Horticulture 4.0
Vocational Education
for Digital Transformation in Horticulture





SMART GREENHOUSE TECHNOLOGIES

E-BOOK

Smart greenhouse technologies

Horticulture 4.0 - Vocational Education for Digital Transformation in Horticulture

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AIM OF THE TRAINING MATERIAL

Welcome to the *Smart Greenhouses Technologies – Horticulture 4.0* project e-book!

Traditionally, agriculture is not immediately associated with fields such as information technology, data analysis, networking, or automated systems. Yet today, e-agriculture has become an integral part of both our everyday lives and the agricultural sector.

> The rapid advancement of technologies — including robotics, remote control systems, mobile communications, the Internet of Things (IoT), data analytics, decision support systems, and artificial intelligence (AI) — has significantly transformed, and continues to reshape, the agricultural landscape. Through the use of sensors, control mechanisms, and communication systems, smart greenhouses are now capable of dynamically adjusting environmental parameters based on real time data, thereby creating optimal conditions for plant growth and enabling the efficient use of resources.

Globally, there is an increasing demand for the automation and remote control of greenhouse operations. However, a significant shortage of skilled farmers and technicians proficient in these technologies persists. Moreover, vocational education often lags behind current industry developments, while the pace of technological innovation continues to accelerate.

This gap inspired the development of the *Horticulture 4.0* project, with the primary objective of creating educational materials for horticultural VET teachers on the technologies employed in smart greenhouses. By engaging with the online training materials, teachers and trainers in vocational education will be better equipped to integrate knowledge of greenhouse automation and remote control into their curricula, thereby empowering students with the digital competencies essential for the future of horticultural production.

The course is structured into three comprehensive modules:

Module 1: IT basics for the operation of smart greenhouses

This module introduces key foundational concepts that underpin more specialised knowledge areas. Topics covered include mobile communication systems, data transmission processes, sensor technologies, and the operation of control systems.

Module 2: Smart Technologies in Greenhouses

In this module, participants will explore the following eight subject areas:

1. Mobile communication in greenhouses
2. Greenhouse automation, sensors, robotics
3. Micropropagation techniques in the laboratory
4. Greenhouse growing
5. Digitisation of the microclimate in greenhouses
6. Precision irrigation
7. Digitalisation of artificial lighting in greenhouses
8. Precision greenhouse crop protection

Module 3: Innovative Teaching MethodS

In addition to technological competencies, this module presents innovative pedagogical approaches aimed at refreshing vocational education practices. As the sector evolves, it is vital not only to keep pace with technological advancements but also to embrace new teaching methods that promote active and engaged learning among students.

We sincerely hope that all participants will discover valuable insights and practical knowledge within the course that they can readily apply to their own teaching practice.

We wish you an enjoyable and enriching learning experience!

The Horticulture 4.0 Team

IT basics for the operation of smart greenhouses

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COMMUNICATION

Communication in everyday life

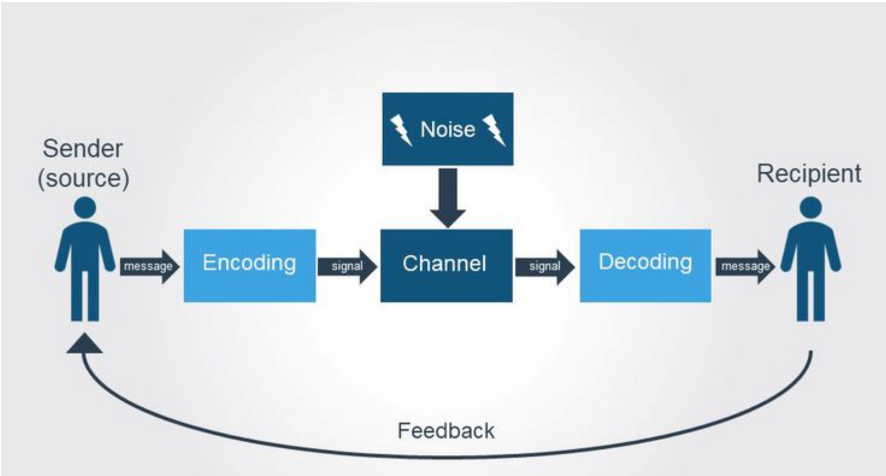
In everyday life, communication usually involves human interactions in which information, thoughts, feelings and ideas are exchanged between two or more parties.

Communication can take several forms. Verbal communication is based on the use of words and language when speaking or writing. Nonverbal communication is based on the use of body language, facial expressions, posture and gestures with the help of which we express our emotions and intentions. In addition, there is written communication, for example, in the form of letters or emails, as well as visual communication, for example, through figures, diagrams or images.

The term now has a much broader meaning than human interpretation. According to the definition of information theory, communication is any process in which information is transmitted, regardless of the form and code in which the information appears. In a broader sense, processes between inorganic and organic matter can be called communication as well as the transfer of information between machine systems.

COMMUNICATION IN IT

In information technology, the concept of communication refers to the exchange of data and information between computers, devices, systems and applications. This includes, for example, the transmission of data over local area networks (LANs) or remote networks, but it can also include human-machine interaction. In this sense, the purpose of communication is the efficient, fast and secure transmission of data, information and instructions between different systems and users.



Components of the communication process
source: https://hu.pinterest.com/pin/482940760039226296/

- **Transmitter/encoder:** the source of information, the individual or group that creates, encodes and transmits the message if necessary.
- **Message:** the information, thought, feeling, or idea that the source wants to convey.
- **Channel:** the medium (medium) through which the message is transmitted, e.g. speech, writing, electronic media, etc.
- **Receiver/decoder:** receives the message, decodes it as needed by an individual or group.
- **Loopback:** The customer's response to the message, which is returned to the source if the communication is bidirectional.
- **Noise:** any factor that impedes, distorts, or interrupts the transmission or reception of a message.

Communication between IT systems can take different forms. Communication between computers is the process of transferring data (exchanging files, e-mail, and other digital content) over a local network or the Internet.

This includes communication between software and applications. For example, application programming interfaces (APIs) allow one software to communicate with another, request or transmit data, helping to integrate between applications and synchronize data.

This includes communication between users and computer systems. This is done through user interfaces (e.g. graphical user interfaces, command-line interfaces), where users provide information, give instructions and receive feedback from the system.

In the field of IT communication, reliability, security and efficiency are important. They use protocols, coding methods, and network architectures to ensure that information flows properly and can be interpreted by communicating systems.

MOBILE COMMUNICATION

Basic concepts

Mobile communications refer to communication using mobile phones and other wireless devices. This technology allows people to communicate in real time with people living in remote locations or other devices.

Source: Shutterstock

Mobile communication data transmission requires network infrastructure, mobile phone towers and base stations that ensure coverage and availability of communication services.

Mobile phone networks can use technologies such as GSM (Global System for Mobile Communications), CDMA (Code Division Multiple Access), 3G (Third Generation), 4G (Fourth Generation), LTE (Long-Term Evolution) and 5G (Fifth Generation). These technologies are gradually evolving and providing new opportunities for mobile communications.

The basic services of mobile communication are mobile calls, text messages (SMS), multimedia messaging (MMS), emails, social media applications, Internet browsing, and the latest applications such as video calling, live streaming, collocation and mobile payments.

The great advantage of these services is fast and efficient person-to-person communication, provided that there is mobile network coverage in the given geographical area. The mobile network allows us to stay in touch with family, friends, business partners. Newer generation mobile networks, such as 4G and 5G, bring additional benefits to mobile communications. They provide faster data speeds, lower latency, and higher capacity, enabling faster and reliable transfer of larger data and the evolution of new applications and services.

Source: Generated with DALL-E

Mobile communications have a significant impact on our daily lives and society. It changed the way people communicate, enabling fast and global contact. Mobile communications are equally important in the personal, business and social spheres, and further advances in technology will provide new opportunities in the future.

Applications

Applications (applications) used in mobile communication are widespread and allow us to perform various activities on mobile devices (smartphones or tablets). Here are some examples of the types of mobile apps you use most often:

1. Communication applications: to send text messages (for example, SMS, WhatsApp, Facebook Messenger), to make calls (for example, Skype, FaceTime, Viber).

2. Social media apps: to keep in touch, share opinions, photos, videos (e.g. Facebook, Instagram, Twitter, TikTok).

3. Email applications: used to set up an email account, send and receive emails (e.g. Gmail, Microsoft Outlook).
4. Music and video player apps: to play music, podcasts, movies, and series on your mobile device (e.g. Spotify, YouTube, Netflix).
5. Navigation applications: for route planning, receiving traffic information (e.g. Google Maps, Waze).
6. Health and fitness apps: to support health promotion, track nutrition, and access other health information (e.g. Fitbit, MyFitnessPal).
7. Banking and payment applications: for making bank transactions, paying with a mobile device, tracking finances (for example, PayPal, Revolut).

These are just a few examples of the diversity of mobile apps. Mobile apps are constantly evolving and offer new features and options for users to use their mobile devices more conveniently and efficiently in everyday life.

