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INDUSTRIAL EXPERT

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INDEX: Industrial Expert - Basic Module

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About This Course

The INDEX – Industrial Expert Basic Module provides comprehensive knowledge for the successful implementation of Industry 4.0 solutions. This class on Introduction Industry 4.0 provides basic knowledge about the key innovative concepts and technologies and covers five areas:

1. Entrepreneurship, Technology and Restructuring Management (E-TRIM)
2. Sensors and Automation
3. Additives Manufacturing
4. Internet of Things
5. Augmented Reality

Format

The form of education is e-learning with aprrox. 40 hours of lessons and self-studying. Weekly lessons include lectures, thematic videos and performing test tasks. An important part of this course is performing final exam in the form of multiple choices quiz, which contains answers based on study material. The course is set up in compliance with the ECVET System with possibility to obtain the Certificate of attendance.

Who can take this course?

The BASIC module does not require any specific knowledge on Industry 4.0 and is designed for a wide audience, who want to learn about 4th Industrial revolution and smart technologies. This means, first of all, students (bachelors, masters, specialists), whose curricula include disciplines related to the industry 4.0 and smart technologies. The course will be of particular interest to:

- Senior executives or a development department managers of your enterprise interested in learning about Industry 4.0 technologies and opportunities of their implementation;
- Professionals interested in application of Industry 4.0-based solutions in his area of expertise.
- Founders of high-technology startups;
- Young engineers of the company who is already working on development of specific components of Industry 4.0 and their application or is interested in expanding the base of customers that develop smart technologies for new fields of application;
- Educators teaching graduate and postgraduate courses focusing on Industry 4.0 technologies;
- Students or postgraduates interested in Industry 4.0 Technologies.

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INDUSTRIAL EXPERT INDEX

Programme of the course

1. Introduction

- Historical introduction into the industrial revolutions
- Key features of the fourth industrial revolution

Entrepreneurship, Technology and Restructuring Management (E-TRIM)

- Introduction to entrepreneurship
- Innovation management – basic concepts
- Overview of valorisation and technology transfer

Sensors and Automatization

- Introduction
- History of sensors
- Sensors and actuators
- Basics of automation
- Impact for industry 4.0

Additive Manufacturing

- Overview
- What is Additive Manufacturing (AM)
- Advantages and disadvantages of Additive Manufacturing
- Materials and production methods
- What are the use cases for AM?

Internet of Things

- Introduction
- Application cases
- Industrial Internet of Things
- Security

Augmented Reality

- Definition and concepts
- History of Augmented Reality

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Results

As the result of completing the INDEX – Industrial Expert BASIC Module, learners will know:

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- Key aspects of the 4th industrial revolution
- The path that led the 4th industrial revolution
- Definition of entrepreneurship and its core concepts
- Commercialization and technology transfer strategies
- Classification of sensors and automatization strategies
- Basic knowledge about printing technologies and usable materials
- Origin of the Industrial Internet of Things
- Internet of Things infrastructure and its most common configurations
- Key concepts of augmented reality
- Differences between augmented reality and virtual reality

Competences

As the result of completing the INDEX – Industrial Expert BASIC Module, learners will be able:

- to define entrepreneurship and its core concepts
- to use the knowledge and skills about the key aspects of the 4th industrial revolution
- to understand what is commercialisation and technology transfer
- to decide if additive manufacturing technologies are potentially interesting for his intended application
- to design the overall layout of an industrial IoT architecture
- to recognize the difference between augmented reality and virtual reality

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Introduction

Historical Introduction into the Industrial Revolution

Introduction

In the course of modern history, humanity has experienced several changes of its social structures and its connection with nature. Our lifestyle itself has changed a lot over the last two and a half centuries. The main reason for these changes has been the economic transformations, which have occurred as a consequence of the Industrial Revolutions.

Historians usually identify three different Industrial Revolutions, while the fourth one is taking place currently. These revolutions differ from one to another for their industrial and economic consequences. However, they all share some common features:

- A key role in **scientific and technological development;**
- A central role in **politics** in supporting innovation;
- A strong sentiment of **hope for the future** and the promise for a better lifestyle for workers and their families. All Industrial Revolutions have made, in their own way, a huge and persistent impact on society, culture, technology, economics and politics.

In a nutshell, the actual First Industrial Revolution introduced mechanization, steam power and iconic machines like weaving looms. The second one was the realm of mass production, assembly lines and electrical energy. The third one involved automation, computers and electronics.

The first Industrial Revolution

The *First Industrial Revolution* was the process of transition from the previous concept of economy based on agriculture and handicraft to the new economic model founded on industry and machines. It took place towards the end of the 18th century in England, and then expanded all over Europe, North America and Japan. Later, its paradigm gradually spread worldwide.

The term *Industrial Revolution* was first used in the 19th century by British economic historian Arnold Toynbee. It was later popularized by academics and economists like Karl Marx, Adolphe Blanqui and John Stuart Mill. British economic historian Thomas S. Ashton identified the beginning of the revolution with the first years of the long reign of George III, in the early 1760s, and its end with the first years of the short reign of William IV, in the early 1830s. The First Industrial Revolution mainly involved the textile, the metallurgic and the extractive industries.

The most relevant innovations introduced during the First Industrial Revolution were the use of **new materials**, including iron and steel, the use of **new energy sources**, such as coal and steam engines, the invention of **new machines** and a **new organization of work** known as the *factory system*. These innovations led to disruptive consequences for the involved societies, i.e. mainly **urbanization** and the growth of cities, the rise of a **new working class**, and the increase of the **speed of transport as well as communications**.

From the 1760s to the 1830s the First Industrial Revolution hardly crossed English borders. At first, England was aware of its advantage over the other European countries, and seized the chance to consolidate its economic supremacy. However, its monopoly position could not last forever, and the industrial innovations made in England slowly made their way into neighbouring countries like Germany, France and Belgium. The latter was actually the first to join this economic transformation. But Germany, even if with some delay, gradually gained a dominant position in terms of capacity to innovate its industrial system. The United States and Japan joined the revolution by around the end of the 19th century with an unexpectable success.

Economists usually identify three fundamental aspects that significantly contributed to the growth of the revolution in England:

- the creation of a **strong national market**;
- the availability of **financial means** to invest in new factories and transform handicraft productions;
- the chance to obtain **raw materials at a low price**.

British GDP tripled in 50 years. This exponential growth was made possible by a process of social construction of a new ruling class based on the convergence of the most dynamic elements of the emerging commercial bourgeoisie and the traditional land aristocracy, which led to massive investments in manufacturing technologies.

Some theorists lay emphasis on the importance of the previous *Agricultural Revolution* promoted by the British government at the beginning of the 18th century, which is often overlooked as a driver of the Industrial Revolution. In fact, the agricultural innovations introduced in Britain, such as a widespread use of *Enclousers*, resulted in a significant increase of agricultural production and the consequent acceleration of demographic growth. In addition, the introduction of innovative agricultural techniques mitigated the need for manpower, and so many peasants became available for employment in factories.

One of the most important economists of the 20th century, Joseph A. Schumpeter, pointed out the importance of the difference between *invention* and *innovation*. While *inventors* are those who create something new as a result of their hard individual work, *innovators* are those who manage to bring inventions to the market. One of the fundamental inventions of this period was the flying shuttle ideated by John Kay, which significantly improved the weaving speed in the textile industry. Other inventions were the “Spinning Jenny” by James Hargreaves and the “Mule” by Samuel Crompton. Richard Arkwright was one of the main innovators of the revolution. As an engineer and an entrepreneur, he introduced the water frame spinning machine in his factories. In 1785, Edmund

Cartwright invented an automated weaving machine, which was first powered by horses, but was later upgraded with a steam engine. Thanks to the introduction of these new technologies, the production of clothes vertiginously increased in England, which called for huge amounts of cotton from India. The consequences of the Industrial Revolution were about to spread all over the world. The production of cotton was the fastest flourishing sector of the textile industry.

The metallurgic industry was the second to become involved in the revolution. At the beginning of the 18th century, England was running out of supplies of wood, which was the heat source used to melt iron minerals. Because of this shortage, the metallurgic industry underwent a setback. In 1709, Abraham Darby came up with a process to use coal in the cast iron production. Coal was used in the form of coke. The steam machine was an important innovation that helped boost the growth of the metallurgic industry. One of the first prototypes of the steam machine was that proposed by Thomas Newcomen, which was improved by James Watt in 1765, who is still celebrated as a pioneer of the Industrial Revolution. Steam machines were installed in textile and iron factories from around 1785.

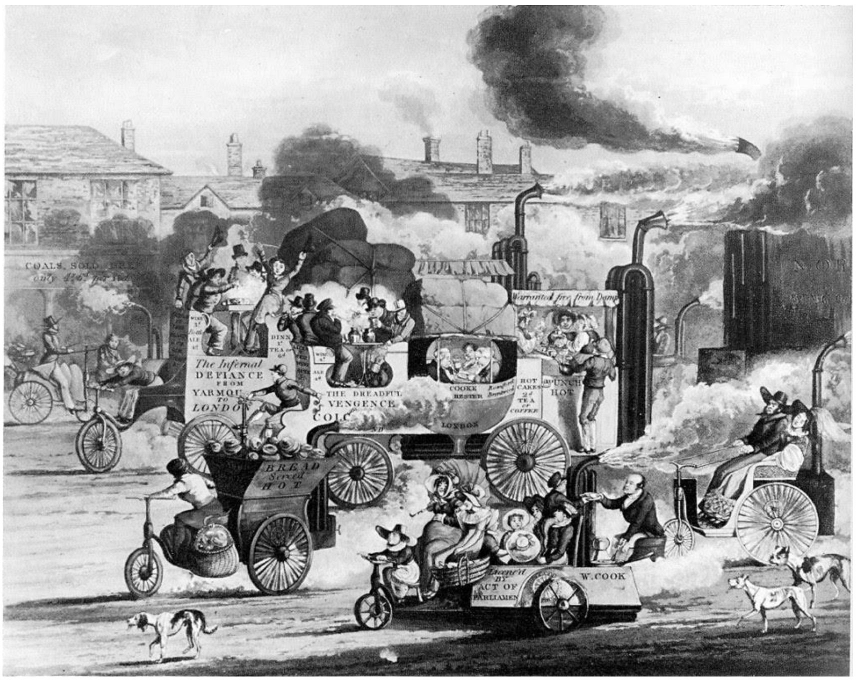

Figure 1: A view in Whitechapel road, a caricature of steam carriages by H. T. Alken. Source: Public domain work of art

At the dawn of the 18th century, the English road network was somewhat obsolete. From 1760 to 1774, the British Parliament promoted the construction of new roads together with the improvement of the existing network. The government introduced the payment of tolls to encourage private companies to fund road works. In an attempt to promote the transportation of coke, new canals were opened. In turn, railways did not play a key role in the First Industrial Revolution, given that the steam locomotive was invented after 1830. Another important innovation in transport was a massive construction of bridges. Bridges were made of cast iron at first, which is not as elastic as the steel

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introduced in the 19th century. Steel bridges were much safer than their cast iron predecessors, and could cover much longer distances.

Figure 2: Cromford Canal Towpath. Looking South along Cromford Canal, about 1 km South of Whatstandwell, the picture shows the four forms of transport running through this section of the valley, from left to right: the canal and its towpath, the railway line, the road and the river Derwent. Source: CC BY-SA by Sharkstar, via Wikimedia Commons

The industrial revolution led to striking **social changes**. Thanks to the combination of new agricultural techniques and progress in medicine and hygiene, the population in Europe has almost quadrupled over the last 200 years. Life expectancy was between 25 to 35 years before the revolution, and it now exceeds 75 years. However, the First Industrial Revolution also caused **social problems**. It rapidly turned the previous social structure upside down. In a few decades, the lives and habits of people underwent dramatic changes. Factory workers were called upon to endure 16 to 17 hours of work in unsafe places and poor hygienic conditions. Workplace injuries, accidents and even casualties were frequent. Workers used to live in big overcrowded buildings in new boroughs. The appearance of these boroughs is one of the most evident consequences of the social changes brought by the revolution. In some of the earliest industrial cities in England, the houses of the working class are still there today. The working class is only one of the new social groups that developed during the First Industrial Revolution. Another major one is the so-called industrial bourgeoisie. The revolution arose with the success and rise of bourgeois entrepreneurs. The social changes that occurred in those years also affected the common imagery arts and culture, such as the well-known body of work of Charles Dickens.

The First Industrial Revolution introduced many useful innovations in the industrial sector and in the economy, but at the same time it also raised outstanding **controversies**. In this period, the first trade unions were created to guarantee the rights and preserve the health of workers, who were asked to endure inhumane conditions and unsafe environments.

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The revolution has also made a **huge impact on the environment.** For instance, the wings of peppered moths range from white to black in England. It has been observed that the black ones mostly live in industrialized regions, while the white ones are more present in the more rural countryside. This pigmentation probably results from the soot deposited on the bark of birch trees during the years of the Industrial Revolution: close to the factories running on coal, the white moths were more exposed to predatory birds than their black counterparts. This is a simple and clear example of how human activities affect their ecosystems.

The First Industrial Revolution completely changed the world. Its inheritance has direct or indirect bearing on the development of three more industrial revolutions.

The second Industrial Revolution

The *Second Industrial Revolution*, also known as the *Technological Revolution*, is generally dated between 1870 and 1914. It mainly developed in the UK, Germany and the USA, but also Japan, Italy, France and the Netherlands took part in this process. Some of the most characteristic innovations of this period were the **telegraph**, the **use of petroleum**, the **internal combustion engine** and the **beginning of electrification**.

Historian and economist David Landes pointed out that the key feature of the Second Industrial Revolution was a synergistic combination of new technologies, new materials, including alloys and chemicals, and new communication technologies such as the telegraph, the radio and the telephone. The second revolution was also characterized by the construction of railroads, a larger production of iron and steel and a more extensive use of steam power. Policy analyst Vaclav Smil called this period *The Age of Synergy*. For example, railways were a result of the synergy between iron, steel and coal. Railways enabled the transportation of materials and end-products, which in turn led to cheaper tracks to build more railway lines. Railways also benefited from cheaper coal for their steam locomotives. This synergy led to the construction of about 120,000 km of railways in the USA in the 1880s, which is a record in world history. In this period, step-change innovations and inventions merged together to improve industrial productions and boost scientific, technological and economic progress.

In the iron industry, in 1828, James Beaumont Neilson invented a new technology called hot blast, whereby hot exhaust gases from a blast furnace are reused to preheat the combustion air blown into the stove. Hot blast was the single most important advance in fuel efficiency in the metallurgical industry, as it significantly reduced fuel consumption for the production of cast iron, and was one of the most important advances developed during the Industrial Revolution. The drop-in costs for the production of wrought iron was key to the development of railways in the 1830s. With a significant reduction of the costs for the production of cast iron with coke obtained by hot blast, the demand grew to a considerable extent. At the same time, in the steel industry, Sir Henry Bessemer introduced the Bessemer Process, which consisted of the removal of impurities from pig iron through oxidation with air blown through molten iron. This process allowed the mass production of steel.

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Figure 1: A picture of a Bessemer Converter (original content here). Source: Public domain work of art.

The availability of cheap steel enabled the construction of large bridges, railroads, ships and lastly even skyscrapers, a new type of building that has continued to gain popularity ever since. From the 1860s, railroads could finally be made out of steel at a reasonable cost.

Thanks to the experiments and discoveries of Michael Faraday, it was possible to use **electric power** as an energy source. In 1881, Sir Joseph Swan developed incandescent light bulbs to illuminate the Savoy Theatre in London. His light bulbs were also adopted in Newcastle in the first street lighting installation in the world. In 1891, the first modern power station was completed. It provided 800 kilowatts in central London. Electrification is often regarded as the most important achievement of 20th century engineering. Electric lighting demonstrated various advantages over gas lighting, as it is more efficient and secure and dissipates less heat.

In 1848, in Scotland, the first oil works started, thus opening the **petroleum industry**, which gained more and more relevance through the years. Many derivatives were also produced out of petroleum, such as kerosene, which was used in city lighting before electrification, and gasoline, which was however mostly unused until 1914, when the production of cars began to gain numerical importance.

In the first half of the 19th century, **chemistry** was still in a primitive state. Sir William Henry Perkin discovered that it was possible to produce a synthetic dye called *mauveine* from aniline, and he commercialized it. After his discovery, several aniline derivatives appeared. In 1914 the German chemical industry was predominant in the world.

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The first **telegraph system** was installed in London in 1837 by William Fothergill Cooke and Charles Wheatstone. A rapid expansion of telegraph networks occurred over the century, with the first submarine cable, made by John Watkins Brett, being laid between France and England. The Atlantic Telegraph Company was founded in London in 1856 to commit the creation of a commercial telegraph cable across the Atlantic Ocean. Works were successfully completed after many difficulties on July 18, 1866 by the SS Great Eastern ship captained by Sir James Anderson. From 1850 to 1911, British submarine cable systems dominated the world telegraph network. This was defined as a strategic goal, which became known as the All Red Line. In 1876, Alexander Graham Bell patented the telephone, while in Italy, Guglielmo Marconi invented the radio towards the end of the century. Thanks to all these innovations, the telecommunication system underwent a growth that was so rapid as to be without precedent in the history of technology and engineering.

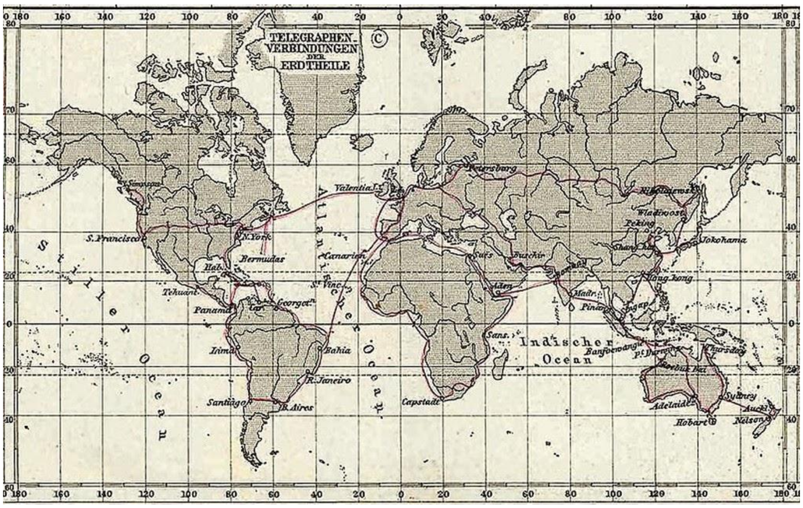

Figure 2: Major telegraph lines in 1891 ([original content here]). Source: [Public domain] work of art.

Other important inventions developed during the Second Industrial Revolution include automobiles, bicycles, synthetic rubbers, fertilizers, various engines and turbines.

The production model underwent important changes, especially due to so-called *Fordism*, often defined as a model of economic expansion and technological progress based on **mass production**, i.e. the manufacture of standardized products in huge volumes using specialized machinery and unskilled workers. It was conceptualized by Henry Ford, and the name *Fordism* originates from the first application of this paradigm in Ford car factories.

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Figure 3: Ford assembly line (original content here). Source: Public domain work of art.

The period from 1870 to 1890 saw the fastest rate of economic growth in history. Living standards significantly improved in newly industrialized countries, as commodity prices dramatically fell as a result of increased productivity. In turn, this also caused unemployment and major upheavals in trade and industry, with many jobs replaced by machines, and many factories, ships and other forms of fixed capital becoming obsolete very quickly. Governmental initiatives led to massive improvements in public health and hygiene, such as the construction of the London sewage system in the 1860s and the passage of laws regulating filtered water supplies. For instance, the Metropolis Water Act introduced regulation of water supply companies in London, including minimum water quality standards for the first time, in 1852. This act greatly reduced the rate of infection and mortality associated with a broad variety of diseases.

The third Industrial Revolution

The *Third Industrial Revolution* is significantly different from the previous one. It included processes of **transformation of the production of goods**. Since the mid-twentieth century, technological innovation has triggered changes that have produced economic development and social progress. This phenomenon, from around the end of the century, has spread to more countries, such as China and India.

The causes that originated the revolution are the advanced scientific and technological knowledge, which was often sponsored for military or dual purposes, and the economic growth that followed the Second World War.

In the years following the Second World War, the United States and the Soviet Union fought for decades for primacy in space exploration. Initially, the Russians prevailed thanks to the artificial satellite, Sputnik I, which was launched into orbit in 1957. In the same year, moreover, they sent the first living being into space, i.e. a dog called Lajka. One year later, the Americans also launched their

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own satellite into orbit, but shortly afterwards, in 1961, the Soviets responded with the first human in orbit, i.e. Soviet Air Forces pilot Yuri Gagarin. In 1969, the Americans sent the first crew onto the Moon. In the following years, there have been enormous innovations in the aerospace field. Since the 1970s, there has been a sharp increase in the launch of artificial satellites. One of the main purposes of their implementation was the field of telecommunications, as well as meteorological and geological surveys, but also military purposes. Other important applications developed after the Second World War were radars and lasers.

The oil shock in 1973 was followed by technological innovations that, over the last decades of the twentieth century, transformed daily lives in the wealthiest countries, through the production of goods like televisions, disks, radios, calculators, computers and mobile phones, which did not only change public relationships, but also domestic lifestyles. Research and development of new technologies became an essential driver of economic growth.

The growth of telecommunications and informatics determined an abrupt decline of processes centered on manpower. Human presence gradually began to fade both in the production of goods and in the provision of services. The enormous changes in the production processes that came with the introduction of high technologies have made it possible to classify this phase as the Third Industrial Revolution.

An important factor associated with the third Industrial Revolution is a constant development of transport enabled by technological progress in the respective industrial sectors, such as the automotive industry, aviation industry with the birth and development of civil aviation, naval industry, as well as by the creation of increasingly advanced and capillary road systems. This widespread network of transport will end up favouring international trade and fueling the phenomenon of globalization.

From the early seventies, a new factory system, called *post-Fordism*, began to grow. At first, it appeared in the United States, and then in the rest of the world, as a significant step beyond the assembly lines and the fragmentation of work that had found their most consistent and complete example in Ford car factories. Post-Fordism entailed the advent of a myriad of smaller companies, ranging from family laboratories to small high-tech plants, embedded within a distributed manufacturing network without a geographically recognizable centre within a single factory or even a city. Even the larger industrial plants radically changed their internal structures, by automating and modifying the previous chain processes.

Since the 1980s, a phenomenon of deindustrialization or the dawn of a new phase of socioeconomic development began, called the *Postindustrial Era* by sociologist Daniel Bell. This era is dominated by new information processing technologies with deep effects on the organization and quality of work in a large number of production processes, which was met with defensive attitudes, especially in the countries of older industrialization. Outsourcing and other services began to prevail over agriculture and industry, both in terms of number of employees and contribution to the GDP. This phase also laid the foundation for the so-called digital revolution by the development of technologies like informatics, electronics, telematics, telecommunications and multimedia.

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In many types of devices, ranging from cars to washing machines, industrial robots or agricultural greenhouses, microprocessors made their appearance to perform pre-ordered repetitive tasks according to rules dictated through a computer programming language. The Third Industrial Revolution is marked by the advent and diffusion of digital electronics with the invention of solid state transistors that gradually replaced analogic systems.

The disciplines of Information and Communication Technology (ICT) have contributed and will continue to contribute to the technological evolution as well as the radical change in the lifestyle of people facing the so-called *New Economy*. During the Third Industrial Revolution, they reached a size comparable to those of other key sectors of modern economy, such as the mechanical, chemical, pharmaceutical, textile, manufacturing and agri-food sectors.

The process of industrialization brought a large use of coal, oil and gas for energetic purposes during the 19th and 20th centuries, which has been established to be the main cause of atmospheric pollution and climate change. This is one of the main problems left behind for contemporary society. The United Nations defined the *Green Economy* as a sustainable paradigm of economic growth promoting the use of renewable energy, and the implementation of concepts of circular economy, ecosystem preservation, forestation and organic farming.

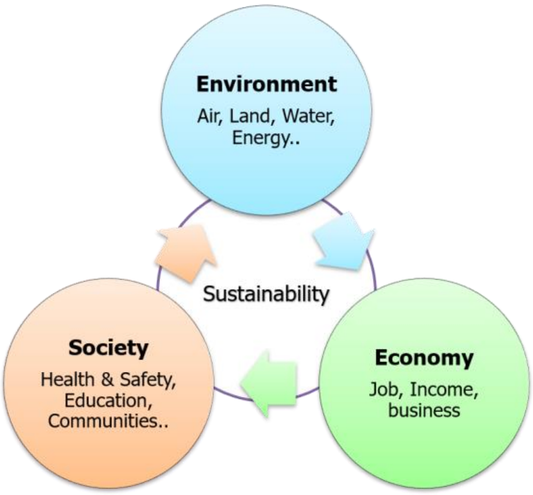

Figure 1: The three main concepts of the Green Economy. Source: [CC BY-SA](CC BY-SA) by INDEX consortium

The Third Industrial Revolution has also made a strong impact on culture and society. Globalization is a new concept that will continue to be important in the future. It indicates the interconnection of countries in the world and the new global economic model. Radios and televisions became more and more widespread among almost every social class across the wealthiest countries. Television broadcasters in particular, starting from the 80s, strongly influenced people's lives. It is estimated that the average time that an American adult spends watching television programmes is approximately four and a half hours a day. Later, the diffusion of personal computers and the Internet made an even greater impact on lifestyles and social interactions.

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Key Features of the Fourth Industrial Revolution

Introduction

The First Industrial Revolution introduced the mechanization of production by using water and steam power. The Second Industrial Revolution was the realm of mass production through the advent of electric power. The Third Industrial Revolution used electronics and information technologies in order to automate production. The Fourth Industrial Revolution is building on the third one right now, and it consists of the smart and interconnected automation of traditional manufacturing and industrial practices. Its main feature is the synergistic combination of different technologies that are gradually fusing three spheres, i.e. the physical, the biological and the digital. One of the key principles of the Fourth Industrial Revolution is inter-connectivity, whereby machines, devices, sensors, actuators and people share the possibility to communicate with each other on a global scale. When compared to the previous revolutions, the fourth one seems to be evolving at a faster pace. Its effects already impact upon every industry worldwide, while the others affected a smaller group of countries and sectors.
In 2005, Professor Detlef Zuehlke underlined the importance of the concept of Lean Technologies, i.e. the production method implemented by Toyota in order to minimize waste, as a tool to integrate smart devices, in order to boost production efficiency.

The possibilities generated by billions of people connected via mobile devices with unprecedented processing power, storage capacity and access to knowledge, are unlimited. Emerging technological innovations in flourishing disciplines like Artificial Intelligence, Robotics, Internet of Things, simulations, additive manufacturing, materials science, global storage and quantum calculus are multiplying the opportunities for growth. For instance, Artificial Intelligence (AI) is already pervading the world around us with autonomous and unmanned vehicles like drones or with virtual assistants. AI has demonstrated impressive opportunities over recent years.

Like the previous revolutions, the Fourth Industrial Revolution holds the potential to increase the global level of incomes and improve the quality of life of people around the world. Until recent years, its most visible outcomes have modified the lifestyle of those consumers who have been able to afford and access the digital world, and to benefit from a large variety of new products and services like calling a taxi, booking a flight, buying consumables, making payments or listening to music with the touch of a smartphone. However, this revolution will be more pervasive than anything we have ever seen in history: smart systems like houses, cars, factories, etc. will help face critical challenges including e.g. climate change.

This revolution will lead to long-term benefits in terms of efficiency and production. Costs for transportation and communication will decrease and exert direct effects on markets and trade. At the same time, the revolution threatens to produce greater inequalities, and in particular to overwhelm the labour market. As automation may make its way across the whole economy, the net replacement of manpower by machines may widen the gap between those who live on return on capital and those who need return on work. On the other hand, it may also happen that the empowerment of workers with more technology, such as so-called cobots, may result in safer and more rewarding jobs.

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Thus far, the demand for highly skilled workers has been increasing, while the demand for workers with lower education and skills has been decreasing. The result is a job market focusing on the highest levels. This helps explain why so many workers feel disillusioned and worried for their future. It also helps understand why middle classes around the world are developing a more and more pervasive sense of dissatisfaction and injustice towards the Fourth Industrial Revolution. With the introduction of the Internet of Things (IoT), assembly lines will no longer need the contribution of workers in mechanical operations, but only for setting high-tech machinery and solving complex problems. Advanced robots will be able to perform activities closer and closer to human skills compared to the machines of the past, and will also penetrate services where automation has made a minor impact to date. Production will be managed through virtual representations, and will undergo remote control from e.g. a personal computer or even a smartphone. Thanks to webcams and sensors, it will be possible to remotely identify and solve all sorts of problems.

