for the integration period is the construction of standards for the communication of various devices. Companies also face another problem, security flaws, as realized from privacy issues.
- Thanks to the recent advances of decreasing costs for sensor networks, NFC, RFID and wireless technologies, communication and networking used for IIoT suddenly became an engaging topic for industry and end-users.
- The potential of IIoT is significant. The determination of the physical status of objects through sensors and integration of Web 2.0 technologies can cause the huge collection and processing of operational data, allows real time response as a reaction of the status of things.
- Today, interoperability with big data processing platforms can provide with agent based services, real-time analytics, and business intelligence systems which is essential for networking.
- As a result of the penetration of manufacturing intelligence, manufacturers can be able to enhance quality, increase manufacturing output. This knowledge provides better insights for detecting root cause of production problems and defect mapping, monitor machine performance and reduce machine failure and downtime. Therefore, IIoT or communicative systems are not only considered as a technology of Industry 4.0 but also evaluated as a "cover" that contains many features from Industry 4.0 tools.
- An **example** could be given form predictive maintenance: Liggan and Lyons (2011) indicated that a sustainable predictive maintenance includes the mechanical evaluation of the production processes such as motor rating, number of pumps and valves, belt length, thermal imaging and base vibration analysis.
- Thus, the integrated system should process the data by considering the historical data captured from sensors and other environmental conditions such as material quality, comments of the material gathered from other users.
- The collection can be supported by using Web 2.0 technologies and extracting knowledge from the collected data can be transformed to organizational "know how". This process requires the assistance of big data analytics and obviously, real time tracking system should be implemented considering two ways: (i) data collection (ii) ordering to the machines or services using knowledge emerged from big data analysis.

- For this reason, communication and networking can be evaluated as an inclusive technology that support the functioning of other Industry 4.0 tools such as big data analytics, simulation and embedded systems.

2.2.2.9 Cyber security

- Industry 4.0 transformation requires intensive data gathering and processing activities. Thus, security of the data storage and transfer processes is fundamental concepts for companies.
- The security should be provided in both cloud technologies, machines, robots and automated systems considering the following **issues**:
    1) Data exportation technologies' security
    2) Privacy regulations and standardization of communication protocols
    3) Personal authorization level for information sharing
    4) Detection and reaction to unexpected changes and unauthorized access by standardized algorithms.
- To avoid the results of these issues, operational recovery, end user education, network security and information security should be ensured by cyber incident response, critical operation recovery and authorization level detection programs. Other preventive actions can be access controls of user account, firewalls, intrusion detection systems and penetration tests that use the vulnerability scanners.
- A **real life example** can be given as CodeMeter from Wibu-Systems AG that IP protection mechanisms prevent illegal copying and reverse engineering of software, theft of production data, and product counterfeiting; machine code integrity foils tampering, Freud detection and cyber-attack identification. In addition to that, a hidden counter sitting inside the software license controls volume productions, making sure only the identified batches are produced. The entire cyber security system provides remote communication adapted by using certificate chains and combined with digital signature and assists end point security for sensors, devices, and machines.
- **Benefits** of cyber security systems are given as follows:
    1) Encryption algorithms for hardware-based protection,
    2) Trustworthy communication protocols between sensors, devices, and machines enabled by using digital signature and certificates,
    3) Flexible licensing models and authorization level detection,
    4) Faster back office automation with the seamless integration of licenses in all leading CRM, ERP, and e-commerce systems.

2.2.2.10 RTLS and RFID Technologies

- Smart Factory has some critical operations such as smart logistics, transportation and storage by satisfying efficient coordination of embedded systems and information logistics. These operations include identification, location detection and condition monitoring of objects and resources within the organization and across company using Auto-ID technologies.