Mobile communication in agriculture

Mobile communications play a key role in modernising agriculture and increasing farmers' competitiveness. The introduction of new technologies and communication tools brings many benefits to farmers in the following areas:

- Data collection and analysis: farmers can collect data on their soil, weather conditions and crop conditions in real time, which will inform them to make the right decisions about the necessary interventions.
- Market information: mobile phones help farmers get up-to-date information, for example, on market price developments for different products.
- Communication and advice: mobile communication makes it easy for farmers to connect with advisors, experts and other farmers to keep up with and share the latest developments and good practices.
- Digital finance: Mobile banking and digital payment platforms facilitate financial transactions, the purchase of fertiliser or seed, and the management of revenues from crop sales.
- Precision agriculture: thanks to precision agriculture technologies, drones and satellite imagery, farmers can accurately monitor and optimise the use of fertiliser, water and crop protection products.
- Training and education: mobile communication allows farmers to access online training and learn about the latest agricultural practices and technologies via mobile devices.

RECEIVING, TRANSFORMING, TRANSMITTING DATA TRANSMISSION SIGNALS

Signals play a key role in all forms of communication and are an essential tool for transmitting data and information in information technology. Signals allow data to be physically transmitted through communication channels. Digital signals transmit information in discrete form (for example, a sequence of 0's and 1's), while analog signals can change continuously over time. Analog signals can take on infinitely many values within a given range and usually represent continuous changes in some physical quantity, such as temperature, pressure, sound waves, or light intensity. Analog signals change continuously, and discrete or digital signals change intermittently or cascadingly.
In the context of IT communication, the role of signals can be grouped according to several aspects.

Group signals by option set and range of interpretation:

- analog signal: both its range of interpretation and its set of values are continuous (temperature changes over a given period),
- discrete signal in the time domain: the signal has a discrete range of interpretation and a continuous set of values (e.g. hourly thermometer),
- discrete signal in amplitude: its interpretation range is continuous, its set of values is discrete (e.g. adjustable output voltage of power supply),
- digital signal: both its range of interpretation and its set of values (e.g., the second hand of a simple digital clock).

Some features, distinguishing features of analog and digital systems are:

- Digital systems use integers (such as binary) for input, processing, transmission, storage, or display.
- Analog systems use a continuous spectrum of values and non-numeric symbols such as letters or icons.
- In analog systems, small fluctuations and fluctuations also have meaning.

The concepts of analog and digital signal, with examples

The analog signal: it can take any value, it is constantly changing, it gives realistic data that can be read at any time.

For example: speedometer, conventional tensionmeters, conventional thermometer (mercury fiber), barometer, hydraulics.

Digital signal: the discrete representation of a variable phenomenon or physical quantity, e.g. only by certain integer values.

For example: digital thermometer, digital clock.

Signal processing, digitization of analog signals

Shannon's sampling law (or Shannon-Nyquist's sampling theorem as it is often called) is one of the fundamental principles of digital signal processing. The law determines the speed at which a continuous temporal signal must be sampled in order to perfectly restore the original signal from the samples without losing information in the process. The law states that for a signal with maximum bandwidth X, the sampling rate (sampling rate) must be at least twice the maximum frequency of the signal (i.e. 2X) in order to restore the original signal without distortion.

For example, if the highest frequency of an audio signal is 20 kHz, then according to the Shannon-Nyquist theorem, a sampling rate of at least 40 kHz is required to perfectly convert the signal into a digital form.

The sampling law is fundamental in digital audio, digital imaging, and many other areas where analog signals need to be converted to digital signals, as it helps prevent sampling error when the sampling rate is too low and high-frequency signal elements distort the restored signal.

Analog-to-digital (A/D) and digital-to-analog (D/A) conversion

Analog signals can be converted into digital signals (and vice versa) using A/D (analog-to-digital) and D/A (digital-to-analog) converters, enabling digital processing, storage and transmission of analog signals. Digital data transmission is often more efficient and less noise-sensitive than direct handling of analog signals. A/D conversion is the "quantization" of a continuous analog signal to discrete digital values, while D/A conversion is the conversion of digital signals to analog signals, allowing physical representation and perception.

Limitations of digitizing analog signals

- During digitization, analog signals are converted into signals that can be represented by digits, which can also be interpreted by a computer.
- The original data is sampled in steps and the continuous data set between the two steps is replaced by a value, which is obviously only an approximate value.
- Specifying a range of values is called quantization. Accuracy can be improved with denser sampling and smaller steps.
- Data loss occurs during digitization, so the original analog signal cannot be converted back from the digital signal.

Steps to digitize analog signals

- Sampling: sample the original continuous data set in increments and replace the variable value between the two steps with a single value.
- Quantization: specify the set of values from which the digital signal takes a specified value that approximates the value of the original signal.
- Coding: the sampled signal is assigned to the quantization value obtained by the encoding unit in a binary sequence.

Data and data volume

Data is a form of facts and concepts that is suitable for interpretation, processing and transmission by data processing tools. Data can be unstructured, such as a plain text document, or structured, such as stored in a database. Information is new knowledge created by processing data by machine or man.

Data volume is a measure that shows how much storage capacity is required to store data. Units of measurement for data volume include bits (the smallest unit of data that can take a value of 0 or 1) and bytes (usually 8 bits, which are used to store a character, such as a letter or digit). Other units of data volume are kilobytes (KB), megabytes (MB), gigabytes (GB), terabytes (TB), petabytes (PB), exabytes (EB), where each unit is usually 1024 times the previous one (although a factor of 1000 is often used to measure storage and throughput capacities for ease of understanding).

Based on the amount of data, we can determine the size of the required data storage device, data transfer rate and data processing capacity. For example, the amount of data required to store a digital image determines the load time on a web page, or the amount of data in a video can determine how long it takes to download or stream it at a given network speed.

Digitization of images and sounds

Digitize images

By digitizing images, photos, documents, images can be stored, edited and shared in digital format on any electronic device. By digitization, the analog image is converted to discrete digital format in two steps: sampling and quantization.

Sampling

By sampling, the image is broken down into small squares called pixels (picture elements) using a grid. Each pixel represents one pixel in the digital image. The sampling rate, or pixel density, determines the resolution of a digital image: the more pixels an image has, the more detailed the digital version. High-resolution images better preserve the details of the original image, but obviously require more storage space.

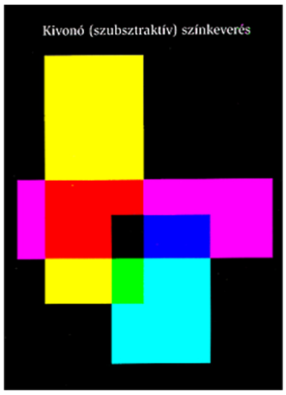
Quantization

The next step is quantization: the light intensity values recorded per pixel are converted to discrete color depth values. Color depth determines how many different colors or shades can be displayed in a digital image. For example, in an image with 8-bit color depth, each pixel can display 256 (2^8) different colors or hues. Quantization determines the color accuracy and detail of a digital image. If 3 bytes (24 bits) are used for storage, more than 16 million (16,777,215) colors can appear in the digital image.

Color coordinate systems and formats

Digital images can be stored and managed in different color models and file formats. RGB (Red, Green, Blue), called additive color mixing, which combines red, green, and blue colors to create different colors, The RGB code contains the codes for red, green, and blue base colors separately.

CMYK (Cyan, Magenta, Yellow, Key/Black) subtraction color mixing is mainly used in image printing. Sunlight contains all the visible colors found on earth. When sunlight illuminates an object, the object absorbs (subtracts) a little of the light and reflects the remainder. Reflected light is the color we see. The fire engine is bright red because it absorbs all colors (blue and green) from the light spectrum except red.



File formats for storing digital images, such as JPEG, PNG, GIF, and TIFF, use various compression techniques and data management methods to optimize image quality and file size.

Compression

We often use compression techniques to store and transmit digital images. Compression can be lossy, like JPEG, where we lose the original data during compression to reduce file size, or lossless, like PNG, where the original quality of the image is preserved but less effective in terms of reducing size.

Audio digitization

Audio digitization converts physical, analog audio signals into signals that can be stored in digital form, enabling sound to be stored, edited, transmitted and copied on a computer. The first step in audio digitization is sampling, followed by quantization and coding, which convert continuous analog signals into discrete digital data.

Sampling
The first step in sound digitization is sampling: samples are taken from the analog signal at given intervals. The sampling rate (or sampling rate) determines how many times per second sampling is performed. The unit of sampling frequency is Hertz (Hz), where 1 Hz represents the reception of one sample per second. CD-quality audio, for example, records at a sample rate of 44.1 kHz, which means it takes 44,100 samples per second.

Quantization
Sampling is followed by quantization: sample amplitudes are rounded to discrete values. In this step, the continuous analog signal is converted into a finite number of digital signals that can be handled in digital systems. The number of quantization levels depends on the so-called "bit depth". The bit depth determines how many bits are used to store the sample amplitude. For example, a 16-bit audio system can distinguish 65,536 (2^16) different amplitude values. During quantization, a so-called quantization noise is generated, since continuous amplitude values are rounded to discrete values, but by increasing the bit depth, the quantization noise can be reduced accordingly.