The present debate on the new transformations is polarized between those who expect endless bright opportunities and those who foresee massive losses of jobs. Indeed, the reality is highly specific to the industry, region and occupation of interest. Then, the real problem is how business, government and people are going to react to these changes. In order to mitigate the risk of mass unemployment and consequent problems, reskilling and upskilling of workers is fundamental. 3D printing, resource-efficient and sustainable production and robotics are strong drivers of employment growth in the field of engineering. Automation processes are designed and controlled by engineers, and so a highly skilled workforce has become a precondition for the successful implementation of these innovations.

There are four main effects that the Fourth Industrial Revolution is exerting on business, customer expectations, product improvement, collaboration, innovation and organizational forms. Customers are increasingly at the epicentre of the economy, which stimulates continuous improvements in customer services. Physical products and customer services ever more routinely include digital features that increase their value. New technologies are called upon to make assets more durable and resilient, while data and their analysis are transforming their life cycles. Meanwhile, a world of customer experiences based on data, services and asset performance management through analytical methods requires new ways of collaboration, also due to the incredible current pace of technological progress.

The transition from the simple digitalization seen in the Third Industrial Revolution to the synergistic combination of technologies proper to the Fourth Industrial Revolution is urging all companies to re-examine the way they do business. The bottom line, however, is the same: business leaders and managers need to understand their changing environment, challenge their operational models and continuously innovate.

While the physical, digital and biological worlds continue to converge, new technologies and platforms will allow citizens to interact, express their views and coordinate their efforts. At the same time, governments will gain new technological tools to increase their control over populations, based on pervasive surveillance systems and the ability to oversee the digital infrastructures. Governments will face increasing pressure to change their current approach to public engagement, by a redistribution and decentralization of power made possible by new technologies.

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Ultimately, the ability of ruling classes and public authorities to adapt to the new situation will determine their survival. If they can prove they have the ability to embrace a world of disruptive changes, by subjecting their structures to a level of transparency and efficiency showcasing their competitive advantage, they will probably endure for a significant time.

Key Concepts of Industry 4.0

The concept of *Smart Factory* includes three major different parts:

- **Smart Production** – new technologies that allow the operators, the machines and the various instruments to cooperate;
- **Smart Service** – the Information Technology infrastructure;
- **Smart Energy** – the choice of green renewable energy sources.

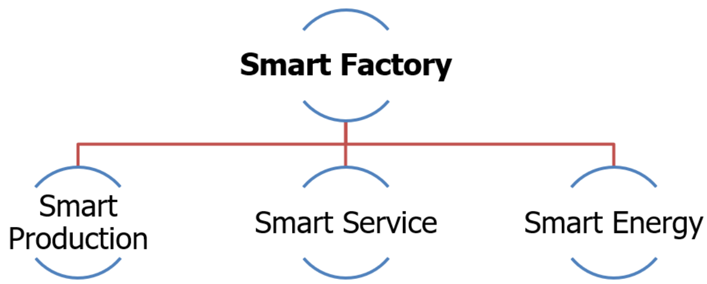

Figure 1: The three components of a Smart Factory. Source: [CC BY-SA] by INDEX consortium.

A smart factory provides adaptive solutions to solve production problems by combining KETs (Key Enabling Technologies) like RFID (Radio-Frequency IDentification), 3D Printing, IoT (Internet of Things) and ubicomp (ubiquitous computing). These technologies synergize to accelerate the innovation process and help store and elaborate large and heterogeneous amounts of data.

CPS (Cyber-Physical Systems) are there to monitor physical processes and make decentralized decisions, by communicating with each other and cooperating with humans, if needed. **Cloud Manufacturing** stands for the possibility to access a broad range of resources related to production in a way that is widespread, easy, selective, distributed and on-demand. Cloud Manufacturing therefore represents an extension of the applications of cloud computing to the world

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of physical manufacturing, both with regard to the factory and the entire supply chain, as well as the ability to make all resources needed for production to be virtualizable, bookable and on demand.
3D Printing is fundamental to Industry 4.0. It is a versatile technology that is becoming more and more feasible to realize small and complex parts and simplify the process of product design. Because of all its benefits, 3D Printing is gaining increasing importance inside Smart Factories in many different industrial sectors.
Smart sensors are devices that generate data and enable further functionalities, from self-monitoring and self-configuration to condition-monitoring of complex processes. Thanks to the possibility of wireless communication, the installation of dense arrays of smart sensors is becoming more and more seamless.
IoT (Internet of Things) involves smart devices combining sensors and actuators with functionalities related to localization, identification, diagnosis, collection, elaboration and communication of data. Thanks to Smart Sensors and IoT, Industry 4.0 is providing such benefits as *Predictive maintenance*, i.e. the ability to identify issues related to the conditions of facilities in real time.
Advanced Human-Machine Interfaces is another characteristic trait of Industry 4.0. It refers to the interactions between humans and machines. The first example of these smart interfaces is touch displays, which have become ubiquitous in many devices. Latest innovation in this sector has led to new tools like Augmented Reality Simulators and wearables.

Entrepreneurship, Technology and Restructuring Management (E-TRIM)

Introduction to entrepreneurship

Who is an entrepreneur?

THE WORLD NEEDS DREAMERS AND THE WORLD NEEDS DOERS. BUT ABOVE ALL, THE WORLD NEEDS DREAMERS WHO DO.

Sarah Ban Breathnach, Simple Abundance: A Daybook Of Comfort , And Joy

Who is an entrepreneur?

Although terms like entrepreneur or entrepreneurship are in common usage, the meaning of these two words actually differ in people’s minds. Also, scientists do sometimes have slightly, other times significantly, divergent perspectives on these expressions. This results from the fact that many scientific disciplines deal with people’s economic activity: economy, management, law, psychology, administration etc.
Economist say [Hébert, Link, 1988]:

- An entrepreneur is the person who assumes the risk associated with uncertainty.
- An entrepreneur is the person who supplies financial capital.
- An entrepreneur is an innovator.
- An entrepreneur is a decision maker.
- An entrepreneur is an industrial leader.
- An entrepreneur is a manager or superintendent.
- An entrepreneur is an organizer and coordinator of economic resources.
- An entrepreneur is the owner of an enterprise.
- An entrepreneur is an employer of factors of production.
- An entrepreneur is a contractor.
- An entrepreneur is an arbitrageur.
- An entrepreneur is an allocator of resources among alternative uses.

The above listed notions reflect the variety of points of view and complexity of the phenomenon. Some of the statements reveal the dynamic nature of an entrepreneur. He/she creates or reveals new opportunities, makes decisions on the usage of resources, organizes and manages the undertaking, takes risks related to the possibility of failure. In common language, entrepreneurship refers to the activity of a person who enters into something, undertakes action, ventures. This means such a person has a very particular personality. Entrepreneurs can be characterized by [Schmitt-Rodermund, 2004]:

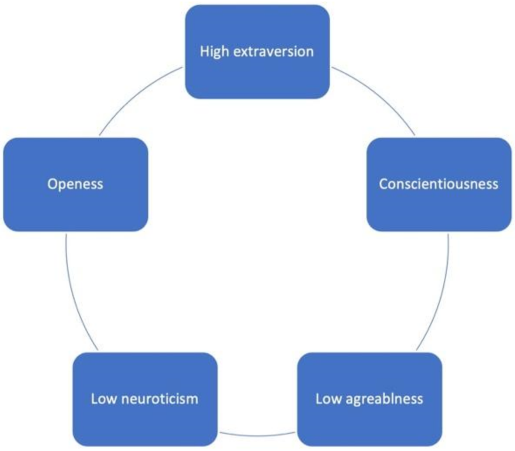

Figure 1: Entrepreneurs characteristics. Source: Schmitt-Rodermund E., Pathways to successful entrepreneurship: Parenting, personality, early entrepreneurial competence, and interests, "Journal of Vocational Behavior", Volume 65, Issue 3, December 2004, p. 498-518.

These qualities allow people to struggle with risk of failure, fear of the unknown, be persuasive, set goals and respond to opportunities or create new ones.

Some entrepreneurs decide to establish business with friends. This means trust, ability to cooperate, share duties and responsibilities. Becoming an employer is challenging too, an entrepreneur must be able to delegate tasks, motivate employees, therefore also possess leadership competences.

Exercise

An entrepreneur is a person who:

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- Follows old existing pathways
- Is an opportunist and creative risk-taker
- Is oriented to be self-sufficient
- Is very conservative in taking action, prefers to be 100% sure his/her decision is risk-free

Sources of start-up ideas

When considering running their own business, people usually state that there has to be a good idea to do so. Where do those ideas for business come from? There can be various sources: [Longenecker et al, 2012]:

Figure 1: Sources of business ideas. Source: Longenecker J. G., J. Petty W., Palich L. E., Hoy F., Small Business Management: Launching and Growing Entrepreneurial Ventures, Cengage Learning, 2012.

A very common source is personal experience. Everyday life, both personal and professional can result in ideas for a new venture. Our activity brings us observations of products or processes which can be modified in order to better satisfy our needs or needs of a business proprietor (e.g. lowering costs). Our personal interests may lead to us combining them with our professional life. A hobby is usually accompanied by consumption of specific goods, which means that we ourselves can provide such services or sell related products.

Sometimes very specific circumstances occur and one can experience serendipity. Development of some fortunate events turn out to be beneficial in terms of new company creation. Startup ideas also appear through a purposeful exploration. It is beneficial to search for ideas, related trade shows, activities undertaken by friends or relatives, cooperants or competitors. There are also many Internet sources which can help find an idea for a new business.

The real story about how Airbnb was founded - Nathan Blecharczyk Co-founder Airbnb - Startup Success
https://youtu.be/M6GBqqk2mY4

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Small business ownership opportunities

Every business begins with an idea. Great businesses begin with great ideas. To become an entrepreneur, it nonetheless does not mean you have to establish a genuine new enterprise. There are various methods of owning a business.

Launching one's **own business idea** from the beginning is related to the autonomic development of a person as an entrepreneur. Such a person creates a novel business and takes responsibility to seize the opportunities and minimize threats in order to develop the business project. This is for sure the most creative and most challenging path but also extremely satisfactory when successful. There is also the possibility of launching a new business with relation to an existing business network. An example can be establishing the business idea on the basis of franchising. In a **franchising system**, the enterprise owning the patent-right (franchiser) assigns the right to produce/sell a certain product or service within the settled know-how, standards and commercial techniques and routines to another company (franchisee). In return, the franchisee guarantees to pay to the franchiser the franchise fee and usually a certain percentage of the sales proceeds which was determined in the agreement. Franchising is a good idea when you don't have your own business idea yet or you have a project in your mind, but you are unsure about the opportunities it creates. The main advantage of franchising is the already established image of the franchiser, verified business model which is related to lower risk. There are also other benefits of running one's own business on the basis of another's company know-how, like licensing, dealership, agency system or acquisition.

Some entrepreneurs join or inherit the **family business**. Although the majority of such businesses are identified with small and medium sized companies, there are also big players in the market. The specificity of these entities lies in the family structure of the ownership, strategic control held by family, family members' engagement in management processes and more than one generation involved in the functioning of the business [Sulkowski 2011].

Some people are somehow forced to run their own business because of the nature of the relation of their profession – eg. freelancers from the creative industry but also people who cooperate with companies unwilling to give a stable job.

Some entrepreneurs can also decide to **buy shares** in an existing company or buy the business as a whole. It would be wiser to buy the assets only, as the business which is for sale may not be doing well, although the reasons why a business is for sales can be as follows [Longenecker, 2009]:

- Old age or illness of the owner.
- Desire to relocate to another place of living.
- Opportunity to start another business.
- Decision to accept a position with another company.
- Unprofitability of the business.
- Discontinuance of an exclusive sales franchise.
- Maturation of the industry and lack of growth potential.

Each path leading to running a business includes risk which has to be evaluated before.

Exercise

Which approach can one use to become a business owner when not having a genuine new idea for business?

- Buy shares in an existing company
- Inherit a family business
- Launch a business within a franchise network
- Each of the presented possibilities can be taken into consideration

Innovation management – basic concepts

The definition of innovation

The notion of innovation was introduced to economic sciences by J.A. Schumpeter at the beginning of the previous century. According to this author, one should understand innovation as:

- The introduction of a new or improved product;
- The introduction of a new or improved method of production;
- The creation of a new market;

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- The use of a new form of sale or purchase;
- The use of new materials or semi-manufactured products;
- Or also the introduction of a new organisation of processes.

The concept of innovation proposed by Schumpeter is very broad and includes both technical and organisational changes that can take place in any organisation.

Michael Porter defines innovation as: "both improvements in technology and better methods or ways of doing things. It can be manifested in product changes, process changes, new approaches to marketing, new forms of distribution, and new concepts of scope". According to him, they can result "as much from organizational learning as from formal R&D".

A broad understanding of innovation is also presented in the Oslo Manual. This is a document published by the Organisation for Economic Co-operation and Development (OECD) that describes guidelines for collecting, reporting and using data on innovation and is considered as an internationally recognised standard of innovation activities definition and classification.

The Oslo Manual defines innovation as a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).

This definition uses the generic term "unit" to describe the actor responsible for innovations. It refers to any institutional unit in any sector, including households and their individual members.

Depending on the context of use, the definition of innovation can be embedded into different environments. If placed within business activities, then it can be stated that business innovation is a new or improved product or business process (or combination thereof) that differs significantly from the firm's previous products or business processes and that has been introduced on the market or brought into use by the firm.

Innovation activities include all developmental, financial and commercial activities undertaken by a firm that are intended to result in an innovation for the firm.

Classifications of innovation

There are many classifications of innovation. One of them incorporates the criterion of novelty or scale in which the changes are implemented. This classification is included in the table below:

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	Description
Breakthrough innovations (radical)	Breakthrough innovations, also defined as radical or pioneer, are those that do not have a prototype. For example, the construction of the car or invention of electricity were breakthrough innovations. At present, a breakthrough innovation could be the implementation of a product based on new technologies; however, it could also be related to changes in processes or management methods. An example of a radical organisational innovation could be the concept of just-in-time as a solution for stock reduction or the use of reengineering as a concept of processes improvement.
Substantial innovations (semi-radical)	Substantial innovations, also called semi-radical, are those which lead to considerable improvements but are not the result of essentially new technologies or approaches.
Incremental innovations (small improvements)	Incremental innovations, also defined as small improvements can be understood as having small effects, but being the result of continuous improvement. Progress in this case consists of significant improvements of products, shortening customer service time or cost reduction (the introduction of a new colour of an article or the simplification of a product delivery process are examples of incremental innovations). This kind of innovation is very close to the idea of continuous improvement originating from quality management standards – continuous, small improvements of products and the management system contribute to achieving long-term benefits (e.g. competitive advantage).

Table 1: Classification of innovation. Source: Tidd, J., & Bessant, J. i Pavitt, K. 2005. Managing Innovation. Integrating Technological, Market and Organizational Change. Chichester: John Wiley and Sons

While it is comparatively easy to decide what a breakthrough or incremental innovation is, the category of substantial innovations is quite difficult to define. This classification criterion will often be subjective and dependent on the range of implemented changes from the individual point of view. An improvement in customer service processes that could be insignificant for a large firm operating in the global market may be at the same time a substantial or even a breakthrough innovation for a small company operating in the local market.

The Oslo Manual has evolved in its view on innovation classification. The latest, 2018 4th edition, distinguishes between two types of innovation – a product innovation and business process innovation. However, over the years, in the past 3 editions of the Oslo Manual, a view that is currently widely used worldwide referred to the object of the innovation process.

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	Description
Product innovation	A product innovation is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics. Product innovations can utilize new knowledge or technologies, or can be based on new uses or combinations of existing knowledge or technologies.
Process innovation	A process innovation is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software. Process innovations can be intended to decrease unit costs of production or delivery, to increase quality, or to produce or deliver new or significantly improved products.
Marketing innovation	A marketing innovation is the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing. Marketing innovations are aimed at better addressing customer needs, opening up new markets, or newly positioning a firm's product on the market, with the objective of increasing the firm's sales.
Organisational innovation	An organisational innovation is the implementation of a new organisational method in the firm's business practices, workplace organisation or external relations. Organisational innovations can be intended to increase a firm's performance by reducing administrative costs or transaction costs, improving workplace satisfaction (and thus labour productivity), gaining access to non-tradable assets (such as non-codified external knowledge) or reducing costs of supplies.

Table 2: Classification of innovation according to Oslo Manual. Source: Organisation for Economic Co-operation and Development, & Statistical Office of the European Communities. (2005). Oslo Manual 2005: Guidelines for collecting, reporting and using data on innovation. OECD publishing

The last version of the Oslo Manual (2018) defines:

- A product innovation is a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market.

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- A business process innovation is a new or improved business process for one or more business functions that differs significantly from the firm's previous business processes and that has been brought into use by the firm.

For further information on the definition of innovation and the classification of innovation, please access the Oslo Manual on-line. The document is available for free from OECD.

Exercise

In the previous subsection, you watched a video about AirBnB. If this venture would be characterized with the type of innovation that was brought to the market, what would it be?

- Incremental innovation
- Substantial innovation
- Breakthrough innovation
- It is not possible to define the type of the innovation
- unanswered

Exercise

Please watch the video below. What type of innovation (according to Oslo Manual) it refers to?

- Product innovation
- Process innovation
- Marketing innovation
- Organisational innovation

Ikea Catalog App

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Figure 1: The three components of a Smart Factory. Source: CC BY-SA by INDEX consortium.

Innovation management

Go through the chapter of the book by Joe Tidd on managing innovation in order to better understand basic innovation management concepts. This is copyrighted material, however it is available as open access on ResearchGate.

Overview of commercialisation and technology transfer

Basics of Technology Transfer

The literature on the transfer of technology uses a rich variety of concepts and definitions which refer to a different level of analysis like the whole economy, industry, or single organisation. In this course, our primary focus is on institutions like companies, universities and others. The notion of technology transfer (TT) is closely related to the concept of technology which is described by Burgelman et al. (2008) as it refers to the theoretical and practical knowledge, skills, and artefacts that can be used to develop products and services as well as their production and delivery systems. Technology can be embodied in people, materials, cognitive and physical processes, plant, equipment and tools.

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Based on the concept of technology, UNCTAD describes the transfer of technology as the transfer of systematic knowledge for the manufacture of a product, for the application of a process, or for the rendering of service and does not extend to the mere sale or lease of goods. Within the TT process along with technologies the following can be transferred:

- Skills;
- Knowledge;
- Methods of manufacturing;
- Samples of manufacturing (prototype, sample products etc.);
- Assets like machinery, equipment etc.

Main categories of transactions which could represent TT are:

- The **sale and licensing** of all forms of industrial property, like patents, industrial design rights and others (except for trademarks);
- The **provision of know-how and technical expertise** in the form of documents like: feasibility studies, plans, instructions, formulae, basic or detailed engineering designs, but also services involving technical advisory and managerial/technical personnel training;
- The provision of **technological knowledge** necessary for the installation, operation and use of plant and equipment, machinery, intermediate goods and/or raw materials which have been purchased or leased;
- The **provision of technological contents** of industrial and technical cooperation arrangements.

TT can be implemented with the use of different channels. A company can obtain technology through:

- **Sub-contracting** - company gets the technology developed from another organization (like R&D laboratory, university, another company, independent experts etc.).
- **Licensing** - the technology receiver purchases the right to utilize someone else's technology.
- **Franchise** - a form of licensing, but usually with continual support to the receiver in the form of the supply of raw material, employee training, but also marketing support etc.
- **Joint Venture** – occurs when two or more entities combine their interests in the form of a new business enterprise. They provide knowledge and other resources to a new company to develop a technology, produce a product, or use their respective know-how to complement one another.
- **Turnkey projects** - a company purchases a complete project from another organisation. The project is designed, implemented and delivered ready to operate.
- **Technical consortium and joint R&D projects** - this takes place between two or more organisations in order to combine their technical and financial resources to develop/improve the technology.

Exercise

What type of transaction stated below does NOT represent technology transfer (TT)

- Licensing of industrial property
- Sale of consumer products based on high technology
- Provision of technological knowledge
- Provision of technical know-how

Introduction to Technology Commercialisation

Technology commercialization is the process of transitioning technologies from the research laboratory to the marketplace, commencing at the very moment of ideation and ending at the point when a venture actually creates wealth.

Universities and research laboratories, in which many new technologies are born, play an important role in this process. Part of their social mission is to ensure that the results of its research are made available for public use and benefit. This can be accomplished in many ways: through educating students, publishing results of research and ensuring that inventions are developed into useful products and services for the benefit of the public. Universities are not in the business of making and selling new products and services, but rather look to partner with industry players to commercialize these inventions.

A technical invention has scientific value and usually also opens up new technical possibilities. However, in commercial terms, it has no value until its market application can be determined. This is where the commercialization process begins. This involves identifying possible technology applications within products or market processes (new or already existing). And then on a thorough examination of the advantages of the new idea in the context of these applications and the related assessment of market potential. Usually, a comparison is made with the substitutes on the market followed by an assessment of:

- The size of the potential market,
- The necessary investment outlays,
- Production costs,
- Potential distribution channels, etc.

The process of technology commercialization thus includes a complex of activities aimed at transforming new technological inventions into broadly understood commercial products. Actions taken include, among others:

- Presentation of new innovative ideas, products/processes,
- Technology development and identification of potential applications,
- Creating and demonstrating prototypes of innovative products,
- Technological audit,
- Market analysis, development and implementation of marketing strategies,
- Implementation works and implementation into production,
- Product launch and sale.

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The starting point of the whole process is therefore the emergence of potentially valuable technology. It can find application in many products that are worth considering and analyse various commercialization options. The challenge is therefore to see, analyse and use the maximum number of market opportunities.

In practice, a number of ways to commercialize technology can be identified, including:

- Sale of intellectual property rights,
- Licensing,
- Strategic alliance,
- Joint venture,
- Independent implementation,
- Creation of a new spin-off company.

As part of universities and research institutions, special units are often created to support the commercialization of newly created technologies. These are usually Technology Transfer Offices (TTOs) and Business Incubators. TTOs deal with a variety of commercial activities that are meant to facilitate the process of bringing research developments to market players. TTOs are often described as creators of the channel between academia and industry. Business Incubators provide help to startup companies created by researchers or students, by providing training services or office space.

Exercise

What is the starting point of the technology commercialisation process?

- Product launch and sale
- Sale of intellectual property rights
- Emergence of potentially valuable technology
- Creation of a new spin-off company

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Sensors and automation

Introduction

To start …

Nowadays we are surrounded by many modern electronic appliances that perform an unimaginable amount of useful functions. In our homes, at our workplaces, but also everywhere we go. They have become an integral part of our lives to such a degree that we often fail to notice the systems that are enabling this.

Figure 1: Smartwatch showing blood pressure. Source: CC-BY-NC-SA by INDEX consortium

Just imagine any random day in your own life. As soon as you get out of your bed, you step out of the door to exercise. The little device around your wrist is detecting very accurately the number of steps you are taking and the speed at which you go. Maybe your device is also capable of keeping track of your heart rate, blood pressure and oxygen saturation levels. All this information is synchronized with your mobile phone to provide you (and maybe your personal trainer) with stats on how you have been doing over the last few days, weeks, months or years. All sweaty and done you step into the shower, which has a thermostat that makes sure the water that is raining down on you has a constant temperature. Next, you turn on your coffee machine that makes the coffee just the way you like it. The amount and temperature of the water used, the pressure with which it is pushed through the coffee is tightly controlled.

Your smart home explained

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You get into your car and type in the address of the person you do have a meeting within about an hour. This navigation system through communication with earth-orbiting satellites and a detailed map (stored on-board or downloaded real-time from the internet) allows it to calculate the most efficient route to get to your final destination. Many systems also include real-time traffic speeds on all the roads in order to more accurately calculate the time of arrival, or in extreme cases, suggest alternative routes. If you are not a car-driver, you most likely use an app to find out if your train connection is on time, and whether there are other disturbances that are important for planning your trip to work, or elsewhere.

This is just a description of the start of a typical day, that we all recognize. It might differ on individual aspects, but it clearly shows how much we are immersed into systems that measure, inform and control many different aspects of our surroundings. All around, we are surrounded by devices, and these devices need to have input signals from the external world in order to do what they need to do. This is why we need sensors.

Contents of the course

As described, nowadays, many modern systems are equipped with a wide range of sensors and actuators, which are used to monitor the environment where these systems are operating/implemented. A well-known example of such systems is a vehicle/car equipped with various sensors to monitor/measure speed, pressure, temperature, etc., and various actuators to provide motion.

This course provides an introduction to various principles and technologies implemented on the most commonly used types of sensors and actuators/transducers. It will provide students with necessary knowledge regarding operation, application and integration of sensors and actuators (including signal processing and interfacing) to enable the design and realization of complete systems.

This course will also discuss recent developments of new, smart and innovative sensors and actuators, which are aimed at:

- realization of more compact, portable/handheld systems;
- better sensitivity, specificity, accuracy and overall performance;
- faster (data) analysis and measurement response (sample/data-in - answer-out);
- lower costs of production and operation;
- ease of use without requirements of special knowledge (plug-and-play);
- integration with mobile communication devices (using proper software/interface), e.g. as part of a data-acquisition system.

Learning objectives

Upon completion of this course, you will have gained necessary knowledge regarding:

- classification of sensors and actuators based on their operation principle;
- most commonly used types of sensors (mechanical, thermal, electro-magnetic and biochemical) and actuators;
- features/functionalities needed to achieve a complete working system;
- analysis of systems and selection of proper types of sensors and actuators that are needed to realize such systems based on required applications.

History of sensors

Earliest sensor definition

Let's start with the very early definition of a sensor:

A device that receives and responds to a signal or stimulus

Schematically, this looks like:

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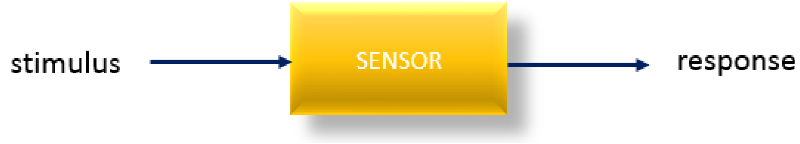

Figure 1: Schematic of a sensor. Source: CC-BY-NC-SA by INDEX consortium.

It acts as a device that converts energy of one type (the stimulus) into another type (the response). The stimulus can be:

- a quantity (the temperature is 21 degrees Celsius)
- a property (the square is triangular, or the boat is green)
- a condition (the car door is not closed)

The sensor converts this stimulus, or measurand (if it is a quantitative number) into something else, that in most cases we can directly observe.

History of the thermometer

The development of sensors started long ago, as humans wanted to record specific conditions about their environment. One of these parameters that intrigued humans was temperature and this initiated the earliest developments of a sensory device that was able to measure and quantify this: the thermometer. This device enabled measurements of temperature of gasses and liquids.

In the video below a brief history of the different thermometers that have been developed is given.