- The aggregation and processing of the real time data gathered from production processes and various environmental resources assist the integration of organization functions and enables self-decision making of the machines and other smart devices.
- Thus, radio-frequency identification (RFID) and real time location systems (RTLS) may generate value in manufacturing and logistics operations in the following way:
    1) Identification—especially RFID with single and bulk reading,
    2) Locating—RTLS like GPS and others,
    3) Sensing—e.g. temperature and humidity sensors.
- In this respect, the possibility of item based tracking—for logistics processes (e.g. control of incoming goods) and also essential for production processes (e.g. control of correct parts assembled)- ensures the automation of the existing processes and remanufacturing of parts.
- Thus, practitioners widely adapt RTLS and RFID based technologies for successful implementation of smart factories and processes.
- For **example**,
    1) Hologram Company RAKO GmbH implemented a smart identification label that enables electronic identification of the individualized products easily and reliably either on the product itself or on the packaging.
    2) The tags used in HP-digital machinery plant have unique serial numbers such as data matrix code, QR code or standard barcode.
    3) Another example can be given from advanced assembly line for floor cleaning machines of Alfred Kärcher GmbH that QR code embedded with a RFID chip is utilized to track the product from the beginning of the production. In this case, data is read out at every workstation in order to follow detailed assembly instructions appeared on a monitor at a specific workstation.
- The **outcomes** of RTLS and RFID based systems are appeared as follows:
    1) Process-optimized production of a product in a large number of versions
    2) Enhanced functionality and flexibility of the assembly line
    3) A high degree of data transparency
    4) Real time data flow to enable rapid support for workers.

2.2.2.11 Sensors and Actuators

- Sensors and actuators are the basic technology for embedded systems as entire system obtains a control unit, usually one or more microcontroller(s), which monitors(s) the sensors and actuators that are necessary to interact with the real world.
- In industrial adaptation of Industry 4.0, embedded systems similarly consist of a control unit, several sensors and actuators, which are connected to the control unit via field buses.

- The control unit conducts signal processing function in such systems.
- As smart sensors and actuators have been developed for industrial conditions, sensors handle the processing of the signal and the actuators independently check production current status, and correct it, if necessary.