Coding
For storage and transmission, after sampling and quantization, digital data must be encoded. Encoding compresses data to reduce the amount of data while maintaining sound quality. Compression can be lossy (for example, MP3, AAC), which omits certain information less perceptible to the human ear, or lossless (for example, FLAC, WAV), which preserves the original digital signal.

Digitization of motion pictures and videos

The digitization of analog moving images, films and videos takes place in steps similar to audio digitization: sampling is the first step, followed by quantization and compression. The result is the conversion of continuous analog signals into discrete digital data. Digitally stored movie can be stored on your computer, edited, and transferred to other devices.

Sampling
The first step in digitization is sampling: the frames of the film are recorded at given intervals. In the case of moving images, two main sampling methods are distinguished: temporal and spatial sampling. Temporal sampling determines the number of frames recorded per second (fps), and spatial sampling determines the resolution of the pixel matrix within a frame.

Quantization
After sampling, quantization follows: in the frames, the brightness of the pixels and color information are rounded to discrete values, that is, continuous analog signals are converted into a finite number of digital values. The quality of quantization is determined by the bit depth, which indicates how many bits per pixel the information per pixel is stored on. A higher bit depth results in better image quality, allowing you to distinguish shades of more colors and brightness.

Compression
Digitally stored video can take up a lot of storage space, so compression is very important. The goal of compression is to reduce the amount of data as much as possible without significantly affecting the quality of the movie. Types: lossy and lossless compression. Lossy compression (for example, MPEG, H.264) omits information that is less important for visual perception, while lossless compression (for example, PNG for images) preserves exactly the original data.

The importance of digitalisation in modern agriculture

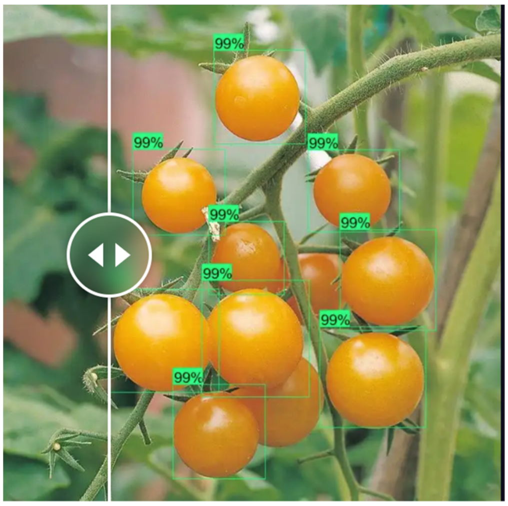
Precision agriculture uses modern technologies and data analysis methods to optimize agricultural practices to increase productivity, reduce environmental impact and improve economic efficiency. Digitalisation plays a key role in this process, as it allows for more accurate observation, analysis and management of agricultural processes. Let's look at some examples.

Audio digitization

- By analyzing audio recordings, we can observe and track the behavior of animals. By identifying sounds that give signs of stress or illness, early intervention is possible.
- Specific sounds indicating the presence of certain pests or diseases, such as insect buzzing or ultrasounds emitted by plants, can be identified using digital technologies, allowing farmers to take timely action.

Image digitization

- Using satellite imagery and aerial imagery taken by drones, farmers can monitor large areas to identify, for example, drought or infections. This allows for more accurate water management and targeted application of plant protection measures.
- With the help of digital images, farmers can detect plant diseases and pests early, enabling quick and targeted treatment, or they can estimate the expected tomato yield in a smart greenhouse using AI analysis.

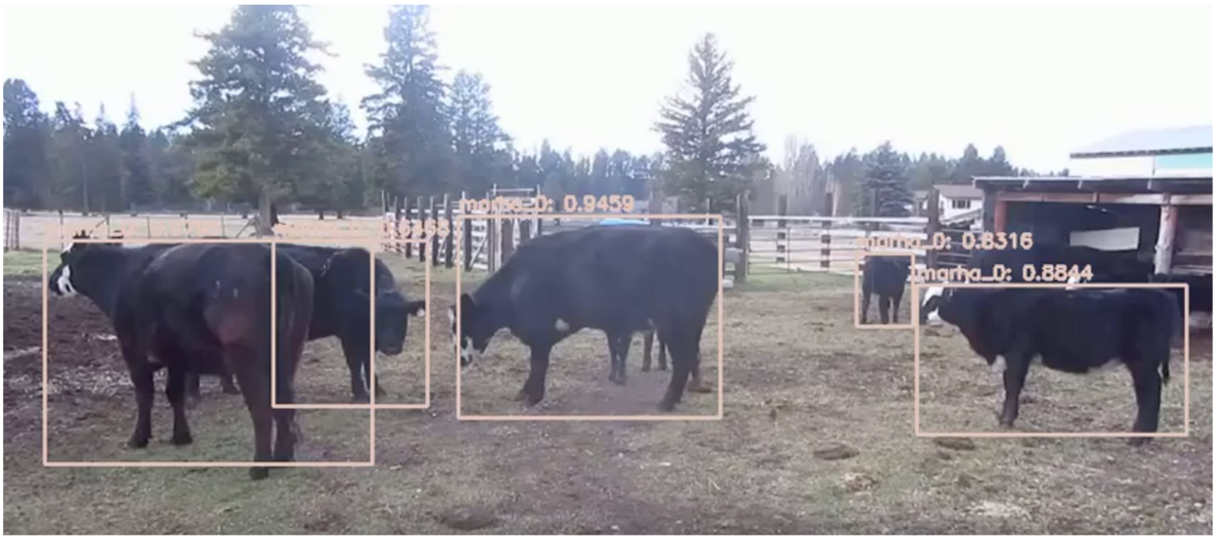


Source: https://www.prompt.hu/szoftver/ai/

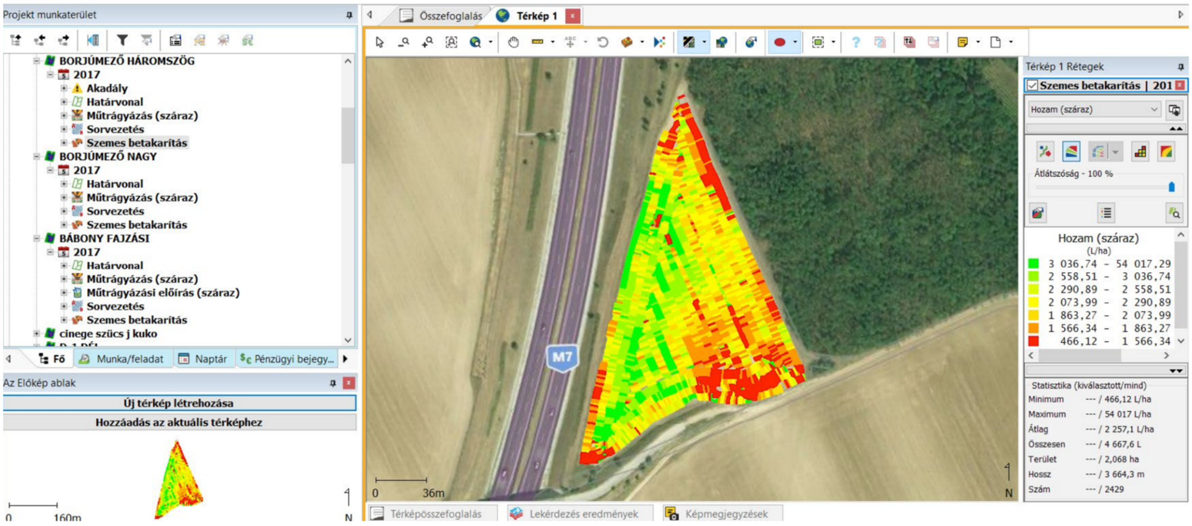
We can see AI solutions for further domestic developments for the above examples on the following website: https://www.prompt.hu/szoftver/ai/

Digitize videos

- With video cameras and artificial intelligence (AI)-based analytics, farmers can monitor the condition of animals and crops in real time. Observing animal behavior can help identify welfare issues, optimize feeding strategies and improve the effectiveness of breeding programs.



- Analysis of digital recordings allows you to improve the efficiency of agricultural workflows such as planting, spraying and harvesting.



Source: Dr Láng, Veres: Precision farming, 2018, https://mlc.itstudy.hu/hu/mlc-browser/precizios-gazdalkodas

Overall, the conversion of analog signals into digital signals, its digitization, is the technology that allows farmers to get a more accurate picture of production processes, helping decision-making processes, increasing productivity, reducing environmental impact and improving overall economic efficiency.

CONCEPT AND OPERATION OF SENSORS

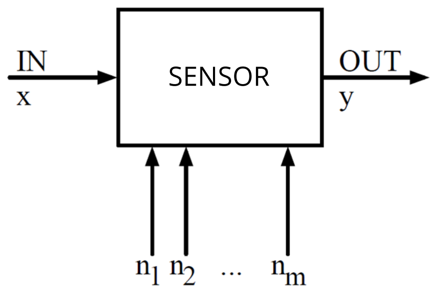
The concept of sensor

A sensor is a device that can detect physical or chemical quantities (such as temperature, light intensity, pressure, moisture, gas concentration, etc.) and convert them into electrical signals. Electrical signals can be analyzed, processed, visualized by various devices, and thus we can obtain information about the environment or perceived phenomena.