Fahrenheit to Celsius: History of the thermometer

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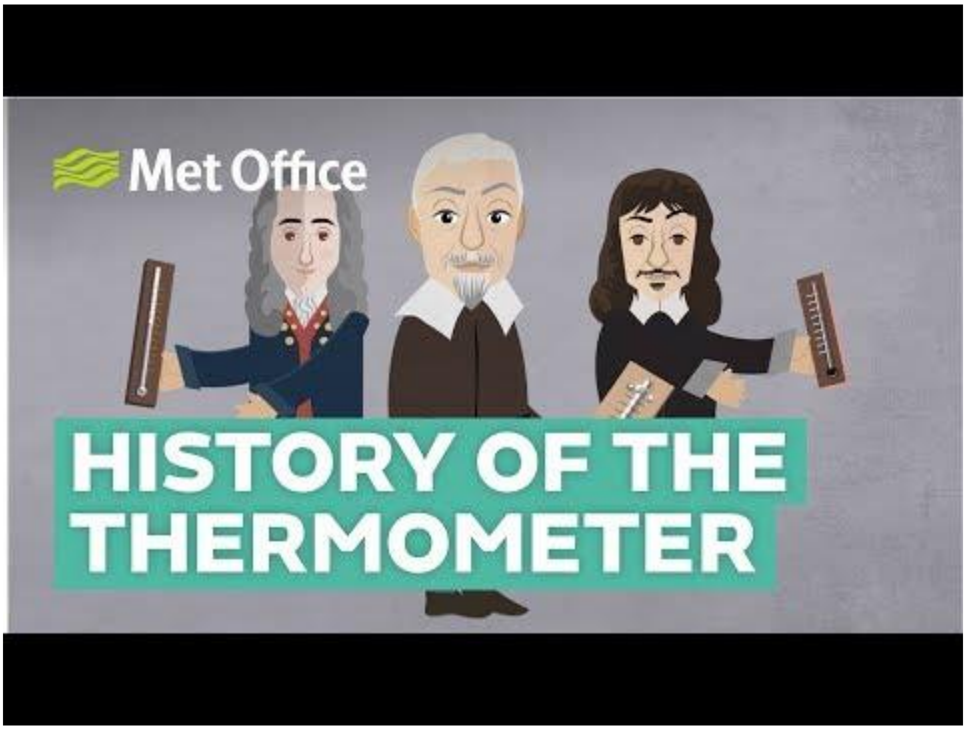

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Exercise

Along with the development of the thermometer, different temperature scales emerged. Each "discoverer" of a new type of temperature sensor, was keen on having their own scale named after them.

Which is one of the scales for temperature that emerged from this development and is still in use today?

- Newton
- Kelvin
- Ferdinando
- Galileo

Wind force scale

Another condition, or property that people were very keen on measuring is that of wind force. This emerged from the long seafaring voyages that were, in those days, the only way to have goods transported around the world. It was thought essential to determine and record the wind force during these long journeys.
In 1805 Francois Beaufort (an Irishman, although his name suggests otherwise) devised a scale, which is known as the Beaufort scale, and which we still use today (check out any weather report during the

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evening news TV programme!). Beaufort was an officer in the Royal Navy and while he was commander of the frigate HMS Woolwich, he developed a scale that was descriptive and based on the force per unit area. Francois looked at the behaviour of his ship, and not at the actual wind or its speed. In 1838 the Royal Navy adopted this scale and made it obligatory for all in the Navy to use this scale to record the wind force.

The Beaufort scale has 13 discrete values (0 to 12), and each value has a description, as you can see in the table below:

0 - Calm: Sea like a mirror

1 - Light air: Ripples with appearance of scale are formed, without foam crests

2 - Light breeze: Small wavelets, still short, but more pronounced. Crests have a glassy appearance but do not break

3 - Gentle breeze, large wavelets. Crests begin to break. Foam of glassy appearance; Perhaps scattered white horses

4 - Moderate breeze: Small waves becoming longer. Fairly frequent white horses

5 - Fresh breeze: moderate waves taking a more pronounced form, many white horses are formed. Chances of some spray

6 - Strong breeze: Large waves begin to form. The white foam crests are more extensive everywhere. Probably some spray

7 - Near gale: sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind

8 - Gale: Moderately high waves of greater length. Edges of crests begin to break into spindrift. The foam is blown in well-marked streaks

9 - Severe gale: High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over, spray affects visibility

10 - Storm: Very high waves with long overhanging crests. Resulting foam in great patches is blown in dense white streaks along the direction of the wind. The whole surface of the sea takes on a white appearance. The "tumbling" of the sea becomes more intense and shock-like. Visibility affected

11 - Violent storm: Exceptionally high waves (small and medium-size ships might be, for a time, lost to view behind the waves. Surface is covered with long white patches of foam lying along the direction of the wind. Everywhere, the edges of the crests of the waves are being blown into the froth. Visibility affected.

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12 - Hurricane: The air is filled with foam and spray. The sea is completely white with driving spray. Visibility is very seriously affected.

Here are some representative images for the Beaufort scale and what it looks like:

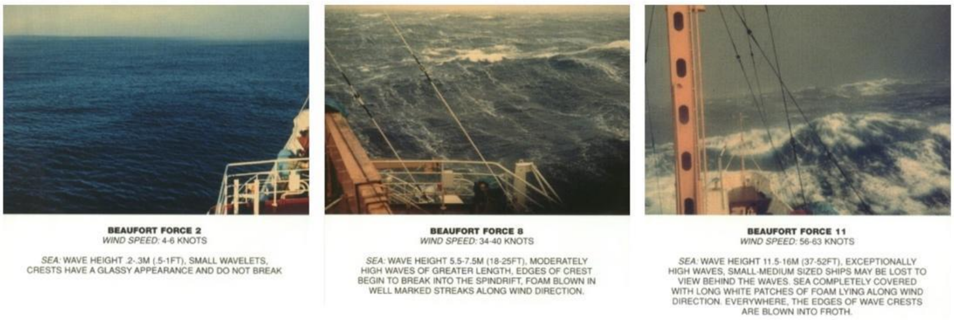

Figure 1: Beaufort wind forces and their impact. Source: Wikipedia Commons Public Domain

Watch the video Beaufort scale on Vimeo

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Beaufort scale

The Beaufort scale was initially devised by Francois Beaufort for describing conditions at sea. Later a second description of the conditions for use on land was added, see: http://www.thudscave.com/petroglyphs/pdf/beaufort.pdf.

The scale has also been converted from a wind force scale to a wind speed scale, see the graph below, where the 13 different Beaufort values are expressed in wind speed, both in metres per second and in knots.

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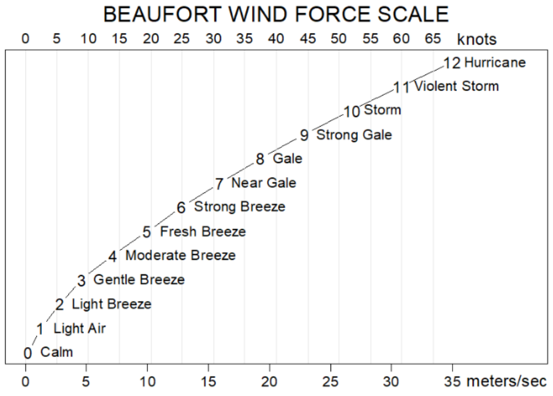

Figure 1: Beaufort wind force scale. Source: Wikipedia (Ldecola): CC-BY-SA 4.0

Exercise

The Beaufort wind force scale is interesting, as when we discuss a sensor we tend to think about a physical device that is indicating a value for a specific property. In this case there is no actual device.

How would you define the sensor here?

- The human eye and the description that is made based on the observations
- The condition of the waves alongside the ship.
- The human eye in combination with the conditions of the waves
- Unanswered

The Beaufort scale is still used a lot for weather predictions. Just pay attention when you watch the news tonight and the weather forecast that follows. Here you will also notice that the Beaufort scale is a discrete scale, and values such as 4.7 or 5.3 are never used. It is always an integer number of "Beaufort 4-5".

Wind speeds are nowadays measured by anemometers, such as the 3 half cups, that you typically see on weather stations. The rotation speed can be calibrated to represent the wind speed.

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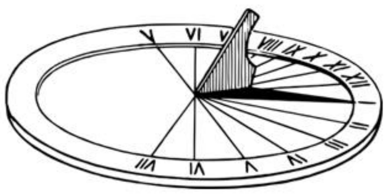
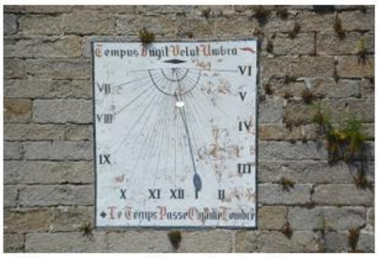
Figure 2: an anemometer for measuring wind speeds. Source:

Sundials

Another parameter that humans wanted to record is time. Today, because we have digital devices that allow us to keep time very accurately, it is very difficult to imagine that long ago most humans did not have much more than the rhythm of day and night as the only indication of time. Another indication of the duration of the day is the change of the seasons (mostly related to harvest).

This is why sundials were developed.





"Time escapes like a shadow"
(Ville Close de Concarneau, France)

Figure 1: examples of sundials. Source: Wikimedia Commons (Pearson Scott Foresman): Public Domain & INDEX consortium license: CC-BY-NC-SA

Sundials use the direction of the sunlight as an input. Using a pole, ball or other pin-like objects a shadow is cast onto a surface onto which a scale is drawn. In some devices the length of the shadow of the object is used to determine (or approximate) the date as well, as the path of the Sun is different during the year. Note that this depends on the latitude of your geographic location. Check out this sundial, which can be found in the small village of Butgenbach in Belgium. This has a resolution of about 30 seconds. If you look carefully you can see that the lines on the metal plate are curved and allow a correction depending on the date:

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Figure 2: Accurate sundial in Belgium, Butgenbach. Source: Wikimedia Commons (Hoffmann Albin): CC-BY-SA 3.0

3D printed digital sundial

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Mechanical sensors

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Another class of early sensors are so-called mechanical devices. As a result of a change in the property that needs to be measured, something changes its shape, which is then transferred into moving parts. A good example of this is an aneroid barometer, which is able to measure the air pressure (in order to predict the weather).

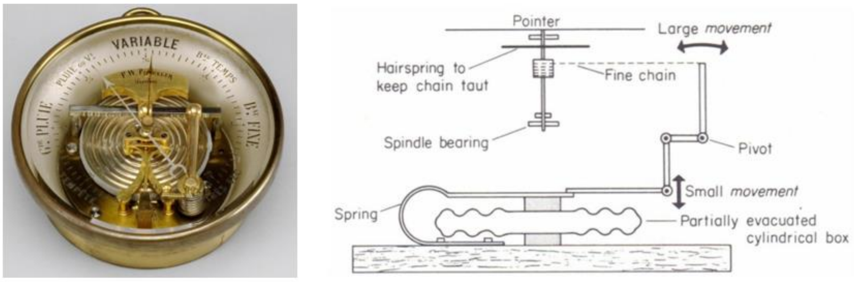
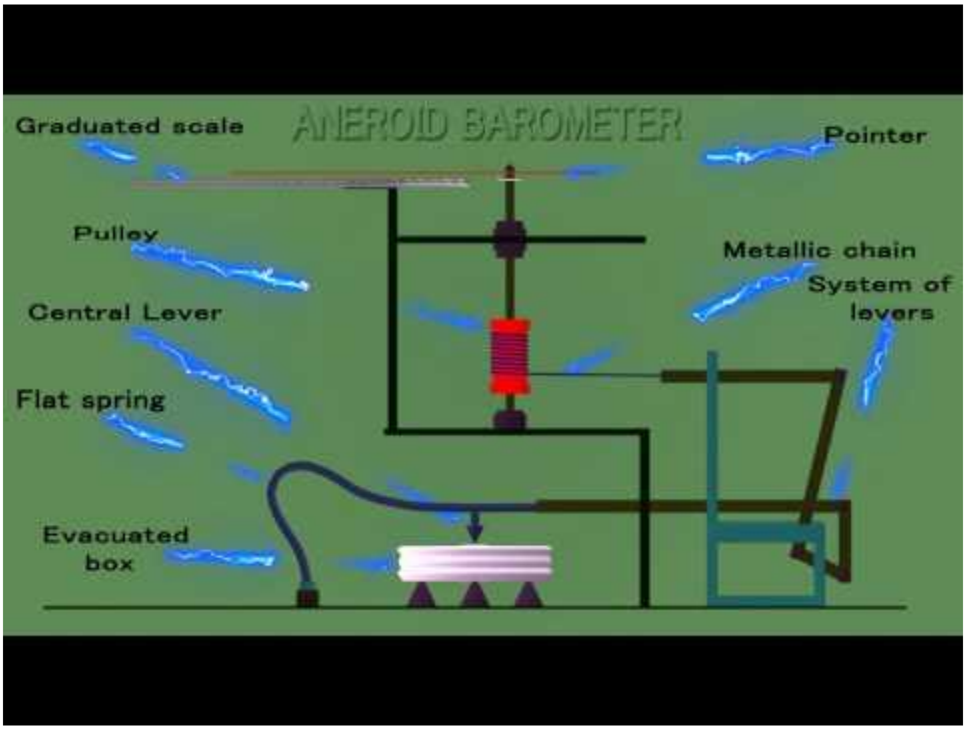


Figure 1: Left; aneroid barometer. Right; Schematic overview of an aneroid barometer. Source: PhysicsMax.com

The way this works is as follows: The main part that changes its shape is the cylindrical box at the bottom of the device, which extends in cases of low pressure and shrinks in cases of high pressure. When this occurs, the spring will bend up or down, this motion is transferred via some small metal bars, pivots to a rotating pointer.

Aneroid barometer construction || aneroid barometer working



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Sensor 2.0

All the examples we have discussed so far are an example of a "Sensor 1.0". As we have seen before, they can be described by:

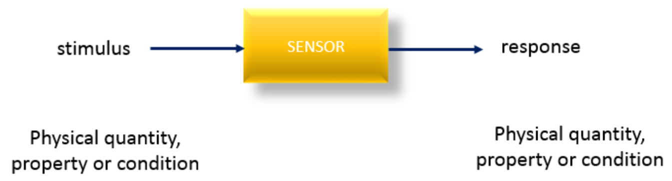

Figure 1: "Sensor 1.0". Source: INDEX consortium license: CC-BY-NC-SA

They are receiving a stimulus, which is either a physical quantity (the temperature is 25 degrees Celsius), property (the colour of this object is green) or condition (the door is open) and convert this stimulus into another physical quantity, a property of condition (a dial that turns, a value, or warning sound).

These are the basic sensors, and still form the heart of most of the sensors that we use today. But, as such, they are not very easy to integrate into larger systems, which means they need to be adapted somewhat.

"Sensor 2.0"

The first step in this development is referred to as "Sensor 2.0". A sensor of this type is not outputting any quantity, property or condition, but always an electrical signal. In schematic terms, this looks like:

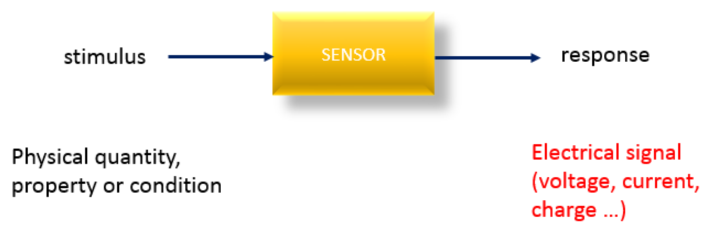

Figure 2: "Sensor 2.0". Source: INDEX consortium license: CC-BY-NC-SA

Therefore, we will redefine the concept of sensors a bit to:

a device that receives a signal or stimulus and responds with an electrical signal.
This is a form of standardization that allows having multiple sensors and multiple types of sensors to generate the same output, which can be compared, added, subtracted, etc. In short, it allows the build-up of complex systems with multiple sensors.

Types of sensors

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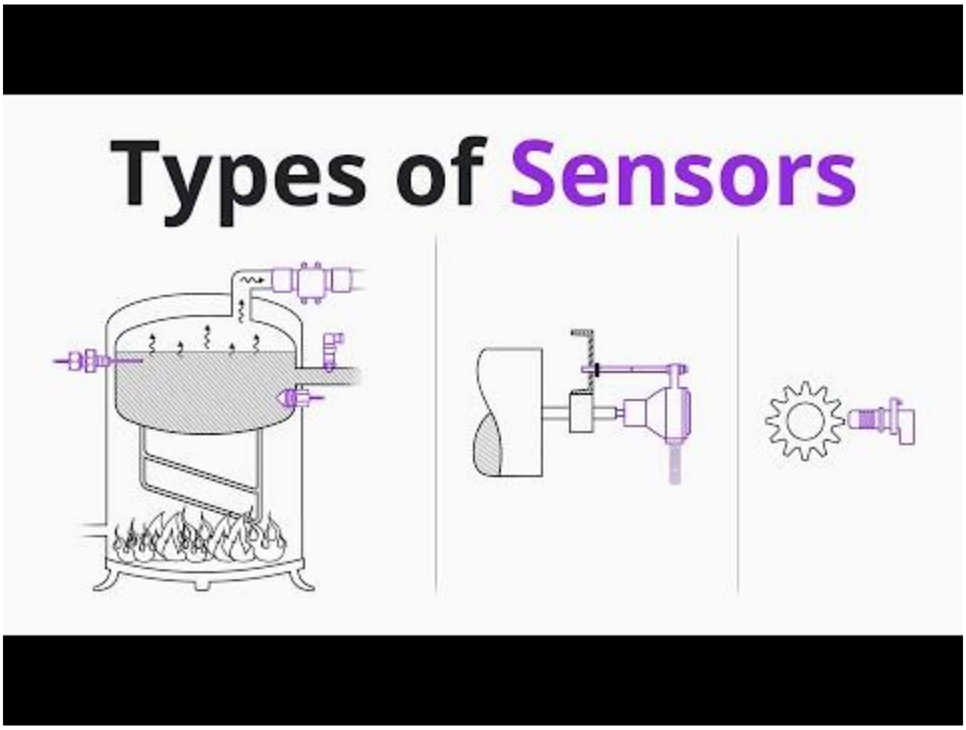

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Exercise

Sensors are able to measure, quantify and detect different physical properties, and can be classified as active and passive sensors.

What is the difference between an active and a passive sensor?

- An active sensor measures dynamically changing physical properties, and the passive sensor can only measure static conditions
- A passive sensor requires an external energy source, the active sensor does not
- A passive sensor can only measure changes between two conditions, and an active sensor measures a calibrated value.

Towards "Sensor 4.0"

Please read the following text (sections 1 and 2), which describe the importance of sensors for the development of Industry 4.0 and their recent developments. It furthermore describes the development of sensors, from their "Sensor 1.0" concept, via various stages to "Sensor 4.0" in order to enable the Industry 4.0 revolution.

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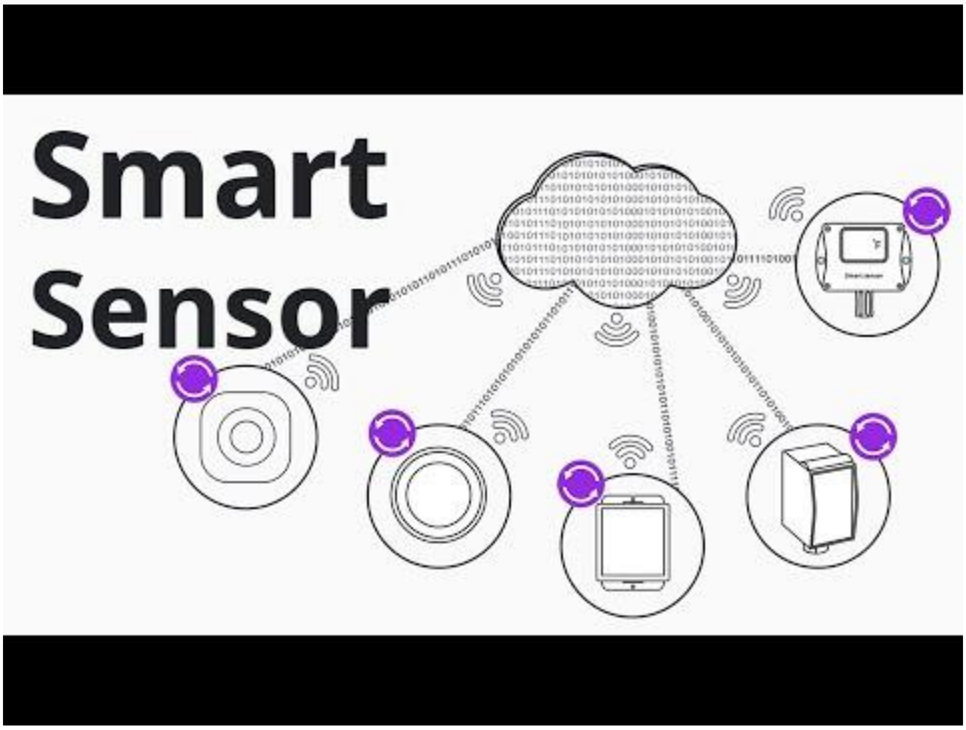
Tizian Schneider et al, (2018), Sensors 4.0 - smart sensors and measurement technology enable Industry 4.0, JSSS, 7, 359-371, doi: 10.5194/jss07-359-2018

Exercise

What is the main distinctive difference between Sensor 3.0 and Sensor 4.0?

- The output of a Sensor 4.0 is electrical
- It is a sensor module which is able to communicate autonomously
- It is able to compensate for unwanted errors and disturbances
- The sensor is a hybrid sensor, consisting of several transducers and a direct sensor

Smart Sensors



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A sensor that measures a physical property, such as temperature, humidity, colour, and converts this into an electrical signal is referred to as a base sensor. It simply outputs the electrical signal to another device that can then do any data processing, transformation or displaying.

A smart sensor consists of this base sensor (or multiple ones) but is also capable of:

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- data processing
- digital processing
- communication to an external device (in the cloud, IoT)
- on-board diagnostics (is the sensor having a failure, or not)

Why sensors?

Figure 1: Overview of the 5 human "sensors". Source: Wikimedia Commons (Allan-Hermann Pool): CC-BY-SA 4.0

Humans need to communicate with our external environment in order to respond to what is happening outside our bodies. This is essential to prevent accidents in case of serious danger (fire, harmful components in drinking water), but is also important in our social behavior with other humans.

To communicate we have 5 different senses:

- Touch (skin)
- Sight (eyes)
- Sound (ears)
- Smell (nose)
- Taste (tongue)

These "sensors" actually do not generate an electrical signal, as is the case for most man-made sensors, but create an electrochemical potential, which is used to communicate with the brain.

It is also interesting to note, that most of our sensors are multiplexed. This means they are not sensing a single parameter, but multiple parameters at the same time. The eye for example has receptors for color, as well as intensity. The skin is able to measure the pressure, temperature and the texture of a surface.

Your body responds ...

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All the sensory inputs are coming together in our brain, and are used to extract information from our environment to determine whether we need to respond, or do nothing. Psychologists nowadays also know that much of the input is detected unnoticed. This means we are not aware of it and in most cases do have control over it. Your body is continuously sensing, and if nothing unexpected comes up, your body will not be alarmed. But fortunately you are not aware of every single input. However, when there is something strange (a smell, sound or sight), your brain and body will respond accordingly, sometimes even before you are aware.

Sensors in industrial systems

Senses (or sensors) are essential for monitoring your environment, and providing your brain with information on which it can react if needed. With industrial equipment and machines, your car, or home surveillance system, it is just the same thing. The senses constantly measure and detect, to provide input about the ongoing processes. If nothing unexpected happens, the process can continue uninterrupted. But, when the sensors detect an anomaly (something odd, or unexpected), this input enables the controlling system to take action. This is why sensors are essential elements in Industry 4.0.

Sensors

In the previous section we have initially introduced the sensor as a device that converts one type of quantity, property or condition (or: energy) into another type. It actually converts energy from one form (a temperature) into another form (position of the air-water interface in a closed tube).

The more generic term for such a device is **transducer**, which literally means "converter".

Sensors are a specific type of transducers, that converts a physical property into an electrical signal.

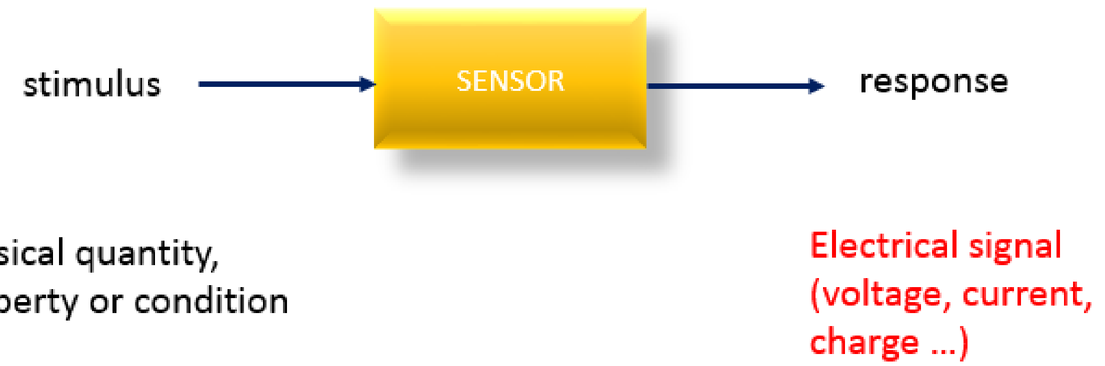

Figure 1: **Sensor 2.0. Source: INDEX consortium license: CC-BY-NC-SA**

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In most real cases, we are dealing with hybrid or complex sensors that consist of one or a number of transducers and a (direct) sensor:

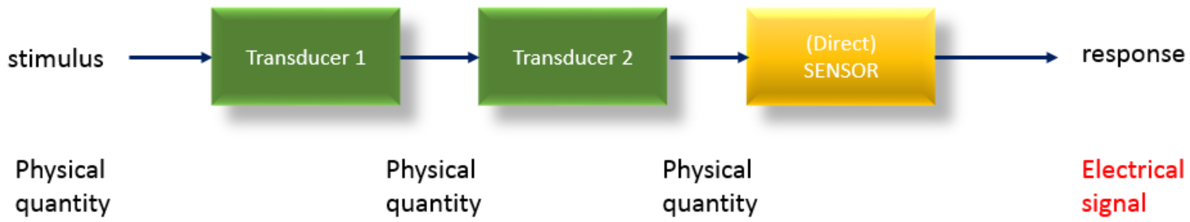
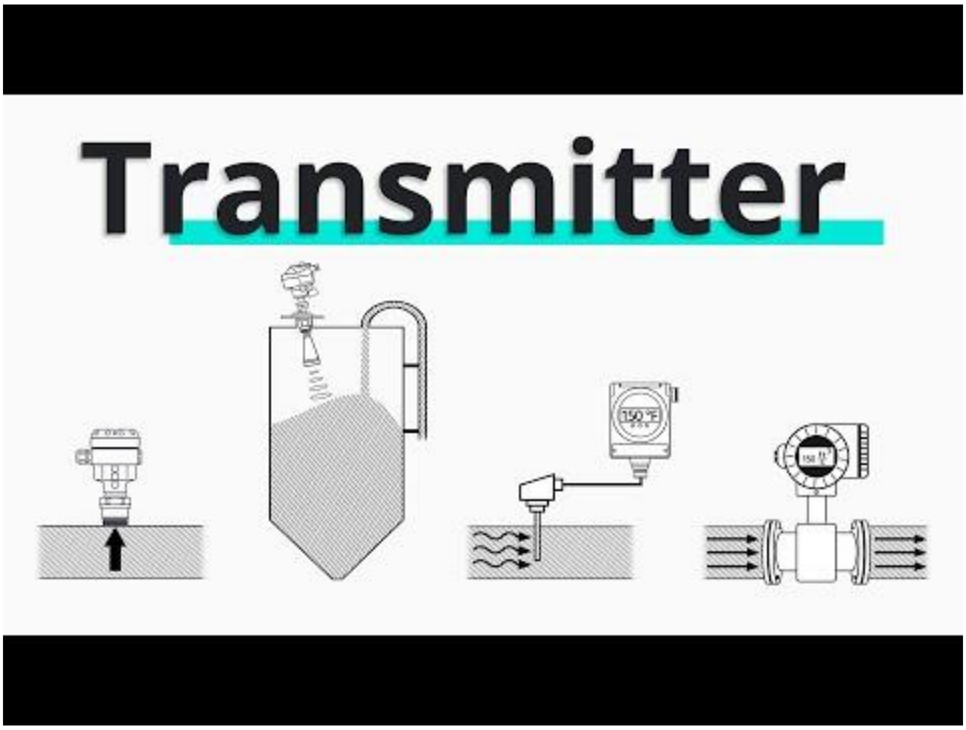


Figure 2: Hybrid sensor consisting out of transducers. Source: INDEX consortium license: CC-BY-NC-SA

In this case a physical quantity is not converted directly into an electrical signal, but is first converted to another physical quantity, and then converted by a different element to an electrical signal.