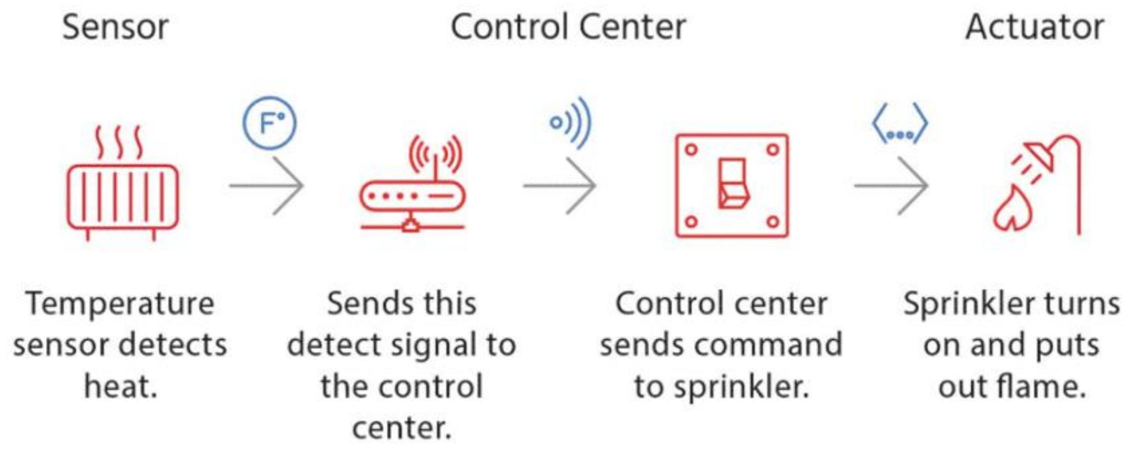

Fig.2.10 – Example of Sensor and Actuator

- These sensors transmit their data to a central control unit, e.g. via fieldbuses. In this respect, sensors and actuators can be defined as the core elements for entire embedded systems.
- **Examples:**
  1) An example of the adaptation of sensors and actuators to Industry 4.0 implementation can be given from in intelligent pneumatics actualized from AVENTICS GmbH. In this case, Advanced Valve (AV) series are adapted with pneumatic valves, sensors, or actuators connected to the valve electronics. This connection links the embedded system to higher-level control by the adaptation of IIoT. The AES supports all conventional fieldbuses and Ethernet protocols for a seamless flow of data to implement preventive maintenance.
  2) Another example can be given from Bosch GmbH that the system enables monitoring product quality in supply chain. In that case, transport packaging is furnished with integrated Bosch sensors that are connected to the Bosch IoT cloud system. They continuously record data that are relevant for product quality, such as temperature, shocks or humidity.
- The **benefits** of sensors and actuators are:
  1) Real-time tracking along the entire production or service systems
  2) Continuous documentation and data collection for supporting big data analytics, deep learning and knowledge extraction
  3) Enriched system availability via condition monitoring.

2.2.2.12 Mobile Technologies

- Mobile devices made a significant progress after these devices were first introduced and are now so much more than just basic communication tools.

- These devices ensure the internet enabled receiving and processing of large amounts of information and are provided with high quality cameras and microphones, which again allow them to record and transmit information.
- Considering the implementation of communication and networking in Industry 4.0 adaptation, connectivity to inanimate objects allows companies to communicate with each other.
- When mobile devices become internet enabled and enriched by Wi-Fi technology, they come to the same platform as other process equipment does.
- This situation implies that mobile devices can receive and transmit process related data in advance, and allow users to address issues as they cope with in real time decision making.
- Using mobile technologies, issues can now be recognized and dealt with faster as information moves with a higher velocity in the right position.
- The mobile devices are now used in practical way and able to interact with process equipment, material, finished goods and parts through IIoT.

2.3 Design Principles of Industry 4.0

- Before implementing Industry 4.0, design principles should be taken into account. The design principles provide the comprehensive adaptation of entire system and enable the coordination between Industry 4.0 components.
- There are seven design principles appeared in the application and implementation of Industry 4.0:
    1) **Agility:** It means the flexibility of the system to changing requirements by replacing or improving separated modules based on standardized software and hardware interfaces
    2) **Interoperability:** It implies the communication of cyber physical systems components with each other using Industrial Internet and regular standardization processes to create a smart factory.
    3) **Virtualization:** Virtualization enables monitoring of entire system, new system adaptation and system changes using simulation tools or augmented reality.
    4) **Decentralization**: It is a key term for self-decision making of the machines and relies on the learning from the previous events and actions.
    5) **Real-time data management:** Real time data management is the tracing and tracking the system by online monitoring to prevent system lacks when a failure appears.
    6) **Service Orientation:** Service orientation is the satisfaction of customer requirements adaptation to entire system with using a perspective of integrating both internal and external sub systems.
    7) **Integrated business processes:** It is the link between physical systems and software platforms by enabling communication and coordination mechanism assisted by corporate data management services and connected networks.

2.4 Proposed Framework for Industry 4.0

- The main motivation of Industry 4.0 is the connection and integration of manufacturing and service systems to provide effectiveness, adaptability, cooperation, coordination and efficiency, as realized from design principles. Therefore, correlation between design principles and existing technologies is explained in *Fig.2.12* for better understanding of proposed framework.

Technologies	**Design Principles**						
	1) Real-time Data Management	2) Interoperability	3) Virtualization	4) Decentralization	5) Agility	6) Service Orientation	7) Integrated Business Processes
Adaptive Robotics					✓		
Big Data	✓			✓	✓	✓	
Simulation			✓		✓		
Embedded Systems				✓			
Comm. & Networking		✓		✓	✓		✓
Cyber Security		✓					✓
Cloud Technology					✓	✓	✓
Additive Manufacturing					✓		
AR & VR			✓		✓		
Sensors & Actuators	✓			✓			✓
RFID & RTLS Tech.	✓			✓	✓		✓
Mobile Technologies					✓		