Sensors can be very simple devices, such as the temperature sensor above, or more complex systems, such as multispectral imaging sensors, which can collect data at different wavelengths of light. The development and application of sensors play a key role in modern technological innovation.

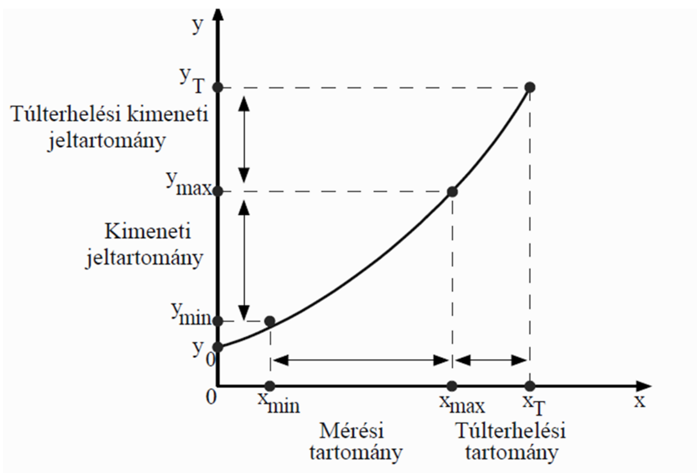
The conversion of the properties of various phenomena into electrical quantities has become so common that a sensor is any technical measuring device whose input is not an electrical quantity and whose output is an electrical quantity, and which satisfies the requirements of methodology: accuracy, repeatability, resolution, shelf life, immunity to environmental influences.

Sensors can be classified according to several criteria: according to their principle of operation, according to the nature and type of input quantities, and according to the nature of the outgoing electrical signals. The output signal (output − y) of each sensor used in the measurement process is a function of several input quantities. Of the input quantities, apart from the one to be measured (input − x), the rest are considered as interference signals (nk − noise), the effect of which we try to reduce during the measurement.



With the help of sensors, we are able to measure and detect physical or environmental characteristics such as temperature, pressure, light, sound or motion. Sensors can be used to monitor environmental conditions, collect data, or operate devices. Sensors convert features in their environment into electrical signals, which can then be transmitted and processed by other devices or systems. Sensors are widely used in industry, science, healthcare, automotive, smart devices and many other fields.

To determine the static characteristics of the sensors, we can determine the steady values of the output by recording the input quantity at a constant value in time. The relationship y(x) between output and input quantities can thus be obtained as a static characteristic.



Based on the static characteristic, quantities characteristic of an important sensor are determined. In order to limit the scope of the curriculum, we will mention only the most important ones:

Measuring range [xmin, xmax] in which the specifications specified for the sensor are met.

Output signal range [ymin, ymax], the interval in which the output signal values are located when x travels over the entire measuring range.

Overload range is the input signal [xmax, xT] value interval in which the sensor is still operational but no longer meets the required specifications. It is important that when returning from the overload range to the measuring range, the sensor operates according to the original static characteristics. If x > xT , then the sensor may become incapable of operation (xT − breaking limit).

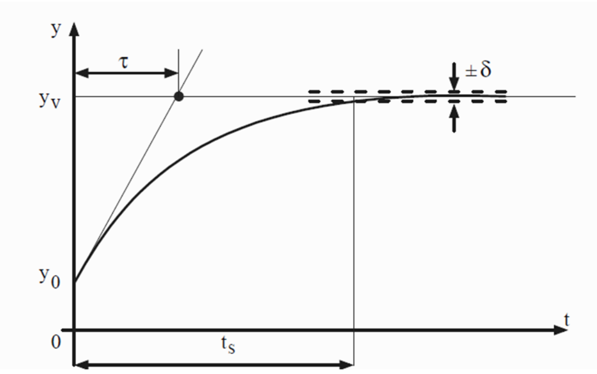
Sensibility is the differential quotient calculated at a given operating point M, which is the ratio of changes in output to input. Expresses the change in sensor output relative to unit change in input.

$$S_a = \frac{\Delta y}{\Delta x}\bigg|_M \quad \left[\frac{\dim\ y}{\dim\ x}\right]$$

Resolution means the change in input quantity that produces a perceptible (quantifiable) change in the output. If the sensor output is digital, the resolution is equal to the least important bit (digit). For example, if the display of a digital thermometer can display differences of 0.1 °C, the resolution of the sensor is r = 0.1 °C.

Dynamic time characteristics: if the input quantity x to be measured changes over time, the instantaneous value of the output quantity can be determined for the input quantity values at each time moment. The relationship between the instantaneous values of the input and output quantity is determined by the time-dependent differential equation of the sensor, commonly referred to as the dynamic characteristic of the sensor.

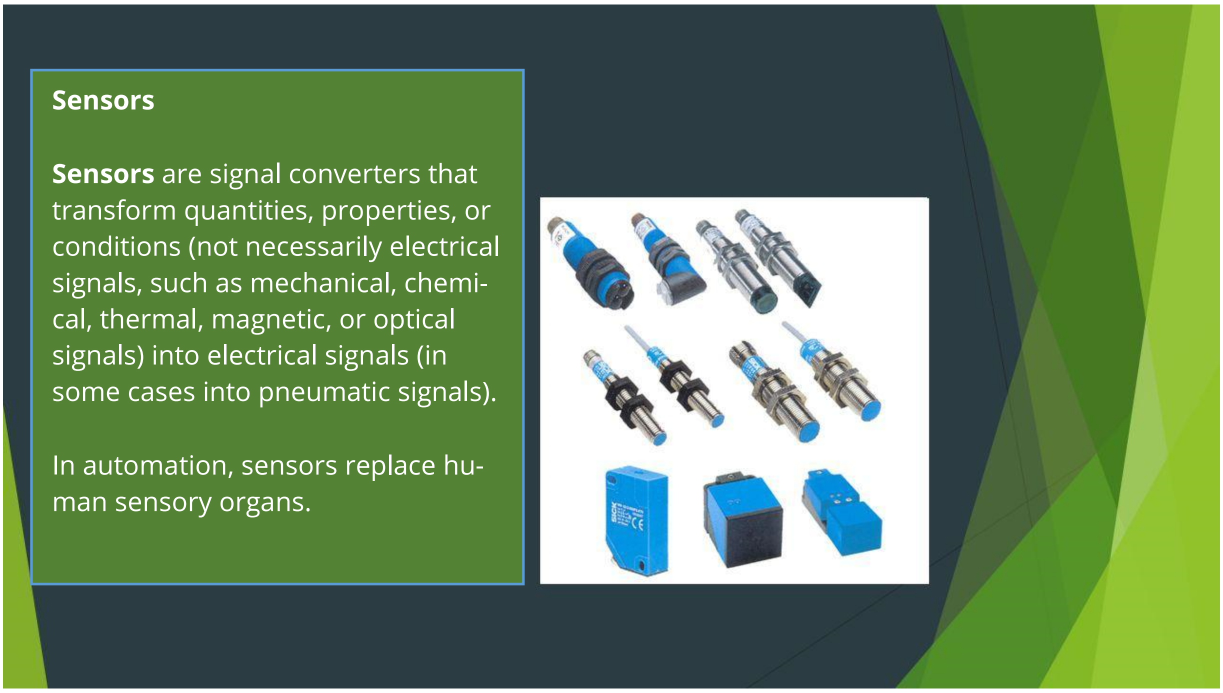
The dynamic time characteristics are determined by switching a stepwise jump input signal to the input. If the sensor can be described by a first-degree, linear, constant coefficient differential equation, then its dynamic characteristics are:



– **time constant – Ƭ** : at the moment of a sharp change in the input signal (t=0), the intersection of the tangent drawn to the curve on the line of the final (steady) value of the output signal YV.

– TS : the time between the sharp change in the input signal (t=0) and the moment when the output signal fits into the permissible deviation band around the final value of YV.