Transmitter Explained



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Actuators (copyright plaatjes)

As mentioned, a sensor is one particular type of transducer. Another type of transducer is an actuator. An actuator converts an electrical signal to a physical quantity. In fact, it is the reverse of what a sensor does:

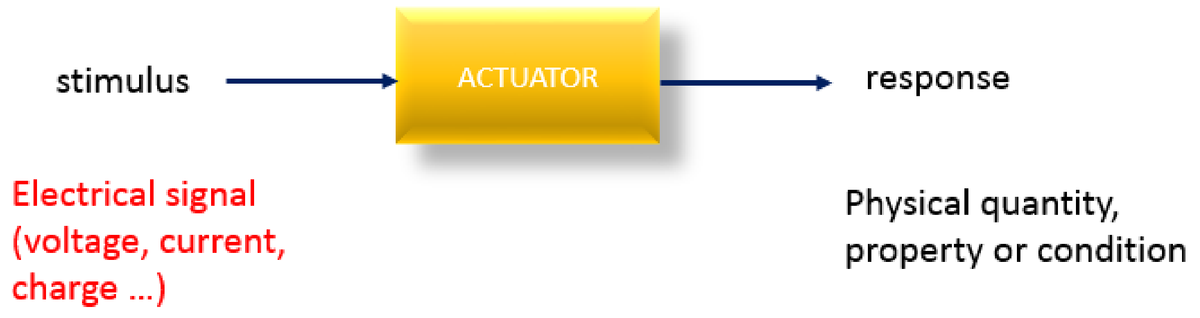

Figure 1: Schematic of an actuator. Source: INDEX consortium license: CC-BY-NC-SA

Think of a heater to heat your house or car, which when you switch it on (apply an electrical signal to it), it generates heat. Or an electrical motor. You apply a specific voltage and it starts moving (rotation or translation, depending on the type of motor you have)

Figure 2: A heater and a pump. Source: n/a

What is an actuator?

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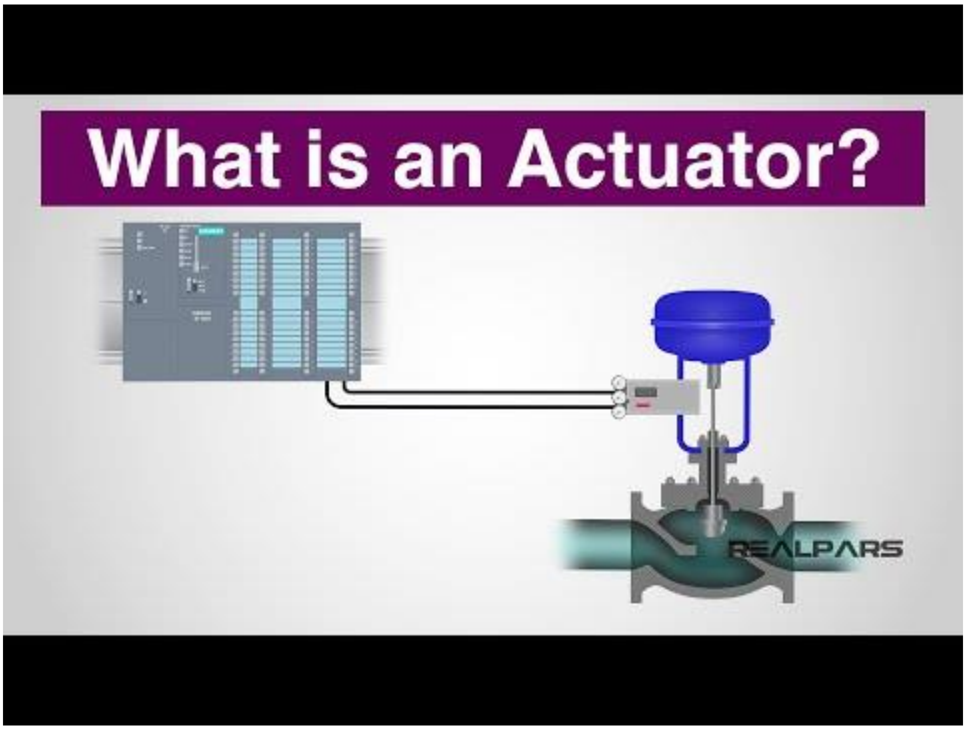

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New developments

As we have seen in the previous section, sensors have been around for quite a long time already. Starting from the early barometers that consisted of a corrugated metal vessel connected via some metal bars to a spring-loaded needle, we now have air pressure sensors that are made using microtechnology in a chip format.

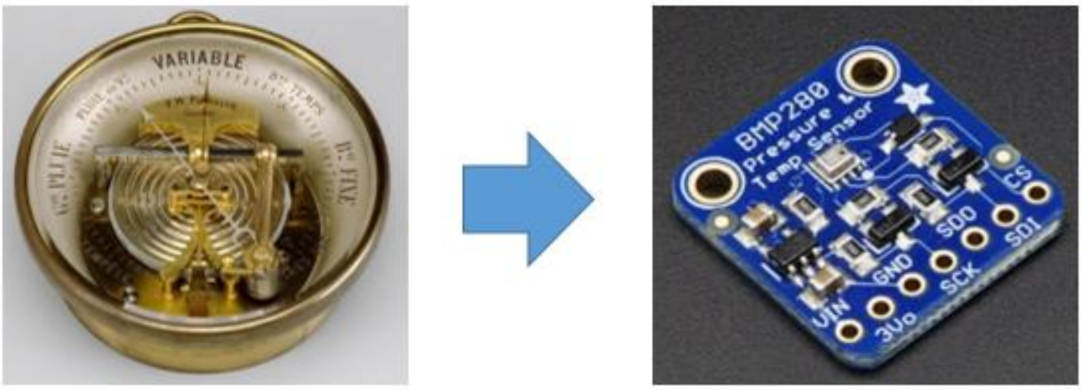

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Figure 1: From a mechanical sensor to a chip-based sensor. Source: Teylers Museum & Adafruit

If we look at the development of sensors and actuators, we typically see 4 different trends occurring:

1.Both sensitivity and selectivity increase

Sensors nowadays are able to measure lower quantities or smaller differences between different values of a parameter. In other words, they are more **sensitive**. But by integration of this sensor with for example amplifiers, signal conditions, adding a protective casing, and so on, the current sensors are also less prone to external disturbances. They actually much better at measuring the parameter that they are expected to measure and are less influenced by other external conditions. This makes the sensors nowadays more **selective**.

2.Size decreases

In the past sensors tended to be rather large, making them not very portable. They tended to be installed at one position where they are stuck. The advent of ultrafine precision manufacturing, followed by microtechnology and nanotechnology enabled us to create smaller structures of the millimeter, micrometer and nowadays nanometer scale, with a precision that was unimaginable in the early days. This allows sensors to be made much smaller.

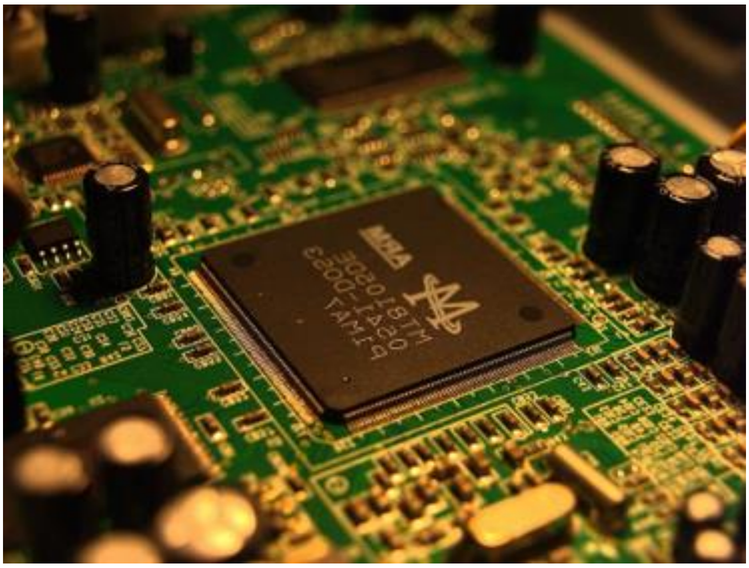

Figure 2: A PCB with chips made possible with micro- and nanotechnology. Source: Pixabay license

We all have seen this development, particularly with computers and other electronic equipment. Just compare the camcorders that people used in the 1980s with the newest smart phone, with 3 or 4 camera systems.

3. Price decreases

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Another development that happened with miniaturization, is that the production costs went down enormously. Specifically, the fast and worldwide development of optical lithography, the base technology for making electronic chips, made it possible to make enormous amounts of chips, which eventually led to the fact that they are relatively cheap in comparison with their earlier versions.

This development opened up the market as sensors and actuators, and technological systems in general were now in reach for everyone, including smaller companies and individuals.

4. Integration with mobile communication devices

As a more recent development, more and more sensors are integrated with our mobile communication devices, our smart phones, tablets, computers, etc. The main advantage of this is the data processing and communication abilities that are already present in your device. They do not have to be separately added to the sensor device. Furthermore, the mobile communication device allows the sensor to be integrated within a larger system, combining it with data from other sensors, or data recorded earlier, leading to a myriad of new products.

Figure 3: **A mobile phone with a wind force meter. Source: Vaavud**

What is automation?

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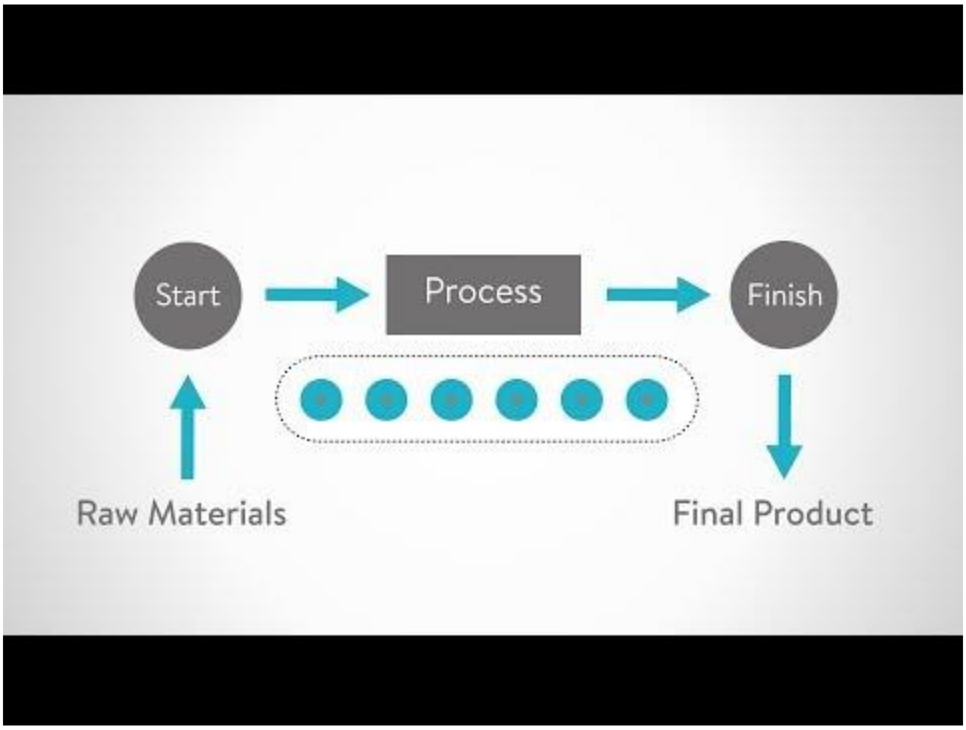
This video shows you the basic concept of automation, both with a simple system such as switching on and off a light, and an example of how automation can be applied in industrial processes.

What is automation



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Exercise

In the video you saw the example of a manual versus automatic light switch.
What are the advantages of the automatic light switch?

- It saves valuable resources
- It is faster
- It is convenient
- The quality is higher

Process automation

Automation is often applied to complex processes. Please study the next video.
What is process automation?

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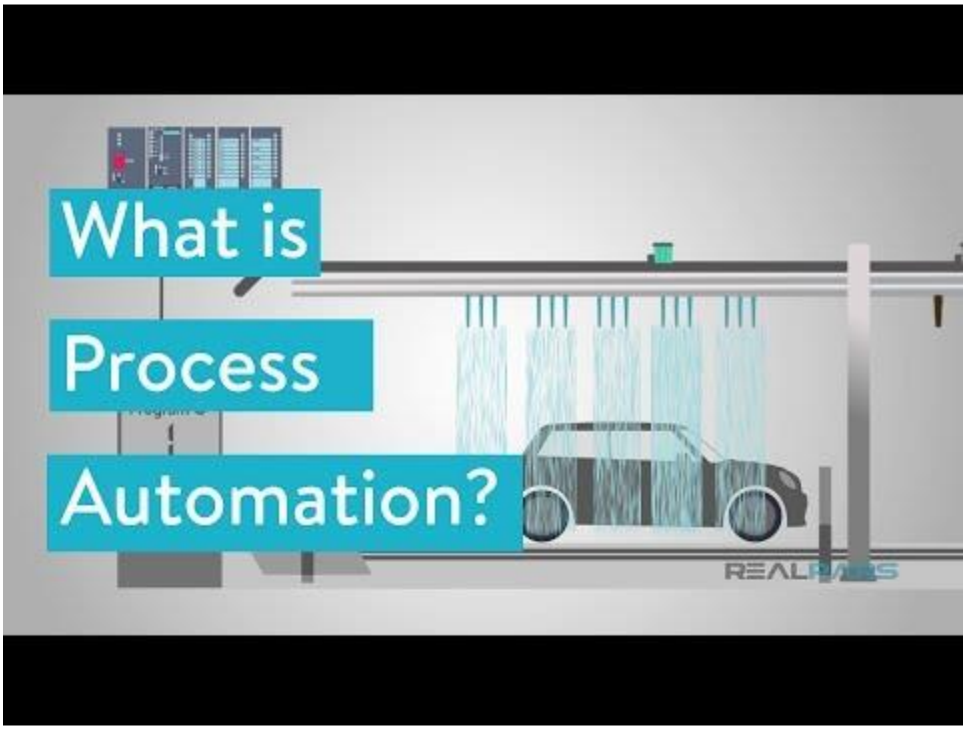

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Exercise

What are the advantages of industrial automation?

- Saves time
- Avoids human errors
- Creates new high paying jobs
- Saves money

Control systems

Automation is the use of self-regulating machinery, electronic equipment, etc. to make a manufacturing system or process operate at greater speed and with little or no human intervention. In order to create a self-regulatory machinery, or system, we need both sensors and actuators.

The sensors in a system measure quantities such as light intensity, temperature, pressure, liquid flow velocity, or detect a condition (open or closed). For a system to respond, it needs actuators. Actuators are elements that can influence the environment. A heater can increase the temperature of a liquid. An electrical motor enables a Tesla to move forward, etc.

When we talk about automation we need to combine the sensors and the actuators into a control system. Next to sensors and actuators we also need controllers. Controllers are the elements that receive the input of the sensors, and based on this, control the actuators. This device is, in most cases, a computer or PLC, a programmable logic controller. This device works using an algorithm and controls the actuators, based on the output of the sensor elements.

So, we need 3 elements:

- sensors
- actuators
- controllers

Car door monitoring system

Control systems come in many different forms and complexities, but in order to give you an initial introduction to this, let's consider a car door monitoring system. This system is implemented in most cars, and ensures that all doors are closed when you move your vehicles. Here we will analyse this system step by step.

Figure 1: Dashboard symbol of a car with the doors ajar. Source: repairpal.com

The first step is to define precisely what you want your control system to do.

This step is important as it defines the sensing, control and actuating elements that you need in your control system.

For now, we will take a control system, as we know it. This system produces an audible signal if one or more of the doors is open.

Notice the difference between

(i) you want to know if at least one door is open

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(ii) you want to know if one, two or three doors are open

(iii) you want to know which doors are open

In this example I will discuss option (i), but for the other two this has consequences for the control system and actuators that you need to implement. (i) can simply use a small speaker producing a tone, but for (ii) and (iii) a visual display is needed.

The next step is to identify the sensors you need, including the type.

In order to determine whether a car door is open or closed, you need some kind of contact sensor, which produces, for example, a digital '1' when the car door is open and a digital '0' when it is closed.

Then you need to identify the actuator. We mentioned that we would like to have an audible signal, so a speaker of some kind will do.

The final step is to add the controller, and for this you need the so-called algorithm, or mathematical function. This defines the output of the controller as a function of the input.

All together, schematically this looks like this:

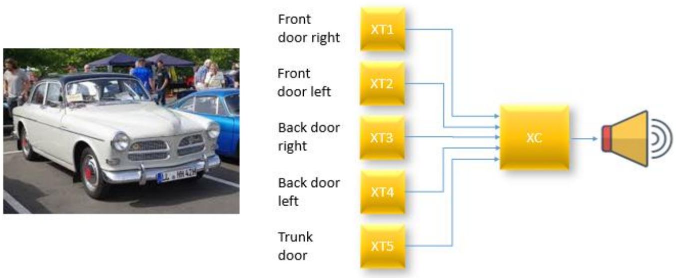

Figure 2: Schematic overview of a car door alarm. Source: INDEX consortium license: CC-BY-NC-SA

Only if all doors are closed, and thus all sensors (XT1 to XT5) produce a digital '0', the controller should not respond (or send no signal to the speaker). Only if one or more doors are open (some sensors produce '1') the controller signals the speaker to produce a sound.

This was a relatively simple control system, containing the very basic components that are needed. From here you can make it more complex. Imagine you would also like to have this sound only when the car is moving (it is annoying when a door opens, the alarm sounds, but the car is not moving). In that case you need to add an additional sensor that detects that the car is moving. This might be a signal from the speedometer.

House heating managing (1)

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Let's look at another control system, which is a little more complicated as it contains a small feedback loop. The system we are going to look at is a house heating control system.

Figure 1: Picture of a house. Source: UXWing

STEP 1 involves **determining the purpose of the control system**. In other words, what does the control system need to do?

The system needs to maintain a constant temperature within the house. That is its purpose, right? So how do we go about this?

STEP 2 is about **determining the elements, the sensors, controllers and actuators** that are needed.

Exercise

So what sensors and actuators do you need for this?

☐Temperature sensor
☐Thermostat
☐IR motion detector
☐Heating device
☐Air conditioner

House heating managing (2) (copyright pictures)

You indeed need a temperature sensor that allows you to measure the actual temperature in the house, and you will need a heater.

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Figure 1: Thermometer to measure temperature, radiator to heat the house. Source: n/a

Besides these two elements, you also need a controller. This device receives the input from the sensors and sends signals to the actuators. The controller can be seen as the communication device between the sensors on one hand and the actuators on the other hand. This controller, (in most cases a PLC) is programmed to operate autonomously. It has a program (or algorithm) that, depending on the values of the sensors that it receives as an input, produces an electrical signal for the actuators.

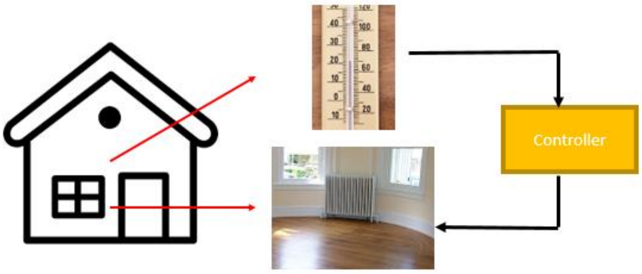

Figure 2: Controller receives data from the thermometer and opens or closes the radiator. Source: n/a

This might sound a bit theoretical, so let's try to make this more practical. Just imagine you are in your rented winter cabin somewhere in the mountains, enjoying a beautiful evening with your friends. Outside it is freezing, and of course you want to enjoy a comfortable and pleasant temperature while being in the house.

Figure 3: House in the snow. Source: Unsplash

So, you have set your temperature setpoint at a comfortable 20 degrees. This is another input that the controller needs to determine what to do. As you are enjoying this get together with your friends, several things happen that are disturbances on the indoor temperature. As the evening falls, the outside temperature drops, as will then the indoor temperature (if nothing is done). As your friends come in, the door opens and warm air escapes, effectively lowering the temperature. Let's see this in the following schematic.

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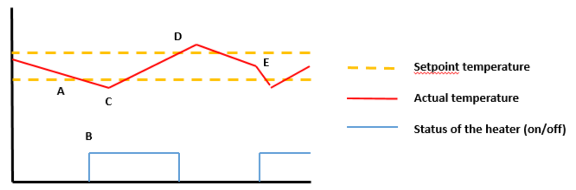

Figure 4: Temperature controlled between setpoints by controller. Source: INDEX consortium license: CC-BY-NC-SA

In this graph you see the time (horizontal axis) and the actual temperature (solid red line). Let's start from the left. The heater is not turned on, and as a result of the cold temperature outside, the temperature is slowly decreasing (A). Just imagine you have put your thermostat at 20 degrees. The controller then defines a lower and higher boundary, for example at 19 and 21 degrees. When the temperature gets below this lower boundary of 19 degrees, it turns on the heater (B). In a simple algorithm this looks like:

IF (T indoor<19) THEN HEATER=ON

As soon as the heater starts, it needs a bit of time before it generates heat, causing a slight delay. At point C, you can see that the temperature starts to go up, again. The heater continues to heat until it reaches the upper boundary (D in the graph), 21 degrees. Then the heater turns off, so again:

IF (T_indoor>21) THEN HEATER=OFF

At point E, for example your friends come into the house, and a lot of warmth is lost through the door, causing the temperature to drop even faster. But again, as soon it gets below the lower boundary the heater is turned on and starts heating the house again.

This is an example of a very basic control system, which we are all quite familiar with. In this example I treated the temperature sensor and the controller as two separate units, but this in practice is a combined device that we know as a thermostat. So, the thermostat is measuring the temperature and this signal is being processed within the thermostat device and outputting a voltage signal to the heater in your house.

Cruise control

ASSIGNMENT
We just discussed the car monitoring system and the house heating system. Now it is time to implement what you have learned on a new case: the cruise control system in your automobile.

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Figure 1: Cruise control dashboard icon. Source: Wikipedia (Nominal Two-Two): CC-BY-SA 4.0

Please answer the following questions:

Question

What sensor do you need?

As in the previous example of the house heating management system, you need to give it a setpoint, which the controller can use to decide what to do. Imagine you set your speed at 80 km/h.

Exercise

At this moment you are driving at a 60 km/h on a flat road and you start the cruise control
What does the control system do?

☐ No response
☐ Increase the amount of gas to the engine
☐ Decrease the amount of gas to the engine

There is an interesting difference between the previous example of the house heating system. In the house heating system, the heater has only 2 different states: it is either OFF or ON. As we have seen in the previous unit, you can describe this algorithmically as:

IF T_indoor < 19 **THEN** Heater=ON
IF T_indoor > 21 **THEN** Heater=OFF

In the case of the accelerator, which determines the amount of gas flowing to the engine, this is a parameter that can vary continuously. It is neither ON or OFF, but can have different values. You can look at this as a valve. If the valve is completely open, the maximum amount of gas that can run through the engine will flow, but as soon as the valve is gradually closed, the amount of gas flowing through decreases.

This can be used in a control system, in a very effective way. It means that you do not use a smaller or

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greater than operation to determine whether the actuator is ON or OFF, but you can measure quantitative difference between the speed of the car, and the speed that you set in the cruise control system. If this difference is large, a lot of gas needs to go to the engine, but as the speed gets closer to the actual value, the amount of gas needs to decrease.

This looks like:

IF ActualSpeed < SpeedSetpoint

THEN AmountGas = K * (SpeedSetpoint - ActualSpeed)

ELSE AmountGas = 0

(The IF-condition is needed to prevent negative values as the gas flow can only be positive: Gas can only go to the engine, not the other way). But here, you can see that the amount of gas going to the engine is directly related (via the constant K) to the difference between the setpoint and the actual speed.

Exercise

Now let's answer the previous question again. You are currently going at 60 km/h, and you start the cruise controller.

What does the controller do? What happens?

☐ The gas flow to the engine is increased, and the car increases its speed until the setpoint is reached, where the gas is going back to its initial value
☐The gas flow to the engine is increased, and the car increases its speed. As it approaches the setpoint value, the amount of gas flowing to the engine is reduced to zero.
☐The gas flow to the engine is increased, and the car increases its speed. As it approaches the setpoint value, the amount of gas flowing to the engine is reduced to a value that maintains the speed at 80 km/h.

Impact for industry 4.0

Industry 4.0

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Industry 4.0 is often schematically depicted as follows:

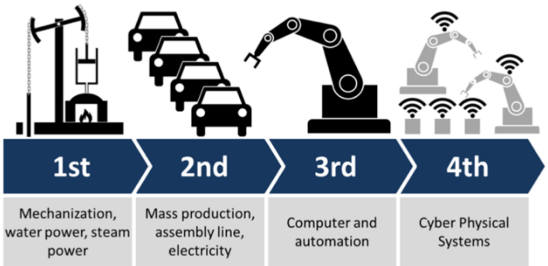

Figure 1: Schematic overview of 4 levels of industry. Source: Wikipedia Christoph Roser: CC-BY-SA-4.0

Industry 4.0, or the 4th Industrial Revolution is about cyber-physical systems. It is the ongoing automation of traditional manufacturing and industrial practices using modern smart and digital technologies.

Exercise

Industry 4.0 is a term that was first publicly used in 2011 in Germany. But it is known by many other names

Select terms that refer to Industry 4.0:
☐Smart Industry
☐Robotic Automation
☐Sensor 4.0
☐Industrial Internet of Things
☐Smart Factory
☐3D printing
☐Cloud-Based Manufacturing (CBM)
☐Factory of the Future
☐Sustainable and Smart
☐Smart manufacturing

Industry 4.0

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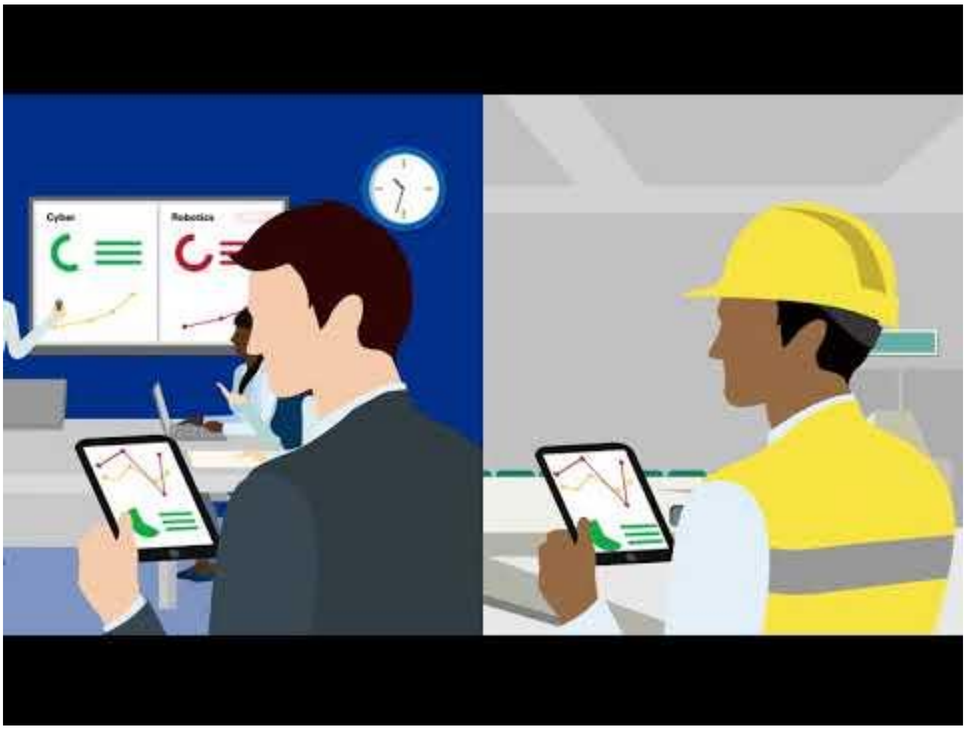

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What is industry 4.0 and what does it mean for you?

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Objectives of Industry 4.0

The overall objective of Industry 4.0 is

to enhance productivity through automation.

This can be achieved through the following 4 approaches:

1. Reduction of waste and improvement of yield
2. Increase sustainability via real-time monitoring and production
3. Reduction of maintenance costs through autonomous control systems
4. Increase of agility of production.

Impact of sensors

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According to a study reported by EY the emphasis with smart sensors so far has been on cost savings rather than boosting revenue. And even in taking advantage of the huge potential that these sensors offer, relatively little progress has been made.

The impact of smart sensors in the industry can therefore be summarized into 4 different aspects

1. Increase if production flexibility and worker responsiveness

Smart sensors enable the optimization of just-in-time processes. If workers/employees have real-time and accurate information accessible to them, it empowers them to move quickly enough to adapt to a changing situation. Dashboards are a good example to get a better understanding of the work processes and streams based on the data produced. This understanding in turn allows additional training for new workflows.