Fig.2.11 – Categorization of Industry 4.0 technologies and design principles

- Interoperability of communicative components could be satisfied using cyber physical system security and Industrial Internet of Things adaptation such as communication and networking.
- In similar manner, monitoring the changes in existing system can be provided by simulation modeling and virtualization techniques such as augmented reality and virtual reality. An example could be given from CAutoD which optimizes the existing design process of trial-and-error by altering the design problem to a simulation problem, as an automating digital prototyping.
- Additionally, adaptive robots, embedded systems based on cyber physical infrastructure, cloud systems and big data analytics should be successfully combined in order to enable self-decision making and autonomy. For instance, by utilizing data processing, analysis and sharing, knowledge discovery can be extracted and preventive actions can be ensured for each cyber physical component.
- RFID and RTLS technologies, sensors, and actuators are the major components for real time data management in terms of traceability and real time reaction to sudden changes appeared in sub systems. To illustrate, real time maintenance systems can set a precedent by presenting the integration of real time data processing. By this way, possible preventive precautions are taken via RTLS platforms and sensors against instantaneous incidents.
- Cloud systems, data analytics and artificial intelligence techniques also ensure the specific customer specifications by assessing the external information from digital manufacturing environment and fulfill service-oriented architecture of Industry 4.0 framework.

- Considering the coordination between design principles and supportive technologies, agility and integrated business processes can be evaluated as the most important design principles.
- In this regard, integrated business process implies the relation between cyber security and cloud systems that are based on a communication and networking infrastructure such as Industrial Internet.
- Besides that, connected and networked adaptive robots, additive manufacturing, cloud systems, data analytics and artificial intelligence play an important role for the adaptation to changing requirements to satisfy system stability and agility.
- Considering the reflections gathered from the relationship between design principles and supporting technologies, a **general framework for Industry 4.0 adaptation** is presented as seen in *Fig.2.12*.