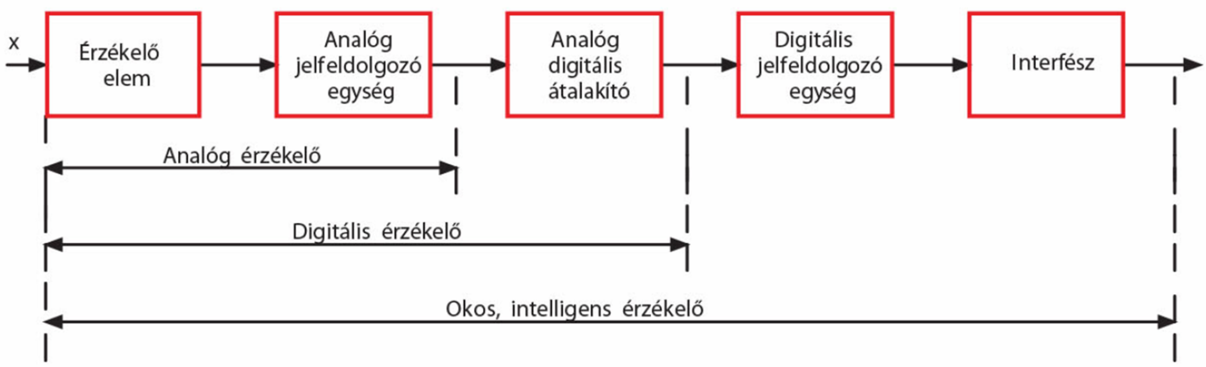
For example, the dynamic characteristics of a temperature sensor are typically used, as the thermal sensing element takes a certain amount of time to warm up to the ambient temperature. In general-terms, however, the dynamics of the sensor can be described by a higher degree differential equation.



The sensor element is the part of the sensor that detects the aforementioned physical factor. Since it is rarely used on its own, this element is accompanied by signal processing, transducer elements, housing, connector and fastening elements.

Sensors can detect one or more characteristics, and we can also talk about a multisensor system, when there are sensor elements capable of detecting multiple values within one sensor.

Diagram of the integration array of analog, digital and smart sensors:



A smart sensor is a micro-electronics integrated unit that includes at least one sensor, an analog signal processing unit, an analog-to-digital converter, a digital signal processing unit and a wired or wireless interface that can be easily connected to other systems.

A smart sensor is a smart sensor that has one or more functions such as self-testing, self-testing, validation, adaptation, etc.

Grouping sensors

Sensors can be grouped in several ways, depending on the characteristics by which we want to organize them. Here are some common groupings for sensors:

By physical characteristics:

- Optical sensors: e.g. light sensors, cameras.
- Sound sensors: e.g. microphones, sound sensors.
- Motion sensors: e.g. gyroscopes, accelerometers.
- Temperature and humidity sensors: e.g. temperature sensors, hygrometers.

By field of application:

- Environmental sensors: e.g. air pressure sensors, earthquake sensors.
- Biometric sensors: e.g. fingerprint readers, heart rate sensors.
- Environmental sensors: e.g. air pollution meters, radiation sensors.
- Positional sensors: e.g. GPS modules, compasses.

By communication interface:

- Analog sensors: sensors that output an analog signal.
- Digital sensors: sensors that emit a digital signal.

Based on the principle applied:

- Photoelectric sensors: e.g. photodiodes, phototransistors.
- Chemical sensors: e.g. gas detectors, pH sensors.
- Biological sensors: e.g. bioluminescent sensors, enzyme sensors.

It is important to note that the grouping of sensors is not clear and strictly defined, as many sensors can be divided into several categories depending on what aspects are taken into account.

In the next section, let's look at the elements of grouping based on the communication interface.

Analog sensors

Analog signals are provided, for example, by flow sensors, displacement sensors or torque meters. Analog sensors are devices that generate analog signals. Analog signals represent continuous values according to the measured characteristics. Analog sensors detect physical signals from their environment, such as temperature, pressure, or luminance, and convert them into analog electrical signals. Analog signals are usually present in the form of voltage or current.

The output of analog sensors usually changes with the measured characteristic. For example, the output voltage of a temperature sensor depends on the measured temperature. Analog sensors are

*SEQ figure * ARABIC 4. Fig. Analog luminance sensor*
Image source: https://www.microcontroller.hu/termek/temt6000-fenyerosseg-mero-szenzor/

usually followed by an analog-to-digital converter (ADC), which converts an analog signal into a digital form for processing by digital systems or microcontrollers.

Analog sensors are widely used in industry, electronics, automotive and other areas where precise measurement and control of ever-changing characteristics is important.

Digital sensors

Digital sensors are devices that generate or output a digital signal as a result of measurements, the output is displayed in binary form, usually with values of 0 and 1 or digital protocols.

Example of digital sensors:

1. Digital temperature sensors: these sensors can measure ambient temperature and return digital values. Digital communication protocols such as I2C or SPI are often used.

2. Digital motion sensors: these sensors detect movement in their surroundings and emit a digital signal when motion is detected. Passive infrared (PIR) technology is often used.
3. Digital light sensors: these sensors measure ambient light intensity and send digital signals based on perceived light conditions.
4. Digital distance sensors: these sensors measure distance relative to other objects. Distance is expressed in digital form, often in the form of pulses or digital codes. For example, laser distance sensors or ultrasonic sensors.
5. Digital pressure sensors: these sensors can measure pressure and output digital values. They can use digital communication protocols such as I2C or SPI.

The advantage of digital sensors is that output signals can be easily read and processed in digital systems. Data is more accurate and less susceptible to interference or noise. In addition, they often include a built-in analog-to-digital converter (ADC), which allows analog signals to be digitized, making it easier to connect sensors to microcontrollers or other digital systems. Some examples of different analog and digital sensors can be seen in the image below:

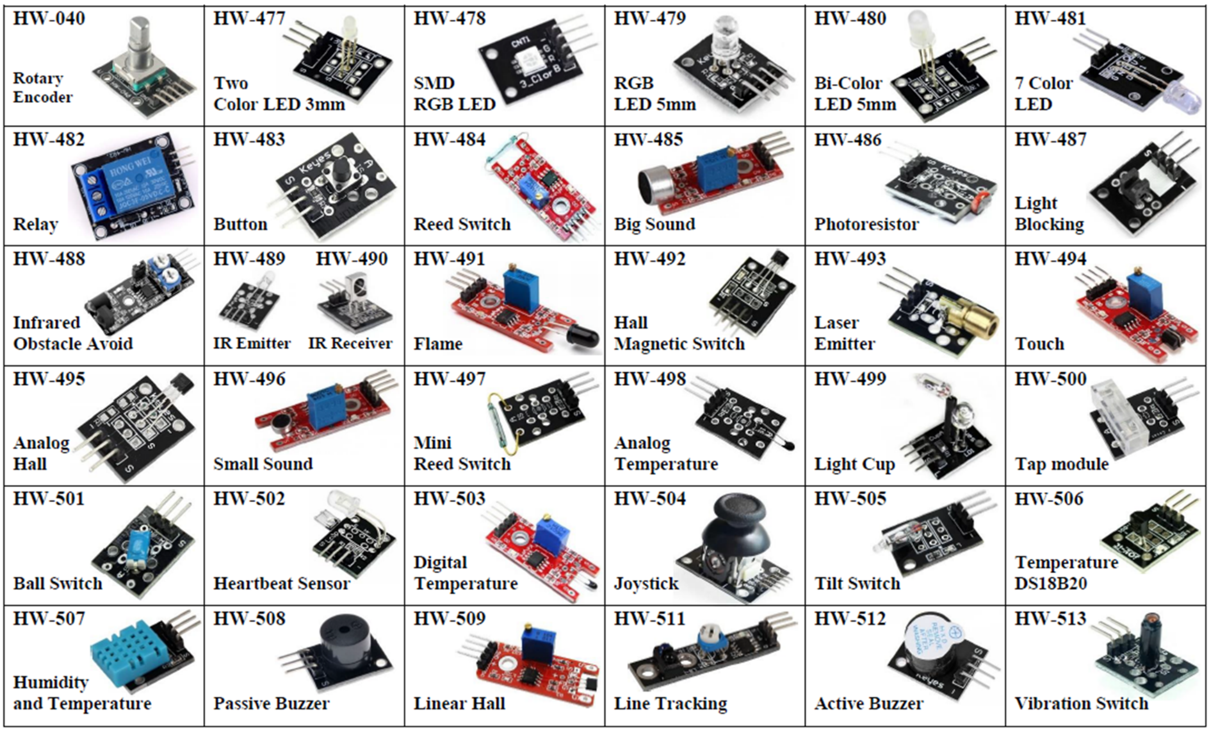


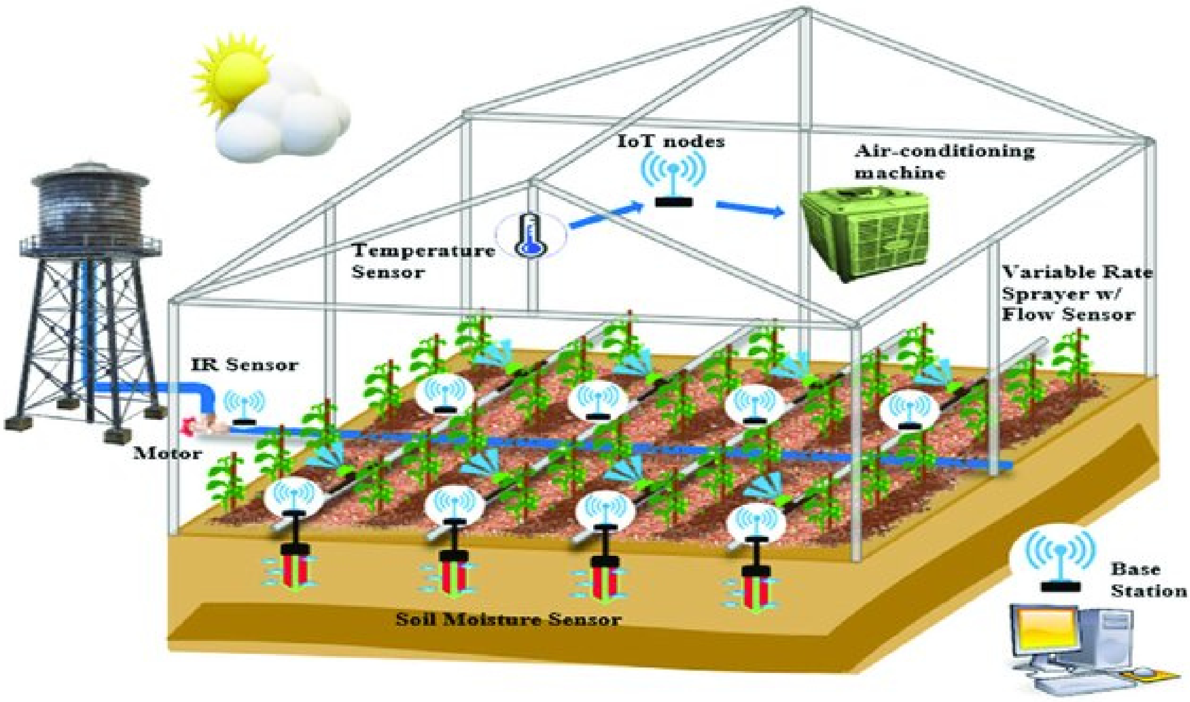
Figure 6 Analog and digital sensors
Image source: https://cleste.ro/kit-37-senzori-arduino.html

CONTROL SYSTEMS

Control systems must be considered from an IT and engineering point of view.

A control system is a set of devices, equipment or software designed to control and control the operation of a particular environment, process or machine in order to achieve the desired results or behavior. The control system monitors input signals from the environment (data coming from sensors) and generates output signals based on them, which affect the operation or status of the system.

Control systems collect data on the state of the environment, process the data, and then generate outputs to control and control the system to achieve optimal operation, efficiency and safety.



[Smart greenhouse ecosystem](#)

Classification of control systems

The two fundamentally different types of control systems are open-loop and closed-loop systems, which represent two basic approaches to automated control of systems. Both types have their own characteristics and scope of application, depending on how important feedback is in the operation of the system.

Open-loop (no feedback) control system

In an open-loop control system, the control device does not receive feedback on the output of the system. This means that the system takes into account only the input signals and performs actions or changes based on them, without checking whether the desired result has been achieved. Open-loop systems are simple, often cheaper, and are used when environmental changes and external disturbances have less impact on system operation or where accuracy and feedback are not critical.

Features of open-loop systems:

- Open-loop systems are generally much easier to use than closed-loop systems. No output data is required, they operate independently of the environment.
- Greater exposure to disturbances. They cannot detect errors, you cannot measure the output of your activities.
- Depending on the quality of programming, the chances of success are either very high or very low. If the system is robustly built, it is most likely to work well, otherwise it is more susceptible to failure.

Examples

- A simple electric heater that is turned on and off by a timer. Based on the settings of the timer, the heater turns on for a specific period of time, without taking into account the actual temperature in the room.
- An easy-to-understand example is an automatic washing machine, which performs washing cycles taking into account a certain period of time to maintain control of the system.

Closed-loop (feedback) control system
The closed-loop control system, also known as feedback control system, continuously monitors its output and sends feedback based on the received data, which affects the input of the system. Continuous feedback allows the system to adapt to environmental changes and unexpected disturbances, allowing it to maintain desired output state or performance more efficiently.

Example: the home heating system, which is equipped with a thermostat. The thermostat measures the temperature in the room, and when the temperature reaches the set value, the heating is turned off. If the temperature drops, the heating turns on again. Here, the feedback provided by the thermostat helps the system maintain the desired temperature.

How does the control system work?
A control system is a set of machines designed to manage other systems. The system usually consists of electronic circuits with pre-"burned-in**"** programs suitable for controlling the system.

The main components of control systems

Sensors
They collect measurable information about the environment or state of the system. These can be, for example, temperature, pressure, speed or position sensors.

Control unit
It processes data coming into the system from sensors, makes decisions and generates output signals to control the system. The control unit can be either a simple circuit or a complex computer system, depending on what tasks it is supposed to perform.

Actuators
Actuators are devices or equipment that respond to the output signals of the control unit and appropriately affect the operation of the system. These can be, for example, engines, valves, controllable electrical or mechanical equipment.

It is important to note that the design and implementation of control systems can be extremely diverse, and there are many different methods, technologies and standards for developing control systems. Depending on the specific application, control systems can be analog or digitally based and use different control strategies such as open loop, closed loop or modular

Basic functions of the control system

Control systems are usually grouped according to different criteria, but there are a few functions that are usually found in all systems. Such are control, planning, backup plan

Control
Control takes priority over other functions of the system, it is the system class that gives the commands. The specific functions vary, but the aim is always to manage the activities in the best possible way.

Planning
Each control system has a pre-programmed algorithm or other design. The plan consists of instructions for the implementation of the functions set. It shall include data defining the objectives and requirements to be met.

Whether it is an open-loop or closed-loop system, there is always the possibility of branching, where the system must choose the path by which it has the highest probability of achieving the intended result.

Fallback plans
Each control system has a "strategy" to avoid failure. Nevertheless, it happens that it is not possible to prevent a malfunction, for such cases there is a backup plan, which, with appropriate intervention, corrects the error and allows the system to return to a previous state.

Input current signals
Input current signals serve as a kind of warning or indication. Based on the input signal, the system is informed that an external power source is available. The signal can be identified by all control systems, but only closed-loop systems are able to interpret the signal and respond accordingly.

Variable that can be manipulated
In the control system, the "manipulable variable" (also known as the controllable or intervening variable) is the variable that is directly controlled or adjusted to achieve the desired output. This variable is the input sent to the system, which is modified by the control system so that the output variable (or measurable response) approaches the desired reference value.

For example, in a temperature control system, where the goal is to control the temperature in the room to a predetermined value, the variable that can be manipulated could be the power of the heating element or the cooling intensity of the air conditioner. The control system adjusts this variable to achieve and maintain the desired temperature level despite changing environmental conditions.

A variable that can be manipulated is often contrasted with disturbance, which is an unwanted external change that the system must compensate for, but cannot directly control. The task of the control system is to compensate for these disturbances and maintain the system in the desired state by properly controlling the variables that can be manipulated.

In open-loop control systems, the setting of manipulable variables does not depend on the output variable, i.e. there is no feedback. In this system, variables that can be manipulated are set according to predefined rules or programs, taking into account possible environmental conditions or other pre-known factors. Since there is no feedback, open-loop control cannot compensate for unexpected changes or disturbances that may affect system output.

In closed-loop (or feedback) control systems, the setting of manipulable variables directly depends on the difference between the output variable and the desired setpoint. The system continuously monitors the output variable and uses the received information (feedback) to precisely adjust the variables that can be manipulated so that the output approaches or matches the desired value. This enables closed-loop systems to react dynamically to changes and disturbances, improving system stability and accuracy.

Basic requirements for the control system:

The basic requirements for control systems can be broad and varied, depending on the application or industry in which they are used. These requirements generally include reliability, accuracy, stability, fast response time, and adaptability. I will go into more detail about these main requirements below:

- **Reliability**: the control system must work continuously for a long time with minimal maintenance. Reliability is key in safety-critical applications such as flight control or medical solutions.
- **Accuracy and repeatability:** the system must be able to produce the desired output values accurately and repeatably, even under changing environmental and operational conditions.
- **Stability**: the system must be stable in its responses, i.e. the output must not oscillate around the desired value, even if external disturbances occur.
- **Fast response time**: the system needs to react quickly to input changes or reference value changes to respond effectively to rapidly changing processes.
- Robustness: the system must be able to operate efficiently and maintain performance even if unexpected disruptions occur.
- **Adaptability and flexibility:** modern control systems must be able to adapt and operate flexibly under changing conditions and requirements, including changes in environmental conditions or user needs.
- **Energy saving and efficiency:** In energy-intensive industries and applications, it is particularly important that control systems operate in an energy-efficient manner, reducing operating costs and reducing the ecological footprint.
- **User-friendly interface:** Control systems must have an intuitive, user-friendly interface that allows easy setup, monitoring and maintenance.

These requirements are essential guidelines to be taken into account during the design phase in order to develop and build efficient, safe and reliable control systems.

Control systems in agriculture

Control systems used in agriculture make a major contribution to more efficient and optimised farming. They are useful both in crop production and animal husbandry, in the management and regulation of greenhouses. Some examples of agricultural control systems include:

Irrigation systems

Irrigation systems automate irrigation processes in agricultural fields. They use sensors to monitor soil moisture, meteorological data and water demand of plants, and then regulate the irrigation system based on this. This allows you to use water more efficiently, optimally water the plants and minimize water wastage.