2. Reducing equipment downtime through predictive maintenance

Predictive maintenance means performing maintenance when it becomes necessary rather than relying of a fixed schedule. Having sensors recording data on equipment enables detection of anomalies, which might be a pre-stage to failure. Having this data available (for example in a cloud) and comparing it with data from similar devices, or previous readings, allows the equipment to become self-monitoring and maybe even self-repairing.

Adoption of new technologies in this area is rather slow, because of the specialized equipment that is used, which requires a specialized sensor system. Another limitation is the requirement of a specialist modeling expert, that need to develop a mathematical model that matches the real process. This turns out to be rather difficult.

3. Improving quality control and reducing waste

The use of smart sensors enables real-time monitoring of a process and reduce waste and non-compliant products.

Oil- and gas industries as an example already have a long history of using sensors and the data they provide. What is new is the inclusion of advanced analytics. By analyzing the sensors in combination and comparing this with values obtained earlier, prediction can be done on the quality of the product being made, and processes can be adjusted in time.

In other sectors, consumer goods, this responsiveness is way lower, and therefore there is a lot to gain here.

Reducing waste is having the potential to benefit most. By having data on the process, waste can be reduced. In many cases this data can also be used to demonstrate compliance with the regulations, which is another cost saving.

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4. Improving understanding of cost structures

Increasing knowledge on factors affecting unit profit and/or loss is among the largest opportunities. It helps optimizing energy and materials consumption.

New business

In the previous section the benefits of smart sensing for Industry 4.0 was very much focused on cost savings, and this is certainly true for the coming years. But as the Industrial Revolution will continue, there will be other benefits from having sensors in the manufacturing industry, such as:

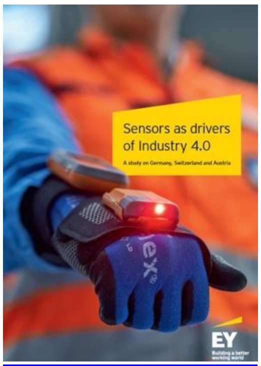
- quicker responses to consumer feedback and order modifications
- sensors that are self-testing, monitoring and improving their own performance

But the largest impact will be expected to come from new business models, services and individualized products.

These products most likely will emerge from customization and their connection with sensor data and analytics. It will enable companies to offer mass customization while delivering a unique product to consumers at a near individual level.

Interesting report on the role of sensors in the Industry 4.0 revolution.

If you want to read in more detail on the impact of sensors in Industry 4.0, check out the following report:



Additive Manufacturing

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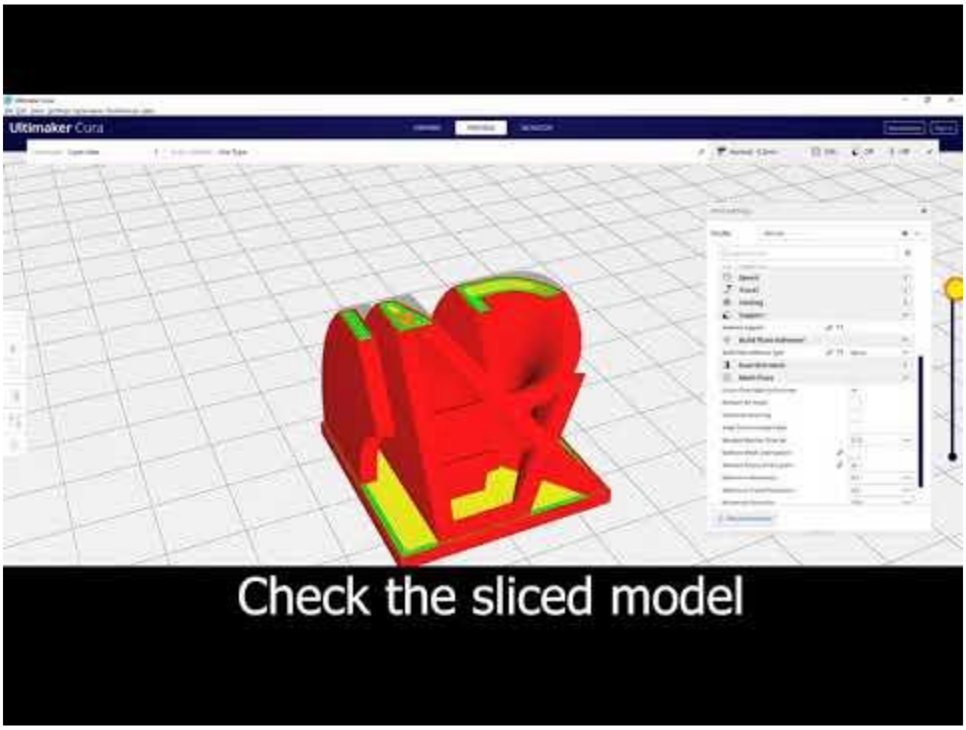
Overview

Learning Objectives

The aim of the course is to familiarize the participant with the essential techniques of Additive Manufacturing. The essential advantages and disadvantages of the technologies are experienced. The participant will learn the typical application area of Additive Manufacturing and will be able to assess whether Additive Manufacturing is interesting and useful for their needs.

Additive Manufacturing (AM), commonly known as 3D printing, is changing the way products are designed, manufactured and maintained. Almost everything around us has been made in a factory and was made possible in part by innovations in manufacturing processes. This course introduces the participant to Additive Manufacturing technologies. Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. Even though most of the cornerstone AM processes were invented and first commercialized more than 25 years ago, only recently Additive Manufacturing is being widely considered for the manufacturing of end products. One of the biggest barriers to the wider adoption of Additive Manufacturing is the lack of knowledge. So, learn more about how you can use the potentials of Additive Manufacturing for your business.

Introduction Video



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What is Additive Manufacturing (AM)

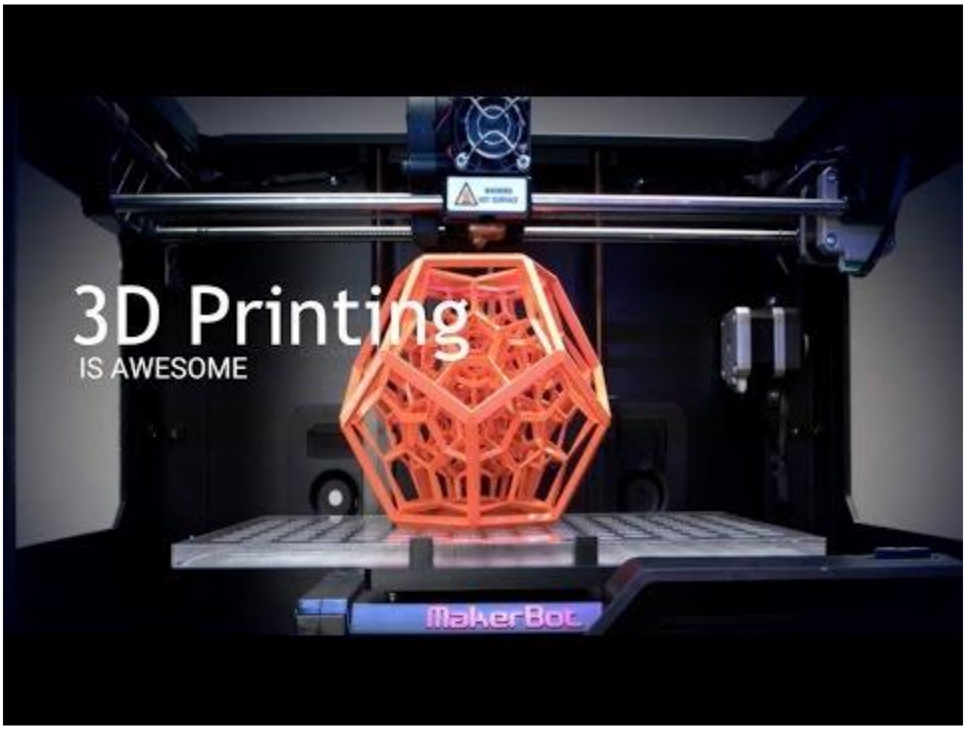
Introduction to Additive Manufacturing and

Additive manufacturing (AM) can be defined as a joining solidification process that builds objects using a digital design data file to create a three-dimensional object, usually by adding layer-upon-layer of materials, whether the material is plastic, metal, ceramic, concrete or even human tissues using a computer driven-technology. AM is a completely different manufacturing approach compared to traditional subtractive manufacturing (through machining) which involves subtracting materials from a larger workpiece (e.g., grinding, polishing) or conventional forming methods (e.g., pressing, casting, injection moulding). The main concept in AM is to "stack layers" of materials in order to reproduce a three-dimensional object.

What is Additive Manufacturing?

Additive manufacturing (AM), also known as 3D printing, is the process of making 3D objects from digital design files, by adding layer-upon-layer of material, using a computer-driven system. The printing material can vary depending on a manufacturer's requirements, with plastic, metal, ceramic or even human tissue in some systems. AM differs from other manufacturing methods such as subtractive manufacturing (machining, grinding, polishing) which involves removing material from a larger workpiece and forming methods (pressing, casting and injection moulding, all of which require tools/dies), in that it stacks layers of material on top of each other without the need for tooling. AM has become an indispensable tool for rapid product development, often used for modelling and prototyping. It is also a popular method for producing tooling components and patterns for metal casting. Recently, AM is increasingly being used to manufacture finished goods. AM machines are currently used in a wide array of areas, including the aerospace, automotive, architectural and defence industries, as well as in medicine and dentistry.

Introduction to 3D printing



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The Additive Manufacturing process

The AM process normally starts with the creation of a digital 3D model through the use of a computer-aided design software tool (CAD) or by scanning an existing part with a 3D scanner. The manufacturer saves the digital model as a .STL (Standard Tessellation Language) file, which is a triangulated representation of the model. STL is the current standard file format of choice. However, there are limitations to its use and suitability for certain applications, as such the industry is working on alternative file formats. Specialist software is then used to slice the model into thousands of individual layers, creating a 2D representation of each slice of the part. The 2D representation is translated and exported as instructions that an AM system can understand, such as a toolpath or motion coordinates before the machine starts to manufacture the part. Some parts may then need additional processing to improve surface finish, depending on the type of material used and the complexity of the model. The AM process flow is shown below.

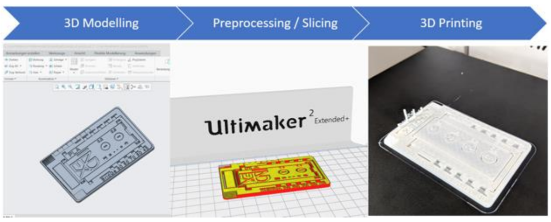

Figure 1: Process of Additive Manufacturing. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

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3D Modelling

A 3D digital design can be made by scanning an existing object with a 3D scanner or designing a totally new object using computer-aided design software (CAD). An engineer can make subsequent edits to a scanned object to adjust design details, accounting for tolerances and material types. After the creation of the 3D object in the scan/design phase, the design needs to be analysed to answer the following questions:

- Can the AM machine correctly build the part?
- How will AM impact part performance?
- How will the part function in production?

Evaluation of the CAD design may be carried out using computational analysis and build simulations. Computational analysis gives detailed information about the structural, thermal and fluid dynamics, while the build simulations emulate the layered structure to provide information on how the build process affects part quality and lifespan. The results obtained from the analysis can then be used to ensure manufacturability and that the design has suitable form, fit, and function.

STL Files

An STL file stores a digital description of a triangulated 3D model. Most CAD software packages can generate STL files and nearly every additive manufacturing machine accepts the format. If the surface of an STL CAD model is rough, the printed part is rough, too, because a 3D printer can only manufacture an object up to the resolution of the STL file. The more triangles that make up the digital model, the smoother the surface will be, but the file size also increases, so there is a trade-off. 3D printers can have STL file size limitations so sacrifices in model accuracy or surface quality can be mandatory.

Advantages:

- smaller file size than many other formats
- universally supported with a large user-base

Disadvantages:

- STL files only contain geometric information, unlike other formats such as OBJ which can include information about colour, texture, and/or material.
- ordinarily, STL files are in a binary format and are difficult to debug (though an ASCII version is available which is much easier to understand).

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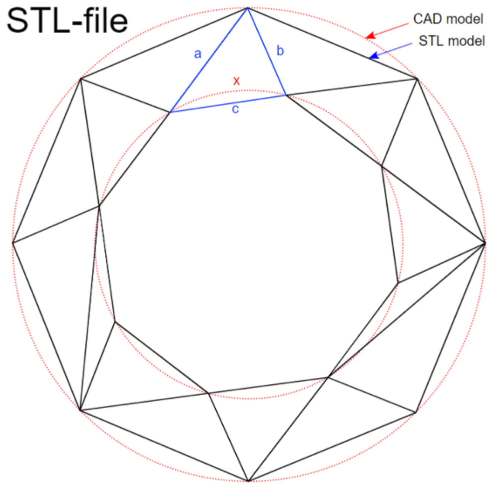

Figure 2: STL approximation of a torus. Source: Copyright Wikipedia.com

Pre-processing / Slicing

AM processes work by stacking layers of material. They involve initially digitally slicing the model before physically adding material in the shape of each cross-section on top of the previous one. Slicing software programs, also known as slicers, are used to convert STL files into the machine code that 3D printers can understand. The machine code contains information about the path the printer needs to follow to create each layer of the design. The distance between slices affects the thickness of each layer of material, the duration of the manufacturing process and the geometric accuracy of the part relative to the digital model. Due to the layering process, AM parts tend to have anisotropy (varying physical properties along different dimensions). Parts are normally weaker in the Z-axis as there tend to be weaker bonds between layers than inside the layers themselves. Conventional slicing methods generate unnecessary layers that increase fabrication time without much improvement in overall surface quality. Software with adaptive slicing capability can allow layers to have varying thicknesses. Adaptive slicing can reduce fabrication time and enhance surface quality.

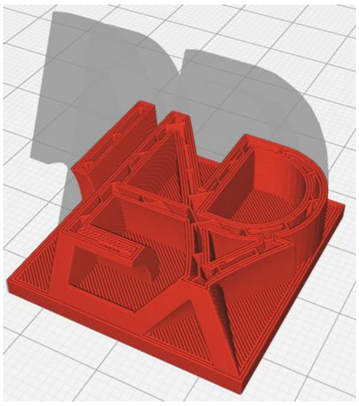

Figure 3: INDEX logo presented in a slicer. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

3D Printing

There are seven main categories of the AM process. They are explored in more detail in module two (AM Technologies).

- Material extrusion, which involves forcing hot material, normally in the form of a filament, through a nozzle.
- Powder bed fusion, which involves selectively fusing layers of powder.
- Material jetting, which involves selectively printing layers of ink on top of each other.
- Binder jetting, which involves selectively glueing layers of powder together, normally with a liquid binder.
- Directed energy deposition, which involves using a multi-axis arm to deposit melted material onto a surface.
- Vat polymerisation, which involves selectively curing layers of photopolymer resin.
- Sheet lamination, which involves binding multiple cut sheets of material together.

Exercise

Usage of Additive Manufacturing

When is additive manufacturing particularly often used?

☐ Rapid product development and prototyping
☐ Mass production
☐ Individual production
☐ High precision parts

Advantages and disadvantages of Additive Manufacturing

Advantages

Complexity of Manufacture
An advantage of additive manufacturing over subtractive manufacturing is that it often only requires a single step to turn a digital design into a physical object, regardless of its complexity. It also allows manufacturers to create intricate parts inside other parts. In subtractive manufacturing, a more complex part usually requires a greater number of steps and tools to manufacture it.

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Figure 1: Complex structured shoe. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Low volume manufacturing

Moving across to 3D printing will make it possible for businesses to consider short-run part production, where focused product teams can launch new products more frequently. They will be able to work beyond the realms of their imagination and certainly beyond the restraints that come with traditional methods. It delivers an agile development process for physical parts and has the ability to accelerate the production and the time it takes to get to market.

There is no doubt that 3D printing is way ahead of conventional methods when it comes to manufacturing the first several hundred parts. But is 3D printing also suitable for manufacturing on a large scale?

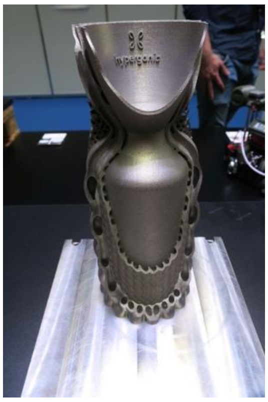

Figure 2: Flow topology optimized metal printed part. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

High volume manufacturing

3D printing is a technology that is developing and growing faster than most other technologies due to the way it can influence manufacturing processes and help businesses perform to a higher level. A production line that is set up for 3D printing is easier to alter than that of a production line for traditional manufacturing, making 3D printing a feasible option for many reasons. The whole production line can be adjusted and adapted with the speed of the printing production line. Therefore, improvements to machinery, adjustments to the print speed or even a change of product can be made almost instantly, compared to older methods where it can take several weeks or months to make the changes and then begin producing again.
It is inevitable that the capabilities that come with 3D printing and the way in which technology is evolving will enable businesses to adopt this new way of producing products or parts and it is likely that this adoption is going to grow well in the future.

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Figure 3: Metal printing combined with traditional manufacturing method. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Cost efficient and fast prototyping

For prototyping, highly complex parts can be produced directly from 3D design data without molds or dies, reducing lead time and enabling faster design iterations and their evaluation. In addition, AM offers the ability to create some unique shapes and structures that are not producible with conventional processes. Traditional manufacturing methods are more expensive when producing small batches of products, whereas the 3D printing process makes the creation of parts products and prototypes cheaper and more accessible. Unlike traditional manufacturing where many different people may be required to operate a number of machines, or a production line is required to piece together the product, 3D printing often removes this. Each 3D printer will require an operator to start the machine before it begins an automated process of creating the uploaded design. Also, pre and post Processing is needed , but overall the expected labour cost per parts are lower for small to midsize production volumes.

Figure 4: Multicolour printed whistle. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Reduction of risks

When businesses have the ability to confirm a design before committing it to production, it can help to remove the risk of errors, wasted materials and money. Creating products with 3D printing can help to increase confidence, especially when you consider that a 3D prototype is easier to redesign and alter than anything that has been created using a traditional method.

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When it comes to setup costs, manufacturers won't have to produce so much of a product in order to justify the setup costs. The traditional methods of production often rely on the efficiencies of mass production and require a large number of assembly workers, whereas, 3D printing requires the filament material and not a lot more to fulfill an order.

Failure is cheaper and faster

3D printers will not need to be retooled between production runs. The speed at which a 3D printer can assemble could be deemed to be slower than that of a traditional assembly line. However, when you factor in machinery problems that can stop production and human error, there is more that can go wrong with traditional manufacturing.

Time to market

3D printing makes it possible to develop ideas at a faster pace. In some instances, it could be possible for 3D concepts to be designed and printed on the same day and in terms of large-scale manufacturing, it is certainly faster than conventional methods. This can help companies to reduce manufacturing time from months to days while ensuring that they remain ahead of their competitors.

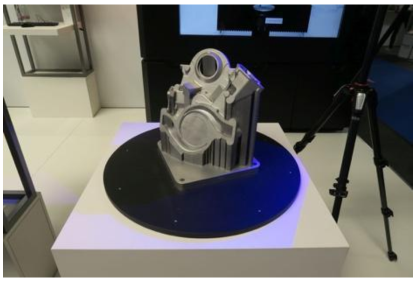

Figure 5: Example of metal printing support structures. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Build and grow

For businesses that adopt 3D manufacturing, it is possible to continue to grow and evolve through the production of items that have been created from their imagination. There are no limits when it comes to 3D manufacturing because things can be created virtually and then printed in a very short time frame. Therefore, for any business, a product can go from an idea to a concept right through to the finished part.

"No" Limitations in geometries

For many years, standard manufacturing techniques have held back the design of products. However, with many improvements made already and more to come in the future, the 3D manufacturing process can create an endless list of possibilities. Geometries that were once difficult can now be achieved, such as holes that change direction or square interior cavities. These kinds of designs have become possible and simpler to construct. The overall freedom in design is higher and easier to realize with additive manufacturing methods than traditional production methods.

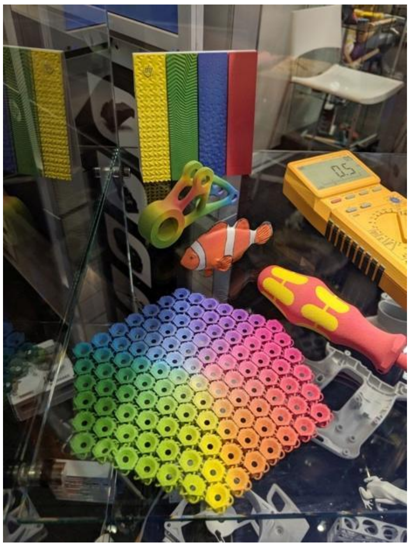

Figure 6: Possibilities of multicolour printing with MJF. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

As this is a relatively new technology that is gaining momentum, the material cost can still remain high. However, the range of materials is growing and this makes it possible for the price to decrease over time. But, in comparison to traditional methods, the overall cost is a lot lower. The manufacturing process can result in a lot of waste, particularly where traditional manufacturing is concerned. However, this is where 3D printing for manufacturing can transform the amount of waste, because of the way in which it uses resources more efficiently. When it comes to using 3D printing for manufacturing, a 3D printer will only use the material that passes through the extruder of the printer and that is used for the assembly of the product.

In comparison to injection–molds, often there is a requirement to use additional materials to fill the molds. In the majority of mass production needs, 3D printing will deliver a lower amount of waste (for example the support material) than traditional manufacturing. Also, subtractive manufacturing requires more material. It requires a block of material larger than the part's dimensions, with the excess removed through machining. The machine cannot usually reuse the discarded material. In AM, support structures require additional material, but they do not tend to be bulky. They can be made from materials that are often cheap and sometimes reusable.

Less storage space

Many industries require businesses to store the parts and products that they need or sell. This means that a significant amount of storage space is required to house goods that can sit on a shelf for months or even years. This costs a lot of money. By using 3D printing for manufacturing, costs can be cut by reducing the amount of storage space that is needed. 3D printing makes it possible for goods to be made as they are sold. This means that there will be no overproduction and reduces storage costs.

Freedom of material choice

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Modern AM methods make it possible to manufacture parts made from a vast and ever-growing range of materials, many of which are extremely difficult to use with conventional methods. AM materials include: 1) polymers, 2) metals and metal alloys, 3) ceramics, 4) composites, including reinforced polymers and concrete. Depending on the technology, the feedstock materials can be in the form of powders, pellets, filaments, sheets, pastes or liquids.

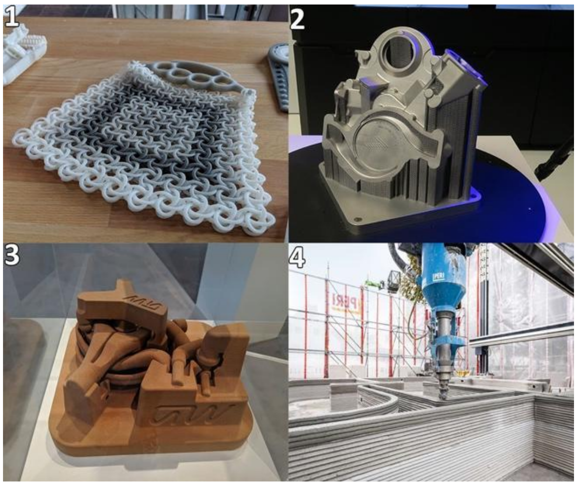
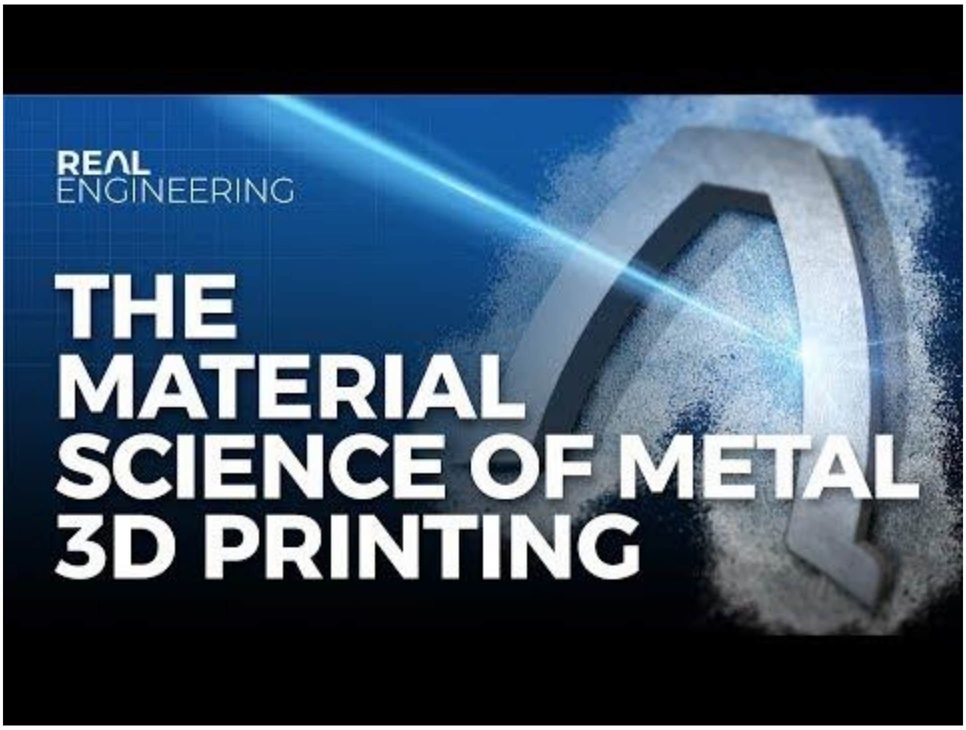


Figure 7: Examples of different printing materials. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Metal printing benefits



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Disadvantages

Manufacturing time

Most common techniques are only suitable for small batches and low or single volume prototyping. The duration of manufacture in AM is often significantly longer than for many traditional manufacturing techniques. Aside from technology dependent factors, manufacturing duration depends on the orientation and the volume of the part. Adding 1cm in height (on the Z-axis) to a model requires much more time than adding 1cm in width or depth (on the X-axis or Y-axis, parallel to the build surface) because the printer has to add additional layers. Hence to increase print speed, it is essential to orientate the part in a way that minimizes the build height. Also, a heavier model requiring more material will probably take longer than a lighter model needing less.

Layering Process

The layering process in AM presents challenges, such as:

- optimizing print duration and material usage;
- minimizing the 'staircase effect' which negatively affects surface finish;
- creating a support structure for overhang and internal flow;
- optimizing the volume of the support structure;
- determining the best orientation for the part;
- optimizing process parameters;
- minimizing tolerances.

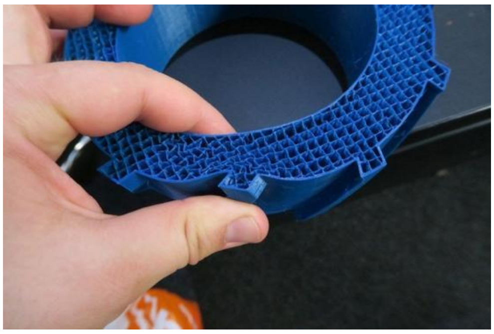

Figure 1: Flexible material possibilities. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

The Staircase Effect and Part Built Orientation

As a result of the layering process, visible steps can occur between layers in the Z-axis, diminishing the surface quality of the part. Optimizing the build orientation and reducing the layer thickness through increasing the number of slices can minimise the appearance of the staircase effect. The minimum layer thickness is one of the most important technical characteristics of AM systems. It defines the resolution of the Z-axis, or in other words, it determines the minimum possible thickness for each new layer of material added. A printer capable of a 50µm layer thickness has twice the resolution in the Z-axis than a 100µm printer and therefore adds twice as many layers when set to its highest resolution for a given part. The overall precision of the AM process does not depend on the layer thickness alone, but it is often necessary to increase the resolution to decrease the staircase effect and ensure smooth surfaces. An appropriately oriented part has its curved surfaces in the XY plane, parallel to the build surface, to reduce the staircase effect even further.