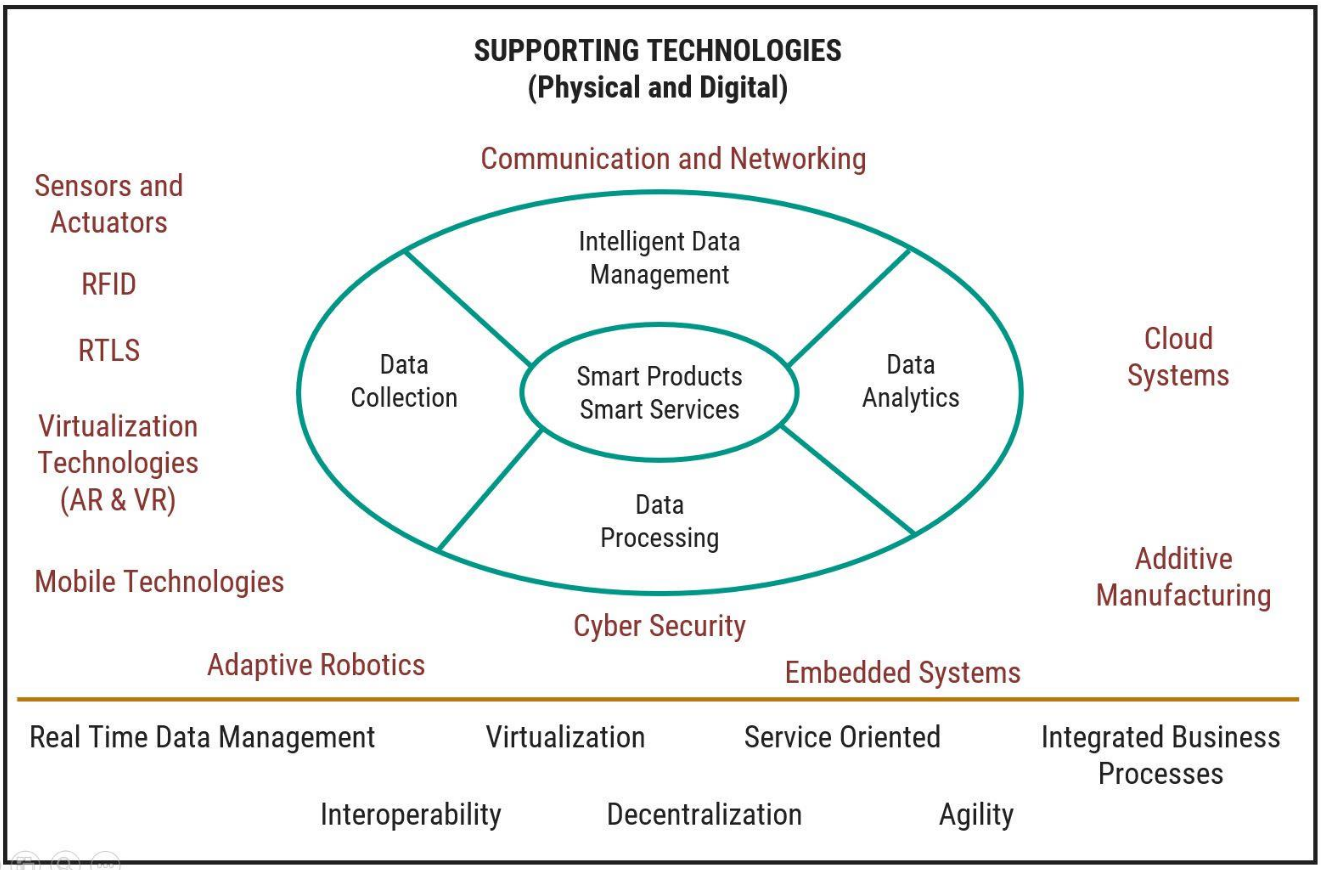

Fig.2.12 – Industry 4.0 Framework

- To enable a successful implementation of Industry 4.0, companies should focus on involving and redefining the smart product and smart processes to their core functions such as product development, manufacturing, logistics, marketing, sales and after sale services.
- In this respect, a smart product contains three basic components: (i) physical parts including a mechanical part, (ii) a smart part that has sensors, microprocessors, embedded operating system and user interface (iii) connectivity part that has ports, antenna and protocols.
- All smart products and processes should have an entire supporting technology platform that relies on the connection and coordination of data exchange, data collection, data processing and analytics between the product and services to external sources.

- Using big data analytics, products and services can be monitored and changes can be observed in numerous environmental conditions.
- Additionally, cloud technologies ensure coordinated and linked production to distributed systems.
- As a consequence, interoperability with big data processing platforms are strengthened by agent-based services, real-time analytics, and business intelligence systems, which is essential for networking. Thus, big data platforms and cloud systems can provide real time data management in order to give fast reactions for data processing, management of data flow and extracting know how to improve entire product performance and utilization.
- In this way, adjustments can be made according to difference between current condition and desired requirements by adapting algorithms and iterative processes such as self-learning and self-assessment.
- This intelligent data management should be promoted by the construction of communication and networking infrastructure based on Industrial Internet and cyber security for successful remote controlling and monitoring.
- To satisfy virtualization part of Industry 4.0, augmented reality and Virtual reality are inevitable tools. Virtual reality (VR) provides a computer-aided simulation tool for reflecting the recreation of real life environment that user feels and sees the simulated reality as they are experiencing in real life.
- On the other hand, augmented reality is progressed in applications to combine digital elements with real world actions.
- The overall integration of VR and AR provides the enrichment of real life cases and actions.
- Furthermore, RFID, sensors and RTLS technologies enable real time data flow and data gathering, which is essential for intelligent data management in decentralized systems.
- Additionally, mobile technologies enable receiving and processing of large amounts of information to record and transmit information and supports agile-remote control of entire business.
- Embedded systems are constructed on the integration of physical systems including sensors and actuators to enhance the autonomous nature of Industry 4.0.
- Besides that, additive manufacturing enables digital models through an additive process by shaping 3D features for agile manufacturing.
- Additionally, companies mainly focus on the entire systems, not the single components of the systems separately.

2.5 References

[1] Alp Ustundag and Emre Cevikcan "Industry 4.0: Managing the Digital Transformation", The Springer Series in Advanced Manufacturing, 2018.