Precision agriculture systems

Precision agriculture systems help farmers manage and monitor agricultural activities with greater precision. With GPS-based technology, they can accurately track the position and movement of machines on farmland, optimizing operations such as sowing, fertilizing or spraying. Precision increases productivity, reduces costs and minimizes environmental impact.

Production management systems

Production management systems help grow crops in greenhouses or other controlled environments. They monitor and regulate crop environmental parameters, temperature, humidity, light intensity and CO2 levels, enabling farmers to provide ideal conditions for plant growth and development and optimise energy production and use.

Links, literature used:

Sensors and measuring networks / László Zsolt Túrós, Gyula Székely.- Cluj-Napoca : Scientia, 2022

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1. Mobile communication in greenhouses

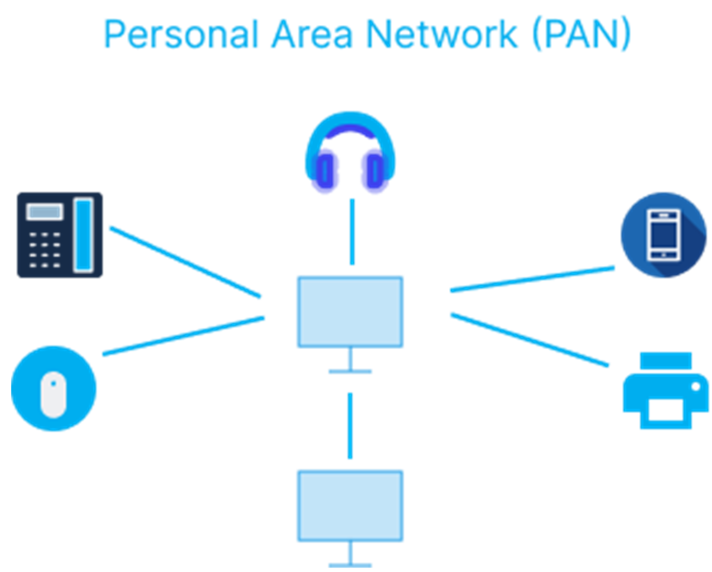
Author:

- Márton Gyöngyvér - Sapientia Erdélyi Magyar Tudományegyetem

1.1 NETWORK COMMUNICATION

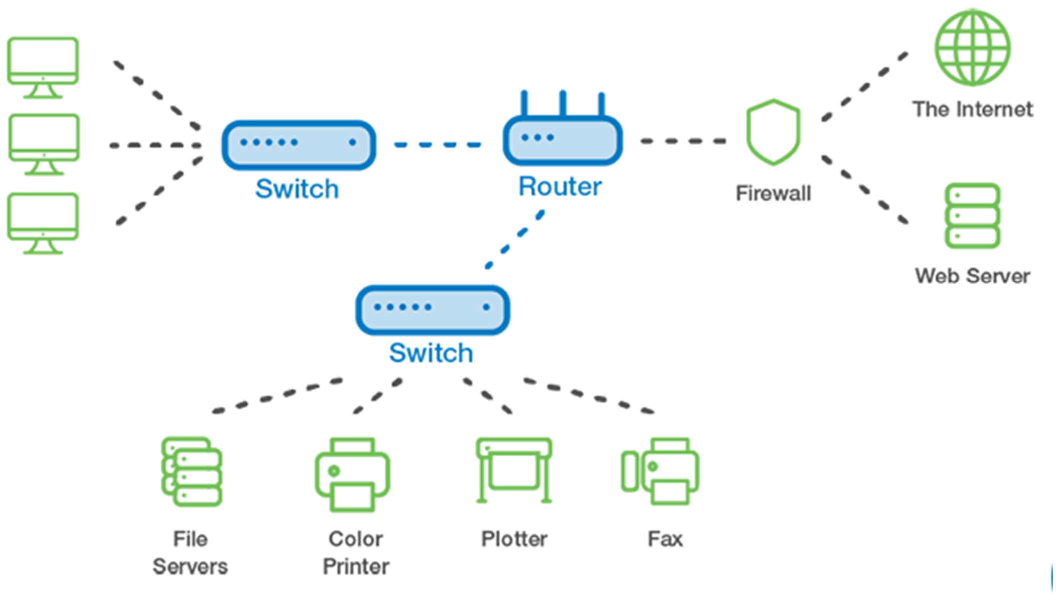
The need to share information and resources between different computers has led to interconnected computer systems, known as networks, so that data can be transferred from one machine to another. In these networks, computer users can exchange messages with each other and share resources such as software packages, data storage facilities, printer access, etc. To run such applications, a software system is required that also provides a network-wide infrastructure (Brookshear & Brylow, 2017). In the case of computer networks, we distinguish between:

- personal area networks (PAN), which are usually short-range systems, where devices involved in communication, such as digital TV, digital camera, printer, etc., are placed within a distance of less than a few metres:



source: https://www.prepbytes.com/blog/computer-network/types-of-computer-networks/

- local area networks (LANs), which are the interconnection of computers, mobile devices, printers, etc. in a single building or group of buildings:

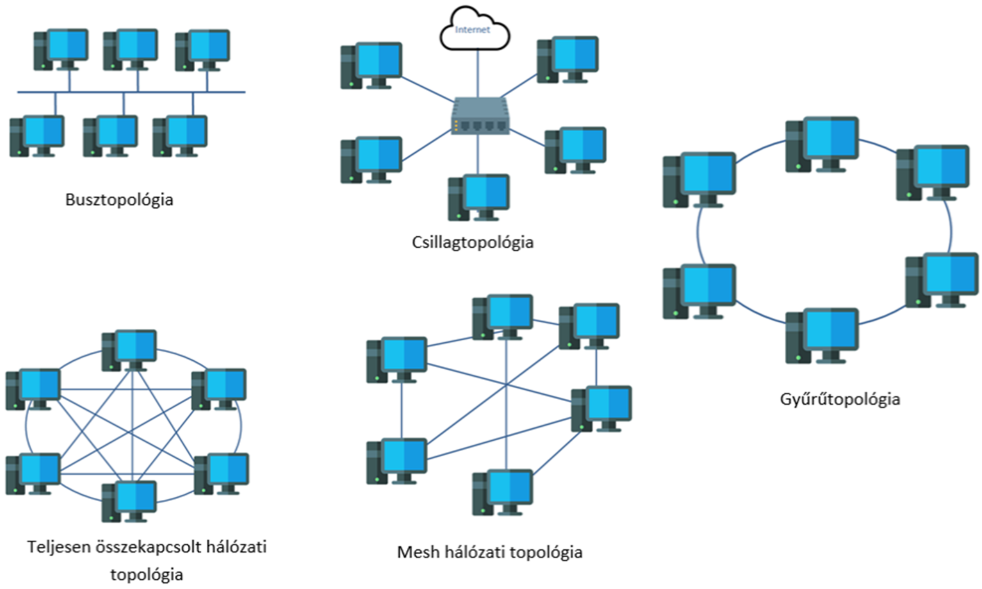


source: https://www.tpx.com/learn/networking-solutions/what-is-a-local-area-network/

- metropolitan area networks (MAN), which are medium-sized networks, such as a network covering a local community,
- wide area networks (WANs), which connect machines that are far apart, for example in neighbouring cities or devices on the other side of the world.

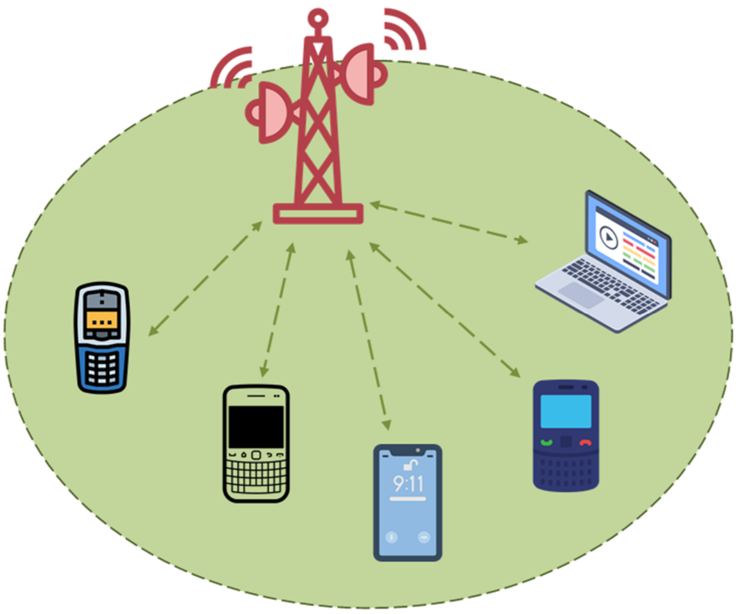
Another way to classify networks is based on whether the internal operation of the network is public or controlled. On this basis, we distinguish between **open** and **closed** networks. For example, the Internet is an open system. Communication over the Internet is governed by an open set of standards known as the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite. Because it is an open system, these standards can be used freely by anyone without paying a fee or signing a licence agreement. In contrast, Novell Inc. develops and operates proprietary systems and earns revenue from the sale or lease of these systems. This is a closed system.