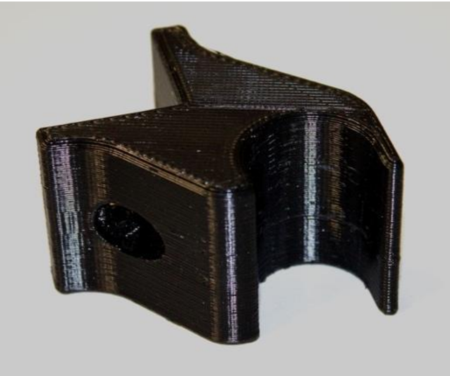

Figure 2: Detailed view on the layers of a printed part. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Support Structures

For most processes, support structures are needed if a part has overhanging features, as new layers require an underlying solid layer to support them to reduce the chance of deformation due to gravity, internal heat and residual stresses. In layer-by-layer laser additive manufacturing, the heat from the laser conducts between layers during the manufacturing process. Support structures in contact with the workpiece can transfer the heat away, helping to prevent distortion or defects which can arise from overheating. Support structures can have a negative impact on the build time as well as the post processing time since supports are generally required to be removed by hand. Furthermore, where supports are attached to the part there is a deleterious effect on the surface finish.

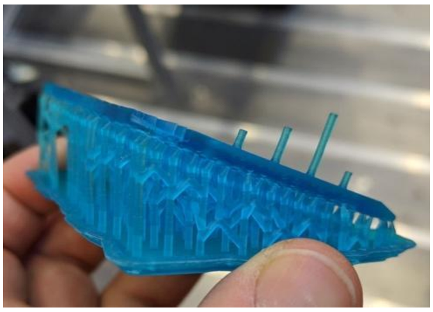

Figure 3: Support structures in SLA printing. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

When are Support Structures Needed?

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Support structures are often necessary for processes such as material extrusion and material jetting but are less likely to be used in powder bed technologies as the excess powder remains on the build plate and can support the part. Support structures can be external, internal or both depending on the AM process and geometry of the model. The support structure can be generated automatically in AM software or created manually.

Resolution

In additive manufacturing, there is a distinction made between the resolution on the manufacturing axis (the Z-axis) and the work plane (in the XY plane). The resolution in the Z-axis describes the layer thickness, and it depends on the material and printing technology used. The Z-axis resolution is often lower than in the XY plane. Powder based AM systems usually have a more limited resolution in the XY plane due to the particle size of the print material. Liquid based systems do not have that problem and tend to be more accurate. In laser-based systems, the impact diameter of the laser beam also influences the resolution.

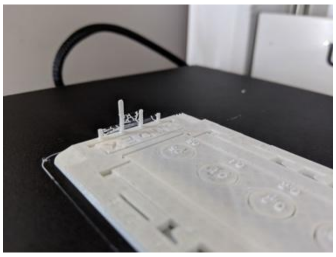

Figure 4: Printed benchmark test for a FDM printer. Source: CC BY-SA 4.0 L. Müller/Hochschule Düsseldorf.

Exercise

Advantages and Disadvantages of Additive Manufacturing

Which challenges provide Additive Manufacturing?
☐ Maximizing the 'Staircase effect'
☐ Optimizing the volume of support structure
☐ Making the difference between the digital model and the manufactured part clear
☐ Creating support structure for all parts

Materials and production methods

Plastics

Polymers and Thermoplastics

Polymers are used extensively in additive manufacturing. Polymer materials can be thermoplastics, which deform and melt when heated. Thermoplastics are suitable for AM processes that use heat as a means for melting and binding material together, such as the filament for extrusion systems or

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powders for SLS. Other polymers in AM are thermosetting plastics, which undergo an irreversible reaction during manufacturing, such as the resins used in vat polymerisation.

Thermoplastics

This section focuses on the most widely available thermoplastic polymers for AM. ABS, PLA, PETG and PC are all amorphous polymers, which means the filament gradually softens when heat is applied. Semicrystalline polymers, such as nylons, have a sharper solid-to-liquid transition time.

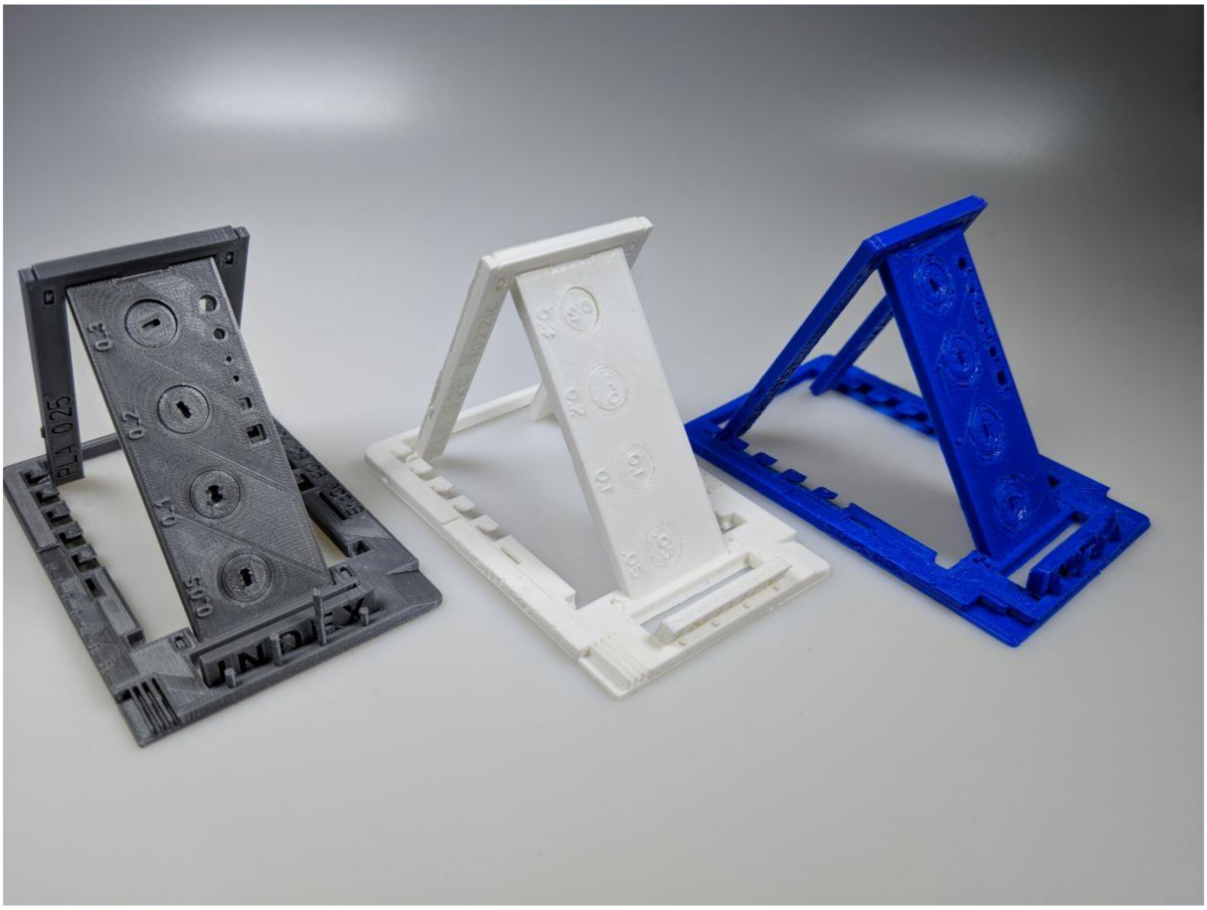

Figure 1: Benchmarks out of different materials. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf

Photopolymers

Photopolymers are used in additive manufacturing for producing highly accurate parts with fine details such as jewellery moulds, presentation models and prototypes. They are also used in dentistry

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and medical applications. AM technologies that use photopolymers include SLA and mask projection. Parts made from photopolymer resins tend to be more accurate but less strong than those made from thermoplastics. Photopolymer resins can cause health issues if not handled correctly. Always refer to the manufacturer's safety data sheets for safety instructions.

Figure 2: Printed bust with complex structures. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Metals

Metal Powder

Metal powder AM utilizes a wide range of metals including titanium, nickel-based alloys, cobalt chrome, copper alloy, Inconel, aluminium, maraging steel, stainless steel and tool steels all of which are supplied commercially in powder form. The quality of the metal powder plays a vital role in the mechanical properties of the part. Metal powders for AM are commonly produced using a gas atomisation process. A high-pressure gas jet transforms a molten metal stream into droplets that form metal powder particles upon solidification. Other atomising technologies are also available such as water and plasma atomisation, along with spheroidisation processes which can transform an angular powder into a spherical feedstock suitable for AM.

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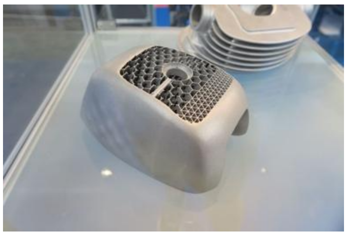

Figure 1: Printed metal part with complex structures. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Metal Wire

Unlike metal powder, wire-based material for AM has minimal processing requirements. The wire diameter is commonly between 0.8mm and 2.4mm. High-quality wire has minimal variation in diameter. It is, however, important to ensure the wire is clean, moisture free and does not have cracks or scratches on its surface, as imperfections may directly translate into porosity inside the part.

Figure 2: Pre-processed metal wire part. Source: CC BY-SA 4.0> by L. Müller/Hochschule Düsseldorf.

Other Materials

In addition to plastics and metals, other materials are also used in additive manufacturing. Typically, sand, wax, ceramics, composites and many other experimental materials.

Sand

Additive manufacturing is widely used in the production of sand casting molds. Additive manufacturing makes it possible to create complex molds that significantly expand the possibilities of classic mold making. The advantage of mold making by 3D printing is that the molds and/or cores can be printed directly and do not have to be positively formed first. In addition, the possibilities of complexity have increased significantly through additive manufacturing.

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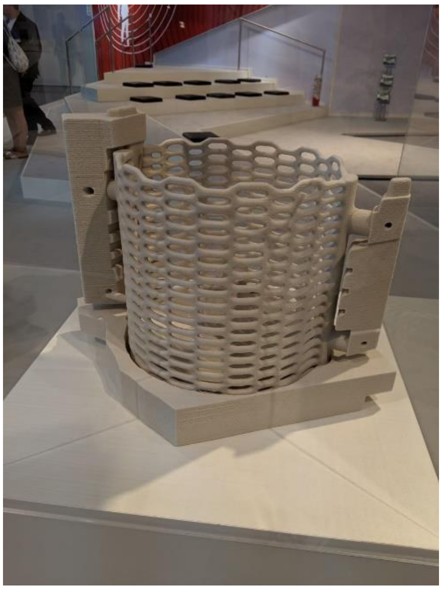

Figure 1: Part fully made out of sand. Source: CC BY-SA 4.0 by L. Müller/Hochschule Düsseldorf.

Sand casting: Digital production of complex sand moulds by voxeljet

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Wax

Wax is another frequently used material. Especially in mold making for investment casting, wax is used for highly detailed molds. Investment casting with wax molds makes it possible to quickly and easily produce high-quality master patterns for small to medium-sized components for highly detailed requirements. Typically for fine specialty components, jewellery and aerospace components.

Figure 2: Wax rings. Source: Copyright Microfabricator.com: Wax rings

Exercise

Materials for Additive Manufacturing

What type of polymers are ABS, PLA, PETG and PC?

☐ Elastomer

☐ Thermoset

☐ Amorphus thermoplastic

☐ Semi crystalline thermoplastic

What are the use cases for AM?

What is happening in the Industry?

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Industry Trends and History

Although additive manufacturing technologies have been around since the 1980s, the industry experienced its greatest hype in the early 2010s, when proponents claimed the technology would find widespread use in consumer applications and at companies ranging from The Home Depot to UPS. Since the breathless hype died down a few years ago, professional 3D printing technologies have matured rapidly in many ways. Recent advances in machines, materials and software have made 3D printing accessible to a broader range of businesses, enabling more and more companies to use tools that were previously limited to a few high-tech industries. Today, professional 3D printers are accelerating innovation and supporting businesses in a variety of industries, including engineering, manufacturing, dentistry, healthcare, education, entertainment, jewellery and audiology.

Current State

According to the analysis, titled "3D Printing Market (Technologies, Materials, Applications and Geography) Global Opportunity Analysis and Forecast-2013-2020," it was projected that the market would grow to $8.6 billion by 2020. The compound annual growth rate is reported to be 20.6% between 2014 and 2020. The main reason for the increase, according to the report, is the need to more quickly and effectively produce complex designs using a variety of materials.

- In 2013, Selective Laser Sintering accounted for 33% of global market revenue. Electron Beam Melting, however, will be the process with the highest growth. It is forecast to grow at an annual rate of 26.7%.
- In materials, polymers have led the way with estimated sales of $193.3 million in 2013; however, metals are forecast to grow 40.5% annually.
- Consumer Product Industry is the largest segment at 22%. The defense sector would have the highest growth at 17.2% annually between 2014 and 2020.
- According to 2013 figures, North America dominated the 3D printing sector. 43.9% of sales were made in this region. It was followed by Europe. The Asian region is the largest growth market with an estimated annual increase of 51.9%.

Metal 3D Printing

Metals have always been at the forefront of the additive manufacturing market, and investment in the metal 3D printing market has skyrocketed in recent years. Metal 3D printing offers the ability to produce exceptionally high-performance parts in steel, titanium, nickel alloys, and aluminium with exotic geometries for demanding, high-value industries such as aerospace and medical devices. These industries are able to take full advantage of 3D printing in the production of metal parts - particularly generatively designed, highly latticed parts and other complex geometries that reduce material requirements and part weight.

Until recently, these metal 3D printers were only practical for a small set of high-value, low-volume applications due to their extraordinary cost and complexity. DMLS and SLM metal printers start at $400,000 and go well beyond $1,000,000, and they require highly skilled operators and carefully controlled environments. Unlike SLS plastic printing, laser-sintered metal parts require support

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structures. Post-processing is labour intensive, and some parts require additional machining steps to meet final requirements. There has been active investment in metal 3D printing in recent years. In 2016, GE acquired two leading metal AM companies, Concept Laser and Arcam. Several venture-funded companies, including Desktop Metal, Markforged, and Xjet, are working on new metal 3D printing processes that promise to lower the cost per part and make metal 3D printing affordable for a broader range of applications.

Desktop Metal and Markforged have developed compact, accessible systems that work similarly to FDM but use composites of metal powders bonded in a plastic matrix to shake up the market from the bottom up. After printing, the parts are cleaned and sintered in a furnace to remove the binder and fuse the metal powder into solid metal parts. With prices starting at about $100,000 for a complete system, these systems are much less expensive than traditional laser-based additive metal manufacturing systems. Desktop Metal's second, higher-end production system combines proven materials from metal injection molding with technology similar to binder jetting to jumpstart the ecosystem and significantly reduce costs. XJet's metal jetting technology suspends metal particles in a liquid and dissipates them with heat to form solid metal and ceramic parts.

While these technologies won't (yet) bring metal 3D printing to the masses, they will lead to much broader adoption of additive manufacturing across a range of low and medium-volume industries and modernize prototyping and product development processes for metal parts.

Automation and volume manufacturing

In most additive processes, labour is the most costly component. A 3D printer is not a magic box that produces a flawless part at the push of a button; technicians must remove parts from the printer and perform some degree of post-processing. This can include anything from light brushing to extensive solvent washing, heat treating, abrasive polishing and coating processes. To gain a foothold in factories, additive manufacturing systems must reduce labour and fit into existing manufacturing workflows. Workflow and technology improvements promise labour cost savings. Some dual-nozzle FDM printers offer soluble substrates that can be easily washed away in solvents. Some SLA systems simplify post-processing with automated cleaning and post-curing stations. Because plastic SLS prints do not require support structures, their post-processing workflow tends to be less labour-intensive than other processes, and more parts can also be packed into the build volume, reducing the amount of handling required per part. Metal AM manufacturers are increasingly offering modular, semi-automated systems that simplify post-processing operations, including powder handling and removal, heat treatment and part removal.

Just as computer technology shifted from mainframes to desktop PCs in the 1980s, 3D printing systems are shifting from monolithic to distributed systems. Formlabs, Stratasys, 3D Systems and Mass Portal have introduced automated, compact and modular printer cells for plastics. Robotic arms and gantry systems handle part removal to reduce operator tasks, allowing printers to run 24 hours a day for continuous production in a "lights-off" setting. Intelligent cell management software optimizes print queues, provides remote monitoring and integrates with factory CRM, ERP and MES systems. A suite of sensors detects pressure failures and protects operators. Modular systems also have the

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added benefit of redundancy - if one machine fails, the others can share the workload and continue production without interruption.

Cost-effectiveness

In many cases, 3D printing serves as an intermediate step alongside conventional manufacturing methods, also known as hybrid production. In the jewellery industry, for example, 3D printing is part of the investment casting process. jewellery makers first design a piece digitally and then 3D print it in a castable resin that can be dipped in a sand-like investment and cleanly burned away in a kiln, just like normal models made from jeweller's wax, leaving a cast for precious metals. A hybrid 3D printing process can also be used to create affordable custom earpieces. The process begins with a quick, non-intrusive digital scan of the customer's ear canal using a 3D scanner. A technician processes the digital file into a printable 3D mold and sends it wirelessly to an SLA 3D printer. After printing, the parts are cleaned and the technician pours biocompatible silicone into the molds, removes the 3D-printed shell, and finishes and coats the final product. 3D printing thus becomes an integral part of these traditionally artisanal processes, even if nothing about the final product itself is 3D printed. Industries such as dentistry, medical technology and audiology are quickly adopting 3D printing to produce final parts that fit unique patient profiles. As 3D printing becomes standard in dental offices and labs, it is increasingly being used to produce splints and dentures directly from biocompatible materials. In audiology, most custom hearing aids are already 3D printed. The broader medical market also offers enormous potential. For example, strong, biocompatible SLS parts can be used to make custom orthotics and other devices that come into contact with the skin. As costs come down, additive manufacturing will make inroads into conventional consumer products as well. In the highest-volume segments of the consumer electronics industry, for example, injection molding is still the only viable method for producing plastic parts. But in the broad mid-volume segment of the electronics industry, 3D printing has begun to make inroads. By using additive manufacturing instead of injection molding, electronics manufacturers are able to streamline product design and production, maintain flexibility and, because 3D printing does not require tooling, break even with injection molding at volumes above 10,000 pieces. Footwear companies such as Adidas are already 3D printing some parts of their high fashion product lines. The Adidas Boost 4D sole is one of the most famous examples. Again, 3D printing will be combined with other manufacturing methods, producing the most critical and customized parts of the product and leaving other parts to low-cost traditional manufacturing and fabrication processes.

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Internet of Things

Introduction

History

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When we talk about the world of the Internet of Things (IoT), giving a concise and complete definition is a substantial challenge. In general, we can say that IoT systems are sets of smart (inter-)connected devices that are also connected to a communication network providing access to the global network, i.e. the Internet, and are able to independently collect data, possibly process it, and take consequent actions, even without human intervention.

This definition will become clearer as we will make headway through the course. For the moment, we retain two fundamental points: 1. the main characters of the IoT, i.e. the smart objects together with the network, and 2. their interactions, which allows the data collected by the smart objects to go elsewhere through the network, and to undergo aggregation and processing at remote level. The latter may occur in synergy with other key technologies of the Fourth Industrial Revolution, such as big data analytics and artificial intelligence.

In certain contexts, this paradigm of automated data collection and processing is referred to using the term big data, which implies the availability of large amounts of data. IoT networks are not necessarily oriented to the production of big data, just as large amounts of information do not necessarily come from IoT networks.

The size of IoT networks can range from a single sensor or actuator up to extremely large dimensions both in terms of the number of devices and their geographical locations. Likewise, they can deal with the collection of raw data as well as the production of finer information after local processing at the level of the smart objects, in order to run simple tasks of their concern, or even, if needed, to make autonomous decisions of greater complexity.

Autonomy from human supervision for the collection of information within a particular scope is the fundamental feature shared by all IoT infrastructures in every field of application. However, this concept does not imply that IoT systems are designed to deny any interaction with humans whatsoever. Conversely, many use cases of the IoT specifically target the extrapolation and presentation of information for easier consumption on the part of humans, with the aim to abstract the tasks of complex systems and so to simplify their management. In other cases, as we shall see, humans may not be the addressees of the information, but may play the role of vehicles for the production of data obtained from devices monitoring their habits, if not also worn as wearable and, most often, smartphones, smartwatches, etc.

Giving computers the ability to sense the world

The term "Internet of Things" was first coined in 1999 by British engineer Kevin Ashton, in order to describe his original idea to couple the Internet to the network of RFID tags used to manage the supply chain of a large multinational manufacturer of consumer goods, where he was employed at that time.

His visionary reasoning started from the simple observation that practically all data processed by computers and disseminated or exchanged through the Internet until then was still originated by people. And that such a manual approach was subject to a variety of issues that are easy to imagine,

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including a high probability of errors in collection and transcription of data, long timeframes required to obtain large amounts of data, etc., which result in severe limitations on the integrity and availability of information.

Ashton also predicted that a network of sensors capable of autonomously collecting data for automatic exchange through the Internet would have held the promise to revolutionize any industrial process, by enormously expanding the reach of classical automation.

The concept imagined by Ashton did not obtain immediate practical confirmation, and several years were to pass before IoT applications came to light. Meanwhile, the gradual maturation of these applications has been stimulating the development of new technologies, devices and infrastructures that have spread across many contexts and specialized in particular areas, such as the case of home automation or the so-called Industrial IoT. Overall, it took almost twenty years for the IoT to justify its original meaning, and to penetrate so many sectors and bring so obvious advantages that it is nowadays recognized as one of the enabling technologies behind the Fourth Industrial Revolution and a pillar of its paradigm.

At the time of writing, the IoT is a mature reality that is estimated to involve tens of millions of smart devices and to enjoy outstanding growth projections. In turn, these forecasts have convinced many countries to invest in infrastructures dedicated to the development and dissemination of this technology. A representative case is that of Switzerland, which has decided to establish a network infrastructure for LoRa technology, the Swisscom Low Power Network that is able to guarantee very extensive coverage throughout the national territory, in order to ensure useful connectivity for the IoT, even in morphologically challenging environments for connection with other technologies.

Towards the Internet of Everything

The IoT is developing the power of billions of smart devices connected to a global network and able to communicate with each other over the Internet. This paradigm is highlighting the opportunities offered by the so-called "Internet ecosystem" and relevant technologies for the creation of objects capable of sensing the physical world and interacting with their local environment.

The development and integration of IoT systems via the Internet opens up new scenarios with unlimited possibilities, towards the ultimate concept of the "Internet of Everything" (IoE or maybe more often IoX).

By connecting devices, people, data and production processes, the IoX will be able to affect every aspect of our lives.

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Figure 1. A schematic representation of IoX paradigm, where machines, devices, homes, people, etc. can interact with each other through a global network. Source: Public domain by Pixabay.

As one can easily imagine, the advent of this technology is not free from controversies mainly related to a broad variety of ethical and social implications, in particular on sensitive issues, such as that of privacy. The IoT and, more, the IoX is normalizing the presence of devices capable of extrapolating information in a more or less direct and knowledgeable way from our lives and habits, often interacting with the user by offering services that may be of a commercial nature, in an extremely streamlined way. Where the line is between servicing and conditioning is a matter of current debate, and policies will need updating in order to adapt to the presence of these devices in our lives.

Further readings

- That 'Internet of Things' Thing
- Low Power Network (LoRaWAN): A highly efficient and dedicated network for the Internet of Things based on the open LoRaWAN specification

Application cases

Introduction

As already stated in the previous units, we can say that the first examples of IoT applications can be considered as smart evolutions of industrial automation systems.

Making computers conscious is the main idea at the foundation of the IoT, as a sort of automation of automatisms and, of course, the industrial sector still represents one of the most interesting, dynamic and exploited fields of application for this concept.

Nonetheless, the IoT has found application in practically each aspect of our lives. Here, without the claim of completeness, we will try to give a brief overview of the most significant ones.

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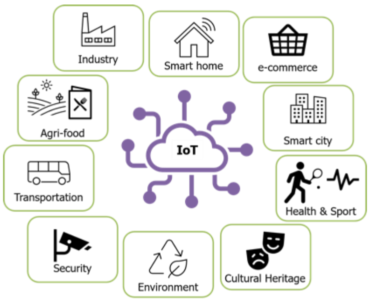

Figure 1: Main IoT applications. Source: CC BY-SA by INDEX consortium

Industry

As anticipated above, the IoT was born within the industrial sector, and here it has found its most extensive and consolidated embodiments.

Among the principal applications of the IoT in the industrial sector, we mention:

- **Production flow monitoring** - Production flow monitoring is a key process in manufacturing. The implementation of connected equipment may support the process of production flow monitoring by delivering functional insight in real-time. Sensors used in this context may serve to monitor the overall machine performance as well as specific components thereof. When machines are interconnected, data can be integrated and analyzed at the level of the entire production process, in order to manage maintenance resources supporting the production line and to optimize the timeline for repairs and adjustments, or, for instance, to schedule cleaning routines with an increase of efficiency and a reduction of downtimes. From the point of view of lot control, better insight into the production levels may guarantee that the production lots can be completed more smoothly, by eliminating overruns or shortages. Depending on the type of sensors and equipment, many adjustments can be automated to tie all these aspects of production together.
- **Stock management** - Stock management is about ordering, storing, tracking and monitoring stock levels. It can be costly and resource-intensive, and most small businesses still manage warehouses in an outdated way, for example with Excel-style spreadsheets that are prone to inaccurate operations and manual errors. IoT devices can help increase the overall warehouse efficiency by reducing manual labour, errors, and by multiplying the processing speed. Deploying an inventory management system based on the IoT improves the real-time knowledge and communication of inventory status, which may be achieved with specific sensors for detailed and itemized location monitoring. The implementation of IoT systems minimizes the need for human intervention through highly-automated devices combined with tracking scanners for item handling. The IoT and a smart warehouse management system can also help optimize the consumption of space, for instance by allocating each item according to its usage pattern inferred by using, for example, Artificial Intelligence algorithms. The IoT in inventory management also includes the use of smart shelves and storage bins that can communicate how long things have been held in a certain place and how full they are.

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- **Safety and security** - The IoT can help create safer workplaces. For instance, a network of wearable sensors to monitor heart rates, toxic gasses, or other factors impacting the safety of workers combined with an easily-accessible mobile information hub allows local processing and monitoring of data by both remote operators and the workers themselves. As practical examples, we mention some prototypes of smart helmets for construction workers (see e.g. https://doi.org/10.3390/s20216241 or https://doi.org/10.1002/itl2.86), which are equipped with sensors to monitor the temperature and heart rate of their wearers, or the outside temperature and humidity. By connecting workers to their environments, factories can improve the safety of workplaces.

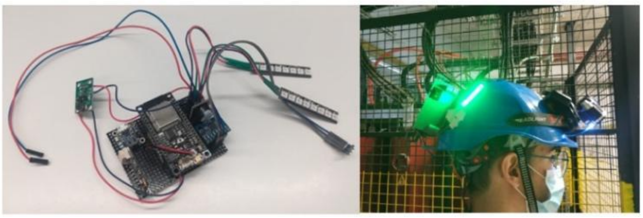

Figure 1: An example of a smart helmet. Source: CC BY-SA by Sensors 2020, 20, 6241

Quality control - Networks of IoT sensors may help gather data 24/7 along the entire production line, thus giving manufacturers the opportunity to enjoy unprecedented control over their operations and product outputs. Indeed, quality managers can instantly detect off-spec conditions in the midst of running equipment and processes, thus intercepting defects at an earlier stage of production and thus reducing relevant costs and waste. Developing quality control models based on all data collected by an IoT system can further optimize all properties of the production line, since such models allow machine operations to automatically adapt to undesired fluctuations in variables like environmental conditions, and to autonomously intervene in the production process.

More details about the applications of the IoT in the industrial sector, such as the description of the underlying Cyber Physical Systems and the concepts of Predictive Maintenance will be tackled in the next section.

Retail and e-Commerce

IoT applications in commerce are now there for everyone to see, not only for the smart management of warehouses and the distribution of goods allowing for ultra-fast deliveries, but also as regards the pervasiveness and personalization of the shopping experience for consumers.
As we have illustrated in the historical introduction, the IoT was born to optimize the control over the flow and storage of goods, therefore essentially for the smart management of stocks not only at manufacturing level but also for retail. Over time, this approach has led to the birth of a genuinely new way of trading goods centered on a smart management of products as its major strength, as the great giants of electronic commerce show us.

The ability to collect more and more personal customer data, as well as data on customer behaviour in stores, has brought a real breakthrough in the field of tailored advertising based on inputs derived from their geographical positions, previous purchases, monitored activities of various kinds, etc. As an example, we mention the introduction of the so-called dash buttons, which are now already conceptually outdated, but have helped people get a sense of the penetration of the IoT in their daily lives or IoT-enabled motion sensors installed in shopping carts or baskets to determine customer movements around a store, i.e. stats like which aisles they go to and which ones they skip, what shelves they stop near and how long they look at the products for, etc. All these sensors transmit information to centralized cloud systems for marketing analysis, which help specialists create more efficient merchandising strategies or to optimize the physical layout of stores. The IoT in stores is also represented by the automation of the shopping processes, not only by automated checkouts and interactive kiosks that are already present in the main large retail chains, but also by new concepts like the Amazon Go chain of supermarkets (see the following video), where there are no lines and no checkouts at all. People take goods and the payment is processed automatically with the help of sensors, cameras and smart weighing devices that integrate with smartphones.

Introducing Amazon Go and the world's most advanced shopping technology

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Automotive and transportation

In the field of automotive and, more generally , transportation, the IoT is present on several levels.

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First of all, as regards the management of the vehicle, which represents a small world on its own, and a very complex one indeed, to control. Onboard a car, a train, an airplane, but also a simpler means of transportation like an electric bike, there are a large number of sensors and actuators interconnected to monitor and adjust parameters associated to different functions. Examples include the efficient management of the engine and consumption of energy or fuel, the durability and safety of the vehicle through fault prediction and scheduled maintenance, as well as monitoring the surrounding environment and communication routes for safety reasons, up to the comfort of passengers. Moreover, all these data can be exploited to monitor the behaviour of the driver and affect, for instance, car insurance premiums. Some insurers today routinely offer the option to install a small telematic device into a diagnostic port of the vehicle to record data such as speed, distance travelled, time of day and the rate of acceleration and braking. By analyzing this data, the insurer can determine the behaviour of the driver and adjust the premium accordingly. These types of devices may also promote a safer driving style.

As an example, we have added, at the end of this sub-unit, a link to a YouTube video, which reports on an innovative platform for automated driving in all environmental conditions, which has been developed in the framework of the European project, RobustSENSE.

In the context of transportation, the IoT also intervenes at a higher and more extensive level as regards the management of traffic and, more in general, communication routes, as will be explained in more detail in the paragraph on smart cities. These applications often rely on aggregate information in the form of big data coming not only from sensors onboard the vehicles but also from mobile devices like smartphones.

An example of the latter case is that of the Wecity application (visit https://maps.wecity.it and directly ask for information). Through voluntary tracking of the movements of users, this application has made it possible to create databases available to local administrators for different scopes, such as to understand the flows of bicycle mobility within cities and plan related interventions, but also to indirectly monitor the safety of roads and the state of their pavement by recording geo-localized information from accelerometric sensors embedded in mobile devices like smartphones. Similar information, although designed for interurban roads, was used in the SmartRoadSense project, where smartphones were exploited as remote loggers onboard cars. Another example is the CROWD4ROADS project, which combines trip sharing and crowd sensing initiatives to harness collective intelligence and contribute to the sustainability of road passenger transport by increasing the car occupancy rate and by engaging drivers and passengers in road monitoring.

RobustSENSE project animation

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Exercise

The following video reports the field-testing phase of the European project entitled FABULOS (Future Automated Bus Urban Level Operation Systems). The aim of the project was to study how cities can exploit automated buses in a systematic way to integrate autonomous lines as part of a public transportation system. In Helsinki, a fleet of three self-driving vehicles began operating on April 14, 2020. The fleet was supported by an on-demand mobile app and a Remote Control Centre. Vehicles ran along a circular route in Eastern Pasila, over a dedicated lane with speeds up to 40 km/h. The route included crossroads with traffic lights, right turns, street-side parking slots, and even a roundabout. For more details about this pilot, visit https://fabulos.eu/helsinki-pilot/

FABULOS - Bringing the robot buses to the streets of Helsinki

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Question

After reading the example above, which of the following statements is false?

☐ Robot buses can be integrated into the public transport network covering, for instance, the last mile from a bus stop to a train station

☐ Robot buses, thanks to the use of sensors, such as laser scanners, visible-light cameras, thermal imagers, high-precision satellite navigation and inertial measurements, are able to autonomously move along routes that may include crossroads with traffic lights, right turns, street-side parking slots or roundabouts

☐ Robot buses need dedicated and closed lanes

☐ Projects like FABULOS may help increase the awareness in public authorities about the potential to include autonomous vehicles in public transport systems

Smart homes

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The houses where we live, and the objects that we use every day within them, certainly represent one of the most obvious examples of the pervasiveness of the IoT in our lives.

The refrigerator that monitors the conservation status of the food that it contains, or the house that turns on the heat when the owner returns, are small miracles in home automation that have made the environment where we live smart, and that have become reality thanks to the integration of IoT technologies.

Figure 1: An example of a smart thermostat. Source: CC BY-SA by INDEX consortium

However, the most important applications of the IoT in home automation applications are not limited to the implementation of household tasks like toggling lights and appliances, but also allow for better, more efficient and more sustainable management of homes, by optimizing energy consumption and comfort.

Most of the gas, water and energy distribution companies are already adopting electronic meters capable of measuring and monitoring consumption, not only for billing purposes, but also to plan interventions on their distribution networks and to control the supply of distributed resources. These are just a few examples in the broad context of what is called smart metering.

In addition, there are voice assistants in our homes that are becoming more and more widespread and offer the possibility of directly interacting with objects and services, even at remote level, thanks to the synergy between IoT and Artificial Intelligence technologies, such as the best known of these, Alexa and Home services produced by the giants Amazon and Google.

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Figure 2: An example of a voice assistant. Source: CC BY-SA by INDEX consortium

Smart cities

If home automation can be considered as our private IoT domain, smart cities represent the application of the IoT at societal level.

As defined by the Smart Cities Council, *A smart city uses information and communications technology (ICT) to enhance its liability, workability and sustainability. First, a smart city collects information about itself through sensors, other devices and existing systems. Next, it communicates that data using wired or wireless networks. Thirdly, it analyses that data to understand what's happening now and what's likely to happen next.*

In this framework, one of most relevant current applications is that related to **traffic management**. For example, the combined analysis of data collected from sensors installed in traffic lights, car parks or other fixed infrastructures with those originating from personal mobility and obtained through web applications installed on smartphones, may help manage and reduce traffic jams, by e.g. tailoring and synchronizing the timing of traffic lights or speed limits. Here, you can find an example of a pilot experiment for smart traffic control in Pittsburgh, USA.

Figure 1: A variable speed limit sign. Source: from Kcida10 at English Wikipedia Public domain work of art.

The information deriving from individual users may also trigger an immediate feedback designed to condition their personal choices, such as recommendations for alternative routes displayed through

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connected navigation applications like Google maps or Waze, and based on real-time traffic monitoring obtained by the analysis of thousands of active mobile devices present on the ground.

The IoT may not only help reduce traffic, but also improve air quality and contribute to **pollution control**. The advent of new sensors for air quality, which are smaller, connected and much less expensive than their former generations, is allowing an increase of data resolution and a prompt communication of the levels of pollutants through the IoT. These sensors may also be mounted on moving objects, such as cars, shared bikes or municipal trucks, and so enhance the overall knowledge of air quality over time and space. Once an air quality sensor network is in place, the collected data may help create pollution maps by using predictive analytics. In turn, these maps may be used to implement real-time countermeasures, such as traffic diversions intended to reduce the local concentration of air pollutants. Once integrated with traffic management systems, these solutions may contribute to pollution control by dynamically offering, or even enforcing, alternate routes when predefined safety thresholds are exceeded. Here, you can find a practical example of an IoT system running in Coventry, UK. The City Council deployed a network of air quality sensors in specific areas where the levels of pollutants tended to be problematic. As soon as predefined safety levels are breached, the sensors automatically send alerts to the Urban Traffic Management Centre, where they automatically trigger variable-message signs for motorists and the general public around the city. The City Council is using messages to suggest drivers and pedestrians entering areas with high levels of air pollution to consider alternative routes. In the future, this system may be modified to automatically limit the number of vehicles in polluted areas, instead of merely suggesting alternative routes.

In smart cities, the IoT can be integrated with other existing infrastructures or merged with complementary technologies for specific purposes, such as safety and security. As an example, in 2020, during the COVID-19 outbreak, some cities exploited video surveillance systems as sensors able to automatically detect the social distance among people in a crowd, thanks to the analysis of images from security cameras with Artificial Intelligence algorithms.

Figure 2: People detection, tracking, and risk assessment in Oxford Town Centre, by using a public CCTV camera. (a) Social distancing monitoring; (b) Accumulated infection risk (red zones), due to breaches of social distancing rules. Source: From Appl. Sci. 2020, 10, 7514 CC BY-SA by Appl. Sci. 2020, 10, 7514.

Finally, sensor networks in urban environments are also used to monitor structural parameters of buildings, such as bridges, communication infrastructures and cultural heritage sites.

Healthcare, sport and wellness

The IoT is also making a high impact on healthcare, sport and wellness.

In the field of healthcare, the hope is that IoT technologies will help move some routine medical checks from hospitals to homes, thus reducing the need for hospitalization. Below is a short and non-exhaustive list of current applications of the IoT for healthcare:

Remote Medical Assistance: this is probably the most popular use of the IoT in healthcare, which exploits connected devices to monitor patients in their own homes. Smart devices acquire parameters like blood pressure, oxygen and blood sugar levels, weight, or observe behavioural patterns, and alert medical professionals in the case of outliers. This approach is particularly suitable for patients suffering from long term or chronic conditions, elderly patients, or post-disease follow-ups. This video demonstrates a practical example.

Smart Glucose Monitoring: diabetes is a chronic disease that affects about one in ten adults, and can require continuous monitoring and treatment. New devices such as Continuous Glucose Monitors or Smart Insulin Pens can improve the quality of life of diabetic patients. Continuous Glucose Monitors are small and connected devices that continuously monitor glucose levels over day and night. Data are wirelessly transmitted to a web service and allow for remote monitoring by a healthcare team. Smart Insulin Pens automatically record the time, amount, and type of insulin dosage, and store long-term data.

Smart Inhalers: chronic obstructive pulmonary diseases affect over 200 million people worldwide. Smart inhalers integrate connectivity with a mobile app, via Bluetooth, for instance. These devices are built-in with a sensor technology that helps record the data about time and location of the patients at each use. Smart inhalers can help patients understand what may trigger their symptoms, track their use of medication, and also predict allergic attacks. This video is about the announcement of the first FDA-approved smart inhaler.

Hospital Operations: The IoT has proved to be particularly useful for cutting unnecessary costs and optimizing daily functions in medical facilities. As an example, millions of euros are lost per year due to lost or stolen equipment, which has a real knock-on effect when it comes to patient treatment and resources. Attaching sensors to critical equipment allows for its real-time tracking, which does not only reduce loss or theft, but also provides valuable data about the overall use of available means. And by tracking usage, administrators can more knowledgeably understand when to plan for a replacement or to perform maintenance, thus avoiding equipment downtimes, which equipment is underused or, on the contrary, which one needs to be multiplied.

Research: The IoT gives access to an extraordinary amount of valuable data and information, thus yielding better solutions to known issues and disclosures of hidden problems. The quantitative analysis of biomedical images, also referred to as radiomics, represents an example of the application of Artificial Intelligence and IoT tools in the context of precision oncology, which provides valuable information on the features or mutations of malignant lesions, and on the personalization of their treatments. For more insight into radiomics, read this article from the INDEX website.

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The IoT is also revolutionizing the domain of sport, both for those who practice and those who provides assistance, especially at professional level. Among the most fascinating cases, we mention:

- smart helmets that can help diagnose concussions in American football players;
- wearable sensors for monitoring the physiological and biochemical profiles of athletes;
- the goal-line technology in football.

Figure 1: a fitbit, an example of wearable devices for monitoring workout activities. Source: CC BY-SA by INDEX consortium.

IoT devices play a fundamental role in protecting the health of athletes and in preventing the risk of injuries, especially in risky, contact or racing sports. A player who is hit or falls to the ground, for instance, and makes use of a smart helmet measuring the extent of the shock and transferring information to the coach and staff, may immediately undergo medical assistance or substitution. Recently, FIA introduced a new race glove capable of monitoring the heart rate of pilots and the amount of oxygen in their blood. In the event of an accident, the sensors inserted inside these gloves are able to communicate physical data and physiological parameters to the medical car and safety team, in order to plan vital operations for rescue and extraction from the cockpit. Furthermore, the use of wearable sensors, combined with predictive data analysis models, allows for the development of personalized risk profiles. The main advantage of tech, in this case, is to offer an overview that is not affected by subjective or emotional considerations, such as a player who wishes to be on the pitch

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even if not in top condition. In this case, a more objective analysis including the history of previous injuries and the results of standardized screening tests may help the team manager make a more knowledgeable decision.

Likewise, data allow for the optimization of performance not only at professional level, but also for amateurs, thanks to the development of more and more integrated, small and smart sensors inside any type of wearable object, from watches to jackets, which are already available for anyone who wishes to keep their fitness levels under control. Here are some examples:

- trackers that not only measure daily activity with pedometers, stopwatches and timers, but also help improve sleep quality, and consequently health in general, by analyzing the pulse rate to estimate the hours of sleep per night and even how many of these hours relate to deep or light sleep;
- smartwatches able to monitor and record training sessions without interruption;
- shoes equipped with sensors and accelerometers able to establish when the body is ready for running;
- helmets with integrated GPS trackers.

Agriculture

Among the fields where the technological push of the IoT has become predominant, we must include the agricultural sector. Precision Agriculture and Internet of Farming constitute the core of the so-called Agriculture 4.0, i.e. the whole set of tools and strategies that allow all farms to use advanced technologies in a synergistic and interconnected way with the aim of making agricultural production more efficient and sustainable.

The need for a strong push along these directions arises from the increase of the global population and from the ever higher demand for high-quality food. In this framework, there are two main needs in agriculture:

- to increase the production in absolute terms, due to an increasing demand, and this with the lowest possible environmental impact;
- to maintain high production levels with greater efficiency in the use of production factors and, therefore, a lower environmental impact, both in terms of the emission of greenhouse gases and the consumption of nutrients and natural resources.

In any case, these requirements translate into an increase in the efficiency of the use of production factors, which is the realm of Precision Agriculture as the most important tool available today. A strategic management based on Precision Agriculture allows the farmer to plan, according to the spatial variability of the fields, any single agronomic intervention, from soil preparation to sowing, fertilization, irrigation, protection and harvesting of crops. Precision Agriculture can use different and heterogeneous information layers such as: - images of the fields acquired through satellites or drones through multispectral cameras; - high-precision positioning systems; - networks of smart sensors on plants or on the ground for real-time or semi-real-time monitoring of the crops; - information from weather stations and multi-day forecasts; - etc. The data collected by the sensor networks is sent to an online server, and also processed through the use of simulation models that help predict the growth of plants, their irrigation needs and the control of pathogens in the field. It is at this point that the DSS (Decision Support System) that guides the farmer for the ordinary management of the business comes into play.

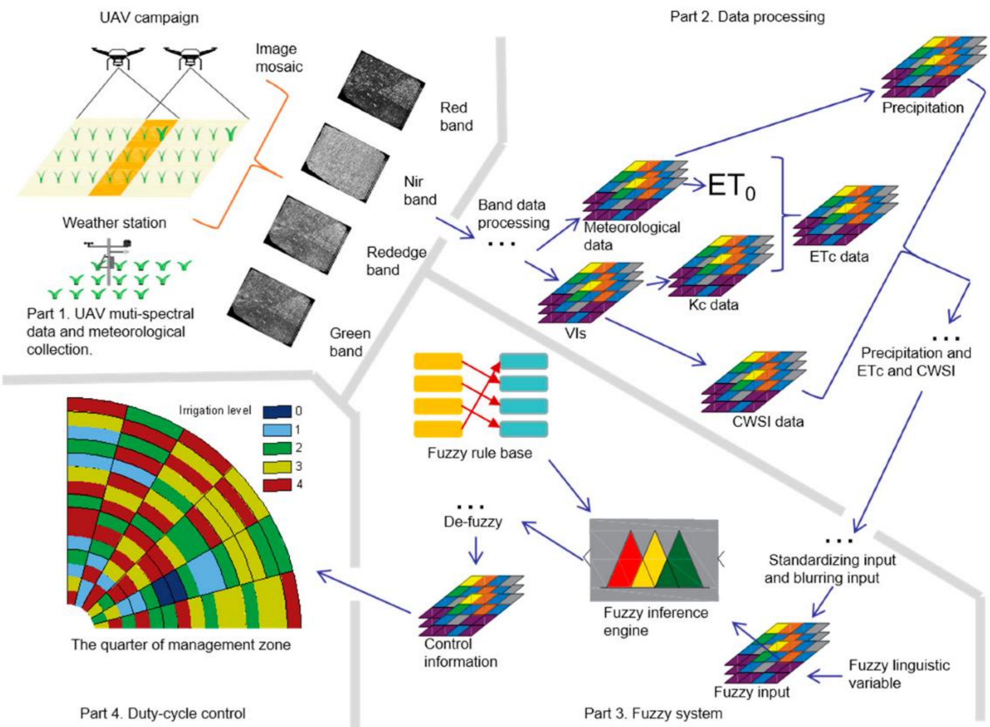

Figure 1: Schematic representation of a Decision Support System for Variable Rate Irrigation (DSS-VRI). The DSS-VRI operational procedures include four parts: Part 1 is to provide Unmanned Aerial Vehicle (UAV) multispectral images and meteorological data as input. Part 2 processes and selects data from Part 1, and figures out the crop evapotranspiration model (ETc), the Crop Water Stress Index (CWSI) and precipitation. The data input to a fuzzy system. Part 3 shows the work flow of the fuzzy system. Part 4 depicts the duty-cycle control map for a partial management zone. Source: From Sensors 2019, 19(13), 2880 CC BY-SA by Sensors 2019, 19(13), 2880.

Industrial Internet of Things

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From industrial automation to Industrial IoT

The Industrial Internet of Things (IIoT) is the term used to identify a specific branch of the IoT, when applied in the industrial context.

One may think of the IIoT as a trendy way to refer to industrial automation, but, as we will see in the following, this is not true. The IIoT is rather a consequence of industrial automation, sort of a smart evolution thereof, which involves radical innovations like predictive maintenance and smart manufacturing.

The main goal of the IIoT is in fact the optimization of the production processes achieved by the remote monitoring of connected machines. That is a substantial upgrade with respect to the simple interconnection of machines realized by industrial automation.

Automation

A dictionary definition of automation says that it is the use or introduction of automatic equipment in a manufacturing or other process or facility. Despite the fact that nowadays this concept is obvious to everyone, it was not so clear when industrial automation was born, and when it started to give way to the IIoT.

Some sort of primordial automation, or better put, of automatism, had already appeared in manufacturing processes in the XVII century, but the modern concept of automation was introduced between the second and third Industrial Revolutions, thanks to the invention of a series of enabling technologies (see the introductory part of this course for a historical explanation).

A modern instance of industrial automation arrived with the introduction of PLCs (Programmable Logic Controllers), between the '60s and '70s in the last century, which are field computers that are able to read sensors and drive actuators with the aim of managing processes without continuous human monitoring. PLCs dominated the field of industrial automation for decades, prompted the development of an entire ecosystem made of standards, protocols, regulations, etc., and ultimately determined the success of the companies that provided their introduction and commercialization, like SIEMENS.

These types of systems operate in the field of the so-called M2M (Machine To Machine) communication, by using wired, or more rarely wireless, connectivity in order to exchange point-to-point messages among sensors, actuators and embedded hardware modules running dedicated control applications. M2M typically makes use of proprietary standards and protocols for communication among devices of the same type and designed for a particular application. Therefore, M2M is often implemented in closed systems, meaning that the data generated within the network cannot be shared with other equipment, nor be reused for purposes different from the intended workflow.

The introduction of PLCs in the production processes led to the concept of SCADA (Supervisory Control And Data Acquisition), which is a system of software and hardware components intended to manage a complex industrial organization. SCADA has been the real link between industrial automation and the IIoT.

Figure 1: An example of M2M automation process. Source: CC BY-SA by INDEX consortium.

IIoT

IIoT systems capitalize on the advantages of IoT technologies to bring the digital enterprise from industrial automation to a higher level.

The connection to the Internet is the key for IIoT systems to enable such abilities as the possibility to share data across an enterprise, in order to obtain better business intelligence and so to better manage operations. With this paradigm, the control process has become open, scalable, multi-functional and prone to the implementation of new models and technologies. In this sense, we can say that the IIoT is sort of a long-term evolutionary control system. IIoT technologies allow the integration of data from devices and sensors with concepts of big data analytics, and with external applications, with a focus on the achievement of improvements in specific operations and on the development of information products as web services targeting enterprise-wide objectives.

The IIoT is enabled by recent advances in technologies like cyber-physical systems, cloud computing, edge computing, mobile technologies, big data analytics, artificial intelligence, machine learning and many others.

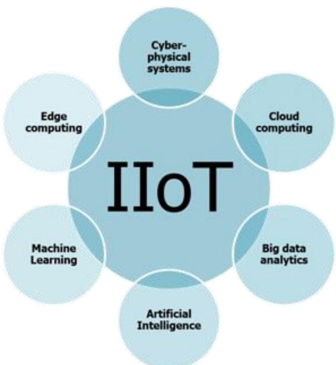

Figure 2: IIoT key technologies. Source: CC BY-SA by INDEX consortium.

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A brief description of the main ones is given below:

- Cyber-physical systems (CPSs): the basic technological platform for the IoT and the IIoT, and therefore the main enabler to connect physical machines that were otherwise previously disconnected. CPSs integrate the domains of physical processes with those of software and communication, thus bringing up abstraction and modeling, design, as well as analytical techniques.
- Cloud computing: with cloud computing, IT services and resources can be uploaded to and retrieved from the Internet, as opposed to a direct connection to a local server. Files can be kept on cloud-based storage systems, rather than on local storage devices.
- Edge computing: A distributed computational paradigm that brings data storage and processing closer to the location where it is needed. In contrast to cloud computing, edge computing refers to a decentralized implementation of data processing at the periphery of the network. The IIoT requires more of an edge-plus-cloud architecture, rather than one based on a purely centralized cloud, in order to transform productivity, products and services.
- Big data analytics: Big data analytics is the process of examining large and heterogeneous data sets, which are often referred to as big data.
- Artificial Intelligence (AI) and Machine Learning (ML): AI is a lively field of computer science and other disciplines, where intelligent machines are created that work and react like humans. ML is a core part of AI, by allowing software to discover patterns and predict outcomes by learning from training, without explicitly being programmed.

The development of the IIoT has paved the way for the integration of Information Technology (IT) systems used to manage business processes for an enterprise with Operational Technology (OT) platforms used to monitor and control the physical equipment and the industrial processes. This integration, often referred to as the IT/OT convergence, is believed to enhance the overall performance of the enterprise, by creating the perspective of the so-called Smart Enterprise Control. In practice, the IIoT makes the IT/OT convergence possible because of its ability to share data gathered by the OT platforms with the IT systems via the Internet, which is sent to the cloud and fed to analytical tools to derive knowledge for better decision-making. Smart Enterprise Control is the tight integration of smart connected machines and smart connected manufacturing assets within the wider enterprise.

A final comparison

Classic M2M automation and the IIoT share the same roots and a similar way of working: they interconnect different devices, whether they include sensors or actuators, into an industrial control system, in order to achieve a tangible result or output. The goal of these two approaches is the main difference, though, while industrial automation just aims to make specific tasks in a production chain to be independent from human intervention, the domain of the IIoT is the optimization of the processes of the plant. This entails practical differences in the implementation of these two paradigms.

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In practice, M2M deals with communication between two or more machines and is therefore intrinsically a closed system. The M2M approach to automation is hardly expansible and not scalable both in terms of size and functionality, such as the kind of harvested data, processed information and so on. On the other hand, the IIoT concept, by inheriting the architectures and principles of the IoT, enjoys much more flexibility in terms of the possibility to expand the overall infrastructure and its individual features.

Another key difference relates to the interconnection with the external world: M2M is closed, again, while the IIoT is, by definition, connected through the Internet. This difference is as obvious as important, and implies that M2M cannot benefit from the broader services, analytics, and applications that are typical components of the IIoT.

In the end, we conclude by saying that M2M and, in general, industrial automation is an inflexible approach dedicated to a specific task, complex though it is, while the IIoT is a more general-purpose and flexible infrastructure that allows a more easy integration of new services.

Building blocks

In this unit we provide an overview of the most important building blocks found in an IIoT infrastructure. Obviously, this document does not pretend to be exhaustive, particularly because the IIoT is an extremely rapidly evolving world. The goal is to give an idea of the state of the art of this technology, starting from the edge, i.e. the *Things*, up to the *Internet*.

Things

Despite the obviousness of the presence of the things in an IoT infrastructure, this class of elements is not so easy to describe in an industrial setting, simply because it includes a broad variety of devices specifically designed to work in a specific context. At a high level of abstraction, we can simply say that the things are devices that are able to sense properties or to actuate functions for the process of industrial control, system, machinery, or other ancillary equipment. The things are located on the edge of the IIoT infrastructure, and produce or consume the data collected through the Internet and managed by the control part of the IIoT system. In the IIoT, more than in other IoT scenarios, the things may feature more or less complex computational capabilities. In some cases, they may collect huge amounts of raw data and process them, in order to forward to the cloud only the useful information wanted therefrom.

Things are connected to each other and / or to the IIoT infrastructure through wired or wireless links and use standardized buses. Communication occurs with standard protocols, such as e.g. serial communication (RS232, RS422 and RS485), DeviceNet, ControlNet, Modbus, ModBus-TCP, FieldBus, Profibus, EtherNet/IPTM, EtherCAT, Profinet, PowerLink, and Sercos III.

Networking devices

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This class includes devices like gateways and other hardware and software components that collectively hold the network infrastructure up.

The main purpose of these devices is to connect the things to the Internet. They perform connectivity consolidation by taking device data of different communication protocols and translating them into a single protocol before forwarding them upstream. More advanced devices support storage and computation, and perform some elaboration in order to optimize the amount of data transferred to the cloud.

Apps, analytics and services

This last category includes all the technologies that work at cloud level. This class includes devices, software, protocols and, more generally speaking, systems aimed at data and information management.

Data management systems handle the essential functions of data acquisition, validation, storage, and provide for the availability of critical information. IIoT systems use a broad variety of devices for data generation, and thus IIoT data are heterogeneous, by spanning multiple temporal, spatial, polymorphic, and proprietary data types.

Data then need elaboration procedures. A first and intuitive elaboration step is that performed with analytics, i.e. a set of techniques that use specific tools to obtain insights and actionable operational intelligence from the data gathered from the connected devices. Even though a part of analytics can be performed on the edge, especially for real-time decisions, the greatest part is performed via batch analysis. Analytics can be behavioural , descriptive, predictive, or prescriptive. Visualization solutions include dashboards, alerts, events, maps, and other tools to present data to a human end-user in an easily comprehensible format. Analyzing data from operational technology can provide insights for reducing maintenance costs, obtaining predictive failure analyses, and implementing overall improvement strategies for business operations.

A more general-purpose elaboration place is represented by an IIoT service, often also referred to as **IoT platform**. IoT platforms will be explained in more detail in the intermediate level of the IoT course. Here, for the purpose of this introduction, it is enough to understand that they represent the place where sensors and actuators are connected by a decision-making system. Data and their flows are made available for any kind of computational step and for the management of the entire network. Usually, platforms make use of a framework where several tools are available to the network owner or maintainer. These frameworks are often available online as SAAS (Software As A Service), and involve the use of other Industry 4.0 technologies like *big data analytics* and *artificial intelligence*, in order to handle and make the most out of huge amounts of data.

Business level

Finally, just a couple of words about an often-neglected aspect of the IIoT infrastructure represented

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by the business processes, i.e. a series of activities within an enterprise that lead to the achievement of specific goals. The IIoT enables business processes by acquiring very detailed data about real-time operations and making them available to the IT system of the enterprise in a timely manner. The result is better business intelligence and more informed decision-making processes.

Exercise

According to Wikipedia, *cobots* are collaborative robots intended for direct interaction with humans within a shared space, or where humans and robots are in close proximity. *Cobots* contrast with traditional industrial robots, which are isolated from humans. The safety of *cobots* may rely on the use of lightweight construction materials, rounded edges, and inherent limitations on speed and force, as well as on sensors and software that ensures safe behaviour.

Figure 1. An example of a cobot. Source: CC BY-SA by aimler und benz Stiftung, via Wikimedia Commons.

Question

Cobots can be part of an IIoT system. What kind of building block best matches their role?

☐ They are Things, although a very complex example thereof
☐ They are Network Devices, on behalf of their vocation to collaborate with their peers
☐ They belong to the domain of Apps, Analytics and Services, on account of their core IT-basedness
☐ They operate at Business Level together with human executives

Architecture

An IoT architecture represents the various layers of technologies and their functionalities in an IIoT system, and illustrates how they relate to each other.

There are two types of IoT architectures: reference and applied.

A reference architecture is a set of guidelines for developing an applied IIoT architecture, with respect to system objectives, design principles, and desired elements.

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An applied architecture is a blueprint for the development of an actual system.

To develop a model for a reference architecture, one needs to first establish the overall system objectives and design principles. Design principles supporting the overall system objectives include, but are not limited to:

- provide services across different business domains of the wider enterprise;
- ensure trust, security, and privacy;
- ensure scalability, performances and integration;
- be capable of complying with different service delivery models;
- life-cycle support.

From a structural point of view, an IIoT architecture is usually conceived as a stack of layers of digital technologies.

These layers are:

- Device Layer, which refers to the physical components like CPSs, sensors, actuators and machines;
- Network Layer, which concerns all technologies involved in communication inside an IIoT system, like the physical network buses, protocols used to aggregate and transport data, cloud storage and computation;
- Service Layer, which consists of applications that translate data into information that can be displayed on a driver dashboard. This layer is basically represented by the IIoT platforms;
- Content Layer represented by the (human) user interfaces to the overall system.

A standard benchmark for the IIoT reference architecture is the IIRA (Industrial Internet Reference Architecture) produced by the Industrial Internet Consortium (IIC), which is an open membership organization born to accelerate the development, adoption and widespread use of interconnected machines and devices and intelligent analytics, and to catalyze and coordinate the priorities and enabling technologies of the Industrial Internet, including the IIoT.

The IIRA establishes definitions at the highest level and a well-defined set of vocabulary entries for use in the design of IIoT architectures. The document presents a core set of standards and a common ground for IoT participants to frame the development, documentation, communication and deployment of industrial applications.

Exercise

According to the document published by IIRA at https://www.iiconsortium.org/pdf/IIRA-v1.9.pdf, a reference architecture for the IIoT may be formulated according to multiple viewpoints. Which of the following statements is wrong?

☐ System engineers and product managers are the principal holders of a so-called business viewpoint focusing on the contextualization of the platform in terms of commercial and regulatory aspects.

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☐ The most important viewpoints focus on business, usage, functions and implementation of the system.

☐ The so-called functional and implementation viewpoints are of concern to a similar group of stakeholders made of component architects, developers and integrators.

☐ The so-called usage viewpoint may be represented as a sequence of activities that lead the planned functionalities to fulfil the desired capabilities of the system.

Security

Introduction

Before starting to talk about security in IoT applications, we need to define the exact meaning of the word:

Security is the capability to protect something of value, whether it be a material asset, an immaterial service, a financial resource, information, or data in general.

In order to implement an appropriate level of security, as well as to undertake adequate measures for its maintenance and improvement, it is vital to understand what risks the asset of interest may be exposed to.

For data, for example, the main risks relate to threats to three main aspects:

- Confidentiality: to make sure that the data or services to be protected are not accessible to unauthorized entities;
- Integrity: to make sure that the data or services to be protected are not compromised at any point of their entire lifecycle, from creation to consumption, including their processing and communication;
- Accessibility: to make sure that the data or services to be protected are available whenever needed.

Therefore, it is necessary to develop a specific security process to protect the data, services or devices involved in an IoT system from the beginning of its design, by following the next steps:

- identify the value of the data or services to be protected;
- identify the weaknesses of the data or services and the threats to their confidentiality, integrity and accessibility;
- plan a strategy to mitigate the risk, by implementing an appropriate level of security;

- Implement the best solution possible according to a careful security analysis.

Types of attacks

In this unit, we list the main security threats of concern in IoT, according to the inventory of ENISA - The European Union Agency for Cybersecurity (Baseline Security Recommendations for IoT in the context of Critical Information Infrastructures - November 2017). For the most part, attacks relate to devices that have been violated or to systems that have been compromised.
In the following list, we briefly outline the most common categories that constitute the threat taxonomy of relevance in IoT.

1. Nefarious activities / abuses. This category includes:

- Malwares: software intentionally designed to execute unwanted and unauthorized actions on a system, resulting in damage or information theft. Their impact can be high and can affect any kind of device;
- Exploit Kits: collections of exploits, i.e. pieces of software, codes, or sequences of commands that take advantage of a bug or vulnerability to gain access to a system and cause unintended behaviour. In IoT environments, the impact of this threat ranges from high to crucial, depending on the assets under attack, i.e. single IoT devices, other IoT Ecosystem devices or the overall IoT infrastructure;
- Targeted Attacks: targeted attacks are a type of threat that actively pursues and compromises a targeted infrastructure while maintaining anonymity for as long as possible, in order to obtain as much sensitive data or control as possible. While the impact of this threat is medium, detecting its presence may be difficult. Targeted attacks usually affect infrastructure, platform and backend, and information;
- Distributed Denial-of-Service attacks (DDoSs): an attempt to make an online service unavailable by overwhelming it with traffic from multiple sources, such as a large number of IoT devices. DDoSs can be pursued by making many connections, thus flooding a communication channel, or by replaying the same communication over and over. This kind of attacks can affect IoT devices, other IoT Ecosystem devices, as well as platform & backend, and infrastructure systems;
- Counterfeits by Malicious Devices: these devices usually have backdoors, and can be used to direct attacks on other ICT systems in the network. This kind of threat is difficult to discover, as a counterfeiter cannot be easily distinguished from the original, and it can affect IoT devices, other IoT Ecosystem devices, and the overall infrastructure;
- Attacks on Privacy: both on the privacy of a single user and the exposure of any element of the network to unauthorized agents;
- Modification of Information: to manipulate the information in order to cause chaos, or often acquire economic gains.

2. Eavesdropping / Interception / Hijacking. This category includes:

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- Man-in-the-middle Attacks (MITM): active eavesdropping attack, where the attacker secretly relays and possibly alters messages exchanged from one victim to another, while making them believe that they are directly communicating with each other. These kind of threats can affect information, communications, and IoT devices;
- IoT Communication Protocol Hijacking: it takes advantage of the ability to take control of an existing communication session, and then it makes use of aggressive techniques like forcing disconnection or resetting, in order to sniff sensible information, notably including passwords. Also, this threat can affect information, communications, and IoT devices;
- Interception of information: it happens when some unauthorized party has gained access to a private communication, such as a phone call, instant messages, e-mails, etc.;
- Network Reconnaissance: it occurs when attackers passively gather information on potential vulnerabilities of a network. From examining email lists to open source information, they can get details about connected devices, used protocols, open ports, services in use, etc. These kind of activities are a threat for the security of information, communications, IoT devices and Infrastructures;
- Session Hijacking: during session hijacking, the attacker aims to steal, modify or delete transmitted data by pretending to act as a legitimate host. These kind of attacks are a threat for information, communications and IoT devices.
- Information Gathering: this is another case where the goal is to passively obtain internal information about a network, such as connected devices or used protocols;
- Replay of Messages: this is an attack on a security protocol or targeted device that uses a valid communication for malicious purposes, by repeatedly resending or delaying it, in order to manipulate or crash the target.

3. Outages. This category includes:
- Network Outages: any interruption or failure in the network service, either intentional or accidental;
- Failure of System: threat or failure of specific software services or applications;
- Loss of Support Services: unavailability of support services required for proper operation of the information system.

4. Damage / Loss (IT Assets). This category includes:
- Data / Sensitive Information Leakages: it occurs when sensitive data are unintentionally revealed due to poor data security practices or accidental actions or inactions taken by an individual;
- Data Breach: it occurs when sensitive data are copied, transmitted, viewed, stolen or otherwise used by unauthorized parties.

5. Failures / Malfunctions. This category includes:
- Software Vulnerabilities: these are weaknesses that can be exploited by a threat actor. In the context of IoT, the most common vulnerabilities are due to the use of weak or default passwords, software bugs and configuration errors, which may pose a risk to the overall network. This threat is usually connected to others, such as exploit kits, and is regarded as a key factor to consider with care.

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- Third Parties Failures: errors on an active element of the network caused by the misconfiguration of another element that has a direct relation to the former.

6. Disasters. This category includes:
- Natural Disasters: these include events such as floods, heavy winds, heavy snows, landslides, etc., just to name a few natural disasters that can physically damage devices.

7. Physical Attacks. This category includes:
- Device Modifications: alteration of a device by, for instance, taking advantage of a bad configuration of ports, by exploiting those left open.
- Device Destruction (sabotage): incidents such as theft of devices, bomb attacks, vandalism or sabotage that may damage devices.

Exercise

Look at the this Suggested Reading from ENISA: https://www.enisa.europa.eu/publications/info-notes/major-ddos-attacks-involving-iot-devices entitled "Major DDoS Attacks Involving IoT Devices" which is about a series of massive DDoS attacks that occurred in 2016, mainly propagated through compromised IoT devices, and targeted websites and web services like Brian Krebs' website "Krebs on Security", web hosting provider OVH, and DNS provider Dyn. As an example, blame for one of these attacks was laid on the doorstep of DVRs and webcams provided by a white label manufacturer. What are the lessons learned from these events?

☐ We should avoid the use of DVRs and webcams connected to the network .
☐ Any technological advancement demands for new legislation to guarantee the protection of smart devices and IoT infrastructures. Regulatory authorities need to create and continually update rules that oblige companies to meet certain security standards.
☐ The use of digital security services always defends a website against DDoS attacks.
☐ The occurrence of these kinds of attacks is the fault of regulatory authorities.

Methods to prevent attacks

In the previous unit, we described the main security threats for IoT systems, but their potential impact may significantly differ from case to case, according to different risk scenarios. Some examples of typical risk scenarios are summarized in the free article entitled: Baseline Security Recommendations for IoT from ENISA, the European Union Agency for Cybersecurity, and a summary of the most common security mechanisms that need to be put in place is reported in the following figure: authentication, availability, authorization mechanisms, or the use of encryption to protect data.

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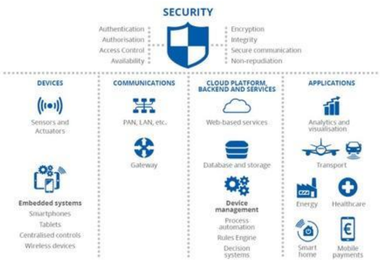

Figure 1: IoT High-level reference model. Source: Copyright by European Union Agency for Network and Information Security (ENISA), 2017.

Planning a strategy to mitigate the risk in a given IoT environment is fundamental, but due to the diversity of application sectors for different IoT systems, such as smart homes, cities, automotive, transport, health, etc., the definition of a common security protocol is hardly meaningful.

Hereafter, we provide a short general checklist of items that need to be overseen in order to design a proper security plan, by referring to more specific protocols for each particular IoT application.

- Resiliency: prepare to protect against attacks.

Firewalls and anti-malware software should be employed to minimize the risk by preventing, detecting, identifying, stopping and removing malicious software. It is important to design an IoT environment with limited things or locations that a hacker can potentially exploit. Firewalls are especially important, in order to filter internet traffic based on source IP, destination port or packet content.

- Secure by default: cryptography

Cryptography is based on an encryption process to turn a message into something that appears to be random and meaningless, and a corresponding decryption process to recover the original message on the other side of the communication channel. Both processes require the use of keys, which can be either symmetric as in the Advanced Encryption Standard (AES), when the sender and receiver need to share a common key for encryption and decryption, or asymmetric as in the X.509 standard, when the sender uses a so-called public key to generate a ciphertext that only the receiver can decipher by using its secret private key. The purpose of cryptography is to mask any information from eavesdropping, and so to safeguard communications against man-in-the-middle attacks. However, not all algorithms for cryptography are equally efficient and up-to-date, and so it is important to employ trustworthy standards. Examples of best practices include:

– Use of approved algorithms;

– Use of keys of a sufficient complexity;

– Use of approved random number generators.

- Proper device management

All connected devices are potentially exposed to external attacks that often exploit firmware and software vulnerabilities, and may from there compromise the entire IoT network. Therefore, proper management of each connected device is essential to ensure the safety of the entire IoT system. In particular, it is fundamental to plan and ensure continuous firmware and software updates and patches.

It may be useful to create an inventory of connected devices, software and firmware versions that must be maintained for real-time control over the entire IoT system.

- Training of people

As a result of considerable research and surveys about security threats in IoT systems, people, i.e. employees, co-workers, etc., are often the weakest link in the cyber-security chain.

Therefore, it is a fundamental step for a protected IoT environment to plan continuous training of all staff on aspects like:

- Never forget to change default passwords;

- How to define a new strong password, such that it should preferably consist of 8 or more characters, with a combination of letters, numbers and special symbols, etc.;

- The importance of multi-factor authentication, especially for access to critical information;

- How to identify a phishing email and what to do in case of doubt; etc.

- Recovery from attacks

Since IoT systems are prone to attacks, it is fundamental to be prepared to undergo failure and to efficiently recover from adverse events. Therefore, basic contingency measures should be taken on a

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regular basis, ranging from frequent backups of system data, including settings, to disaster recovery exercises and simulations.

Augmented Reality

Definition and concepts

Introduction

Augmented Reality (AR) is a technology that overlays digital content and information onto the physical world. The information can be of different types, such as audio, videos, graphics, 3D models, etc. AR occurs in real-time by overlapping the content. Virtual information superimposed on real-time media and objects combines the benefits provided by augmented reality technology and display technology (HUD). In other words, AR changes the manner to connect with the world around us. AR changes the perception of reality by generating the vision of the real-world environment with superimposed computer-generated images.

Augmented reality has become a technology used in many fields, with the rise of the Internet and AR-ready smartphones. Many devices for the direct design of 3D models on physical things have become more accessible. Tech giants such as Apple, Microsoft, and Google offer a lot of real-time augmented reality applications.

AR technology has many important applications in the context of dynamic scenes. It is estimated that the number of users worldwide for AR and VR will reach 443 million by 2025.

AR can be displayed on different types of devices: smartphones, head-mounted displays, glasses, handheld devices, tablets, laptops, etc.

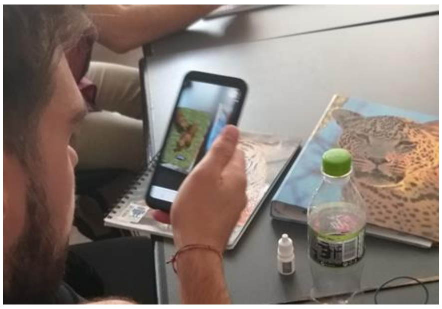

Figure 1: AR application on a smartphone. Source: INDEX consortium (Catalin AMZA)

Thousands of AR platforms and applications have been developed in recent years. Apple has the largest AR platform in the world and many AR applications are available in the App Store. For more information access the link below:

https://www.apple.com/augmented-reality/

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The best-known example of AR technology is the mobile application Pokemon Go, which was launched in 2016. In this game, you can locate and capture Pokemon characters that appear in the real world. The company IKEA offers an AR application (called IKEA Place), which allows you to see what a piece of furniture will look like in your space:

https://newsroom.inter.ikea.com/gallery/video/ikea-place-demo-ar-app/a/c7e1289a-ca7e-4cba-8f65-f84b57e4fb8d

In historical sites such as Pompeii in Italy, AR can project visions of ancient civilizations on the ruins of today, bringing the past into the present.

In historical sites such as Pompeii in Italy, the guided tour is available with AR glasses. AR technology can project images of ancient civilizations onto the ruins of today. https://www.ar-tour.it/

There are four types of augmented reality:

- **Markerless AR.** It is also called location-based AR. This technology relies on location to generate AR content and uses a GPS, a gyroscope, and an accelerometer to provide user location data. The content is overlaid into a scene and holds it to a fixed point in space. Markerless Augmented Reality had a huge impact with Pokémon Go. Also, Wikitude's SLAM markerless augmented reality tracking is one of the most versatile cross-platform 3D-tracking systems available for mobile [2]. Google's ARCore SDKs and Apple's ARKit has developed markerless AR accessible on smartphones and tablets as you can see on the figure below.

Figure 2: AR imagines for smartphones. Source: Paula_Admin on Wikitude https://robots.net/it/augmented-reality-example

- **Marker-based AR**. It is also called Image Recognition or Recognition based AR. This type of technology is based on image recognition (QR code, special symbol, marker). The AR device scans the image and calculates the position and orientation of a marker to overlay the content over objects as you can see in the figure below.

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Figure 3**: AR imagine using Marker-based. Source: by Tanya on Mobile App Daily https://robots.net/it/augmented-reality-examples/**

- **Projection-based AR.** In the figure below you can see the functions by projecting light onto real-world surfaces.

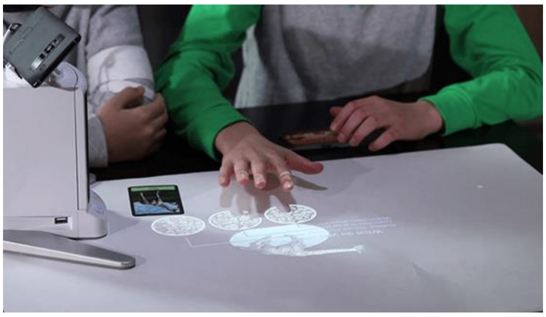

Figure 4: AR imagine using Projection-based AR. Source: Tanya on Mobile App Daily https://robots.net/it/augmented-reality-examples/

- **Superimposition-based AR.** This technology partially or completely replaces the original image of an object with a recently augmented view of the same object. You can see an example of this technology in the figure below.

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Figure 5: AR imagine using Superimposition-based AR. Source: digit.in https://www.inaugment.com/does-your-business-need-the-pinch-of-augmented-reality

If you watch the following video, you can understand what AR means, and its applications in different areas. You will also gain knowledge about the huge size of this technology and its features and power.

What is augmented reality?

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Augmented Reality vs Virtual Reality. The similarities and differences between the two technologies can be easily understood if you watch the movie.

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Augmented reality terminology

To use or design **Augmented Reality** applications, we need to know AR terminology. The following terms are used in the AR systems [3], [4], [5]:

- **Augmented Reality Overlay** - An image or graphic superimposed over an Image Target;
- **Augmented Reality Video Playback** - A video anchored in 3D space (typically superimposed on an **Image Target**) while maintaining the view of the physical environment as opposed to full-screen playback;
- **Augmented Reality viewer app** - An AR app such as Layar or Aurasma that is designed to provide Augmented Reality viewing experiences across multiple brands and content types.
- **Binocular Smart Glasses** - Binocular products offer the ability to put augmented reality data over everything the user sees and enables them to "see-through" what is being displayed
- **Chroma Key Video** - It is defined as a video shot on a unique, brightly coloured background (often called a "green screen");
- **Eye Tracking** - Also known as gaze tracking, a sensor technology that calculates exactly where your eyes gaze or focus.
- **Extended Tracking** – used to launch the AR experience with an **Image Target** in the camera's view which continues the experience even when you're not tracking the image.

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- **Field of View** - The actual distance across your viewing field, from left to right—is the extent of what you can see at any given moment.
- **GL Transmission Format** -It is a royalty-free format for exporting 3D models and scenes from one program and importing them into an application to view in augmented or virtual reality.
- **Head-Mounted Display** - The hardware responsible for creating a virtual reality experience.
- **Head Tracking** - Similar to eye tracking, a sensor technology that monitors the positioning and orientation of your head.
- **Heads-Up Display** - Any transparent display that displays superimposed, visual information onto a medium usually located at the same level as your usual focal point.
- **Hologram** - Typically three-dimensional, often animated, and sometimes accompanied by audio, a hologram is a digital content formed by light that is projected on a transparent display or into open space.
- **Hotspots** - Tappable spots within the AR experience that reveal more content or options.
- **Image Distance** - The perceived distance from a particular object being viewed in virtual reality or an augmented reality environment.
- **Image Target (also: trackable, trigger, marker, AR target)** - The image recognized by the App, which launches the AR experience.
- **Markerless AR** - The technique that allows the use of any part of the physical environment as the base for the placement of superimposed virtual objects.

Augmented reality features

Augmented reality uses existing reality and physical objects to overlap computer-generated images (3D models, videos, and information), in real-time. The AR system can be described using these main characteristics:

- overlapping of the real world and digital world;
- registration in 3D;
- real-time interaction;
- portability.

These are the main features that we must take into account when designing an AR system.

Overlapping of the real world and digital world

The overlay depends on the AR technology and the hardware used. The overlap depends on the AR technologies and the hardware used. The simplest experience for a fully immersive experience for the user without the interaction of the physical world around them is using a mobile phone. The mobile phone to be used as a device that allows the overlapping of the real world and digital world has to contain software, sensors, and a camera that triggers digital displays on physical objects.

3D registration of virtual and real objects

Microsoft's HoloLens embeds 3D images in the real world. Apps such as Zappar and Aurasma allow the creation of AR content with 3D images. Wearable devices, like Head-MountedDisplays

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Real-time interaction
People actively interact against the object in the environment. Real-time software technologies consist of software integrated into an application that comprises the AR interface.

AR Components
The main AR Components are the following [7]:

- Scene Generator;
- Tracking System;
- Display.

Augmented Reality vs Virtual Reality

- Augmented Reality is an immersive technology in the real environment, changing the perception of the real world through totally or partially computerized mediation, while Virtual Reality completely replaces the real environment with a simulated one.
- AR and VR are not competing for technologies but are complementary technologies.
- VR aims at offering a high level of digital recreation of some real-life settings.
- AR is aimed at delivering virtual elements as some kind of an overlay to the real world.
- The schematic representation of VR versus AR technology is shown in the following figure.
- 

Figure 1: Augmented reality VS Virtual Reality. Source: https://technostacks.com/blog/ar-vs-vr

The similarities and differences between the two technologies can be easily understood if you watch the movie below.

Table 1. Augmented reality VS Virtual Reality

Feature	Augmented Reality	Virtual Reality

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TECHNOLOGY	Augmented reality uses the existing real-world environment and puts virtual information on top of it to enhance the experience.	Virtual reality involves users inhabiting an entirely different environment altogether, notably a virtual one.
USERS' PERCEPTION	The user perceives additional computer-generated information that improves the perception of reality. The user is not completely isolated from the real world	Users' perceptions of reality are based entirely on virtual information. The user is completely cut off from the real world.
EQUIPMENT	It can be experienced easily with Smartphone. Head Mounted Display Camera	Head Mounted Display is required. Camera Array Controller VR Head Mounted Display For VR headsets such as Oculus Go, Google Daydream, Google Cardboard or Samsung Gear VR, a smartphone rather than a PC is the device that creates the experience.
TECHNIQUE	Marker Based Markerless	Pre-Render Six Degrees of Freedom Stitching Three Degrees of Freedom Volumetric Capture
SCENE GENERATION	Minimal Rendering	Requires Realistic Images
DISPLAY DEVICE	Non-immersive, small field of view	Full immersive, wide field of view

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TRACKING	High Accuracy	Low to medium accuracy

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Augmented Reality vs Virtual Reality

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History of Augmented Reality

History

The evolution of AR technologies over time and the people who have made significant contributions to their development.

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For the first time, approaches to the concept of augmented reality were mentioned in 1901. In the sense, we know and use today as a technology, the term AR was defined by Thomas Caudell in 1990. AR applications were used by Boeing employees to view complex aircraft systems. Two years later, (1992) Louis Rosenberg developed a complex AR system for the US Air Force. Subsequently, augmented reality applications were implemented for product promotion and entertainment, and games. The rise of smartphones and tablets has significantly intensified the use of AR technology in industry, medicine, education, etc.

The evolution of AR technologies over time and the people who have made significant contributions to their development [1]:

- In 1968 Ivan Sutherland and Bob Sproull created the first head-mounted display, they called it "The Sword of Damocles".
- In 1975 Myron Krueger created Videoplace – an artificial reality laboratory.
- In 1980 Steve Mann developed the first portable computer called EyeTap, designed to be worn in front of the eye.
- In 1987 Douglas George and Robert Morris developed the prototype of a heads-up display (HUD).
- In 1992 Louis Rosenberg of the US Air Force created the AR system called "Virtual Fixtures".
- In 1999, a group of scientists led by Frank Delgado and Mike Abernathy tested new navigation software, which generated runways and street data from a helicopter video.
- In 2000 a Japanese scientist Hirokazu Kato developed and published ARToolKit – an open-source SDK.
- In 2004 Trimble Navigation presented an outdoor helmet-mounted AR system.
- In 2008 Wikitude made the AR Travel Guide for Android mobile devices.
- In 2013 Google beta-tested the Google Glass – with internet connection via Bluetooth.
- In 2015 Microsoft presented two brand new technologies: Windows Holographic and HoloLens (an AR goggles with lots of sensors to display HD holograms).
- In 2016 Niantic launched Pokemon Go game for mobile devices.

You can watch the next video for a brief history of augmented reality.

A Brief History of Augmented Reality

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Exercise

Augmented Reality (AR) is a technology that:

☐ inserts content on platform
☐ overlays digital content and information onto the physical world
☐ overlays information on computers
☐ overlays information on smartphones

Exercise

Which is augmented reality technology?

☐ Marker colour
☐ Markerless
☐ Markervideo
☐ Markersound
☐ Unanswered

Exercise

Augmented Reality Overlay means:

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☐ An image or graphic used to explain something
☐ An image or graphic superimposed over an image target
☐ An image or graphic available on a laptop
☐ An image or graphic available on a smartphone
☐ Unanswered

Exercise

Augmented Reality and Virtual Reality are:
☐ Competing technologies
☐ Complementary technologies
☐ Outdated technologies
☐ Unrealistic technologies

References

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Final Exam

Questions

The implementation of a new or significantly improved production or delivery method, including significant changes in techniques, equipment and/or software. Which type of innovation is it, according to Oslo Manual?

- Product innovation
- Process innovation
- Marketing innovation
- Organisational innovation

Small improvements, having small effects and being the result of continuous improvement can be classified as which type of innovation?

- Incremental innovations
- Breakthrough innovations
- Substantial innovations
- Process innovation

Along with the development of the thermometer, different temperature scales emerged. Each "discoverer" of a new type of temperature sensor, was keen on having its own scale named after him. Which is one of the scales for temperature that emerged from this development and is still in use today?

- Kelvin
- Newton
- Galileo
- Ferdinando

What is main distinctive difference between Sensor 3.0 and Sensor 4.0?

- the output of a Sensor 4.0 is electrical
- it is able to compensate for unwanted errors and disturbances
- the sensor is a hybrid sensor, consisting of several transducers and a direct sensor
- it is a sensor module which is able to communicate autonomously

In which form is metal most commonly used for Additive Manufacturing?

- Powder and wire
- Powder and liquid
- Liquid and wire
- Liquid and gas

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How is the basic 3D printing process structured?

- Preprocessing - 3D Modelling - Slicing - 3D Printing
- Preprocessing - 3D Modelling - Slicing - 3D Printing - Postprocessing
- Creating STL-File - 3D Modelling - Preprocessing/ Slicing - 3D Printing
- 3D Modelling - Preprocessing/ Slicing - 3D Printing

Which of the following technologies has enabled the IIoT?

- Only cyber-physical systems and mobile technologies
- Only big data analytics and machine learning
- Many technologies, such as cyber-physical systems, cloud computing, edge computing, mobile technologies, big data analytics, machine learning and many others
- Many technologies, such as cyber-physical systems, cloud computing, edge computing, mobile technologies, man-in-the-middle systems, Distributed Denial of Service technologies and many

Cryptography is one method to prevent ...

- Man-in-the-middle (MITM) attacks
- Software vulnerabilities
- Device modifications
- The download of malwares

Real-time software technologies consist in:

- software integrated into a head set
- software integrated into an application that comprises the AR interface.
- software integrated into VR
- software integrated into new program

Image Target is:

- The image recognized by the people.
- The image recognized by the App, which launches the AR experience.
- The image recognized by the devices
- The image recognized by the sun-glacess.

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