Another way of classifying networks is by the pattern in which machines are connected. The two most popular topologies are the bus, in which machines are all connected to a common communication channel, and the star, in which one machine is central because it is connected to all the other machines. Ring topologies, fully interconnected network topologies and mesh topologies are also used. Bus topology has been popular since the 1990s, when Ethernet networks were developed. Star topology has its roots in the 1970s and is used today to power wireless networks. In these networks, communication takes place via radio transmission and is coordinated by a central machine called an AP-access point. However, the difference between a bus network and a star network is not always obvious.

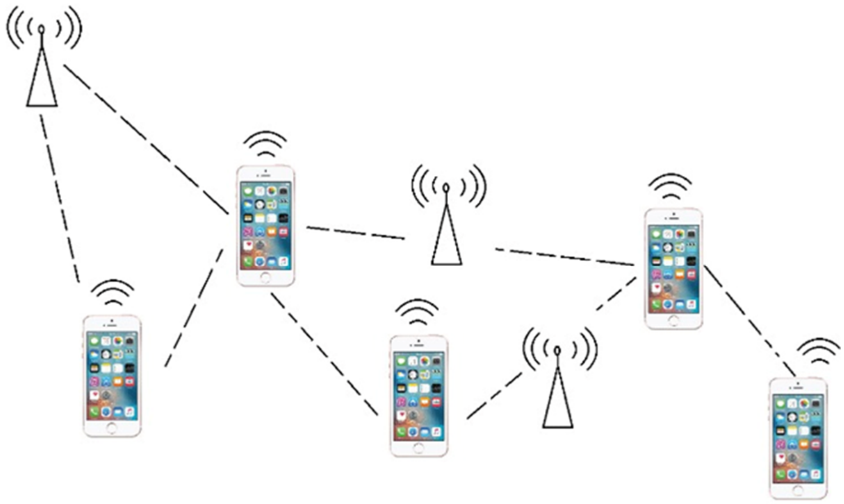


Mobile communication systems are usually divided into three categories. These are:

- Systems based on a fixed communication infrastructure are the most commonly used systems, where an access point is used to connect to the network. This includes mobile systems such as 2G, 3G, etc. networks:



- Communication systems based on autonomous nodes are used for traffic management and routing. These systems often do not use a fixed communication infrastructure. Examples of such systems are ad hoc networks and wireless sensor networks:



- Hybrid networks combine the previous two categories.

In wireless ad hoc networks, data traffic is routed through nodes. Network devices are free to move around and the connections between devices change frequently, so the information needed to manage traffic in the nodes must be kept up to date.

Wireless sensor networks (WSNs) combine sensors with computing elements. They can integrate hundreds or even thousands of low power, low cost sensors. The sensors can be mobile or fixed, and their job is to monitor the environment. They often have one or more base stations. A base station may be connected to another network, to a high-performance data processing and storage centre, or serve as a connection point to human-managed units.

In order for a network to work reliably, it is important to establish the rules by which network activities can be carried out. Such rules are called **protocols** and developing them is an essential process, because without rules, for example, all computers may try to send messages at the same time, or one computer may not receive content from another computer. Protocols can be implemented at the hardware or software level, or a combination of both. During communication, the parties involved must agree on the protocol to be used. To be agreed, the protocol must conform to standard specifications.

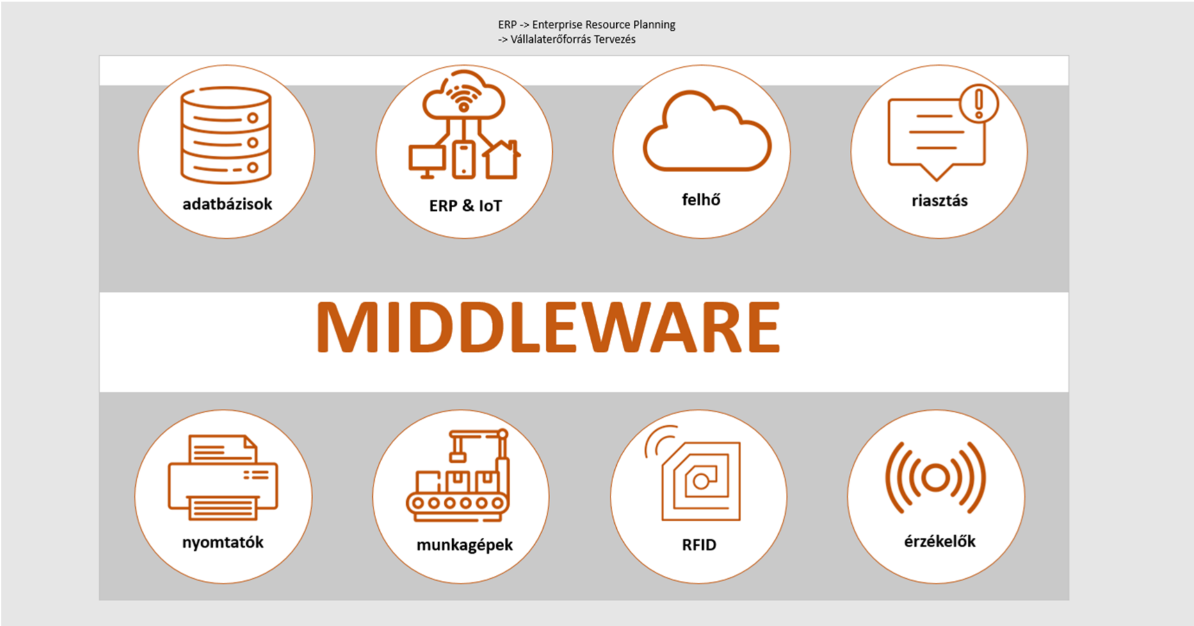
Internet communication protocols are published by the Internet Engineering Task Force (IETF). The Institute of Electrical and Electronics Engineers (IEEE) handles wired and wireless networks, and the International Organization for Standardization (ISO) handles other types.

Request-response (request-reply) is one of the most basic, efficient protocols by which computers communicate with each other. According to the protocol, an exchange of messages between two entities means that the requester sends a requesting message and the receiver, upon receipt, processes the request and sends back a message in response. This is similar to a telephone call, where the caller has to wait for the receiver to pick up and only then can the conversation start. In a client/server architecture, communication is therefore done according to the protocol. The protocol can be used in a **synchronous** mode, for example for web services over HTTP, which means that a connection is maintained until a response is received or the timeout period expires. The protocol can also be implemented in **asynchronous** mode, where the response is returned at an unknown later time.

A **lightweight** protocol in a computer network carries a relatively small amount of data in addition to functional data.

Publish-subscribe is a communication protocol where message senders do not send messages directly to a specific recipient, but to so-called subscribers. Without knowing who the subscribers are, the senders group the published messages, and the subscribers, without knowing who published the message groups, indicate which message group they are interested in, i.e. they subscribe. Thus, subscribers will receive the messages to which they subscribe.

Middleware acts as an intermediary between computer applications, data and users. It makes it easier for software developers to intelligently connect applications, simplifying application development. It helps system operators to deploy applications:



Discovery of services and resources is a technology that enables devices or services to automatically connect to a computer network without manual intervention. It allows different types of applications and microservices to work together. There is client-side and server-side discovery.

M2M (machine to machine) is a set of communication techniques between two devices using a direct channel without human intervention. It can be used in both wired and wireless communication. M2M communication enables a sensor or measuring instrument to transmit the information it records (e.g. temperature, wind speed, humidity, etc.) to a device that stores, pre-processes and analyses this data using its own software.

1.2 SECURITY OF MOBILE SYSTEMS

Security is defined by three factors: confidentiality, integrity, and availability (S. Bharati, et al., 2023):

Confidentiality means that only authorised devices, systems and persons have access to sensitive information. The oldest technique to protect data is to encrypt it. In computing, this means using top-secret information called a key to transform, encrypt, store and transmit data. When we need the original or transmitted data again, we use the key to recover it. However, the sharing of data encrypted during communication must be preceded by an exchange of information in which the parties agree on the top secret key to be used and authenticate each other. Both key agreement and authentication are very important parts of the communication.

Integrity means that data transmitted over the communication channel must reach its destination without modification. To achieve data integrity, hash functions or message authentication codes are most commonly used. Hash functions are mathematical functions that usually produce a smaller fixed-length string of data, such as 128, 160 or 256 bits, from a string of arbitrary length. This is also known as a trace of the data series. One of the most important properties of hash functions is that the trace cannot be used to recover the original data sequence. Both hash functions and message authentication codes have many applications. For example, when storing a password, the system does not store the password, but the hash value of the password. In practice, a frequently used and secure hash function is SHA-256, the first versions of which were designed by the National Security Agency (NSA) in 1993.

Availability means that data on a data storage server, a server device, must always be immediately available to legitimate users. Commonly used by attackers, denial of services (DoS) or distributed denial of service (DDoS) attacks are attacks that attempt to exhaust system resources. To ensure availability, the hardware and software that stores, manages and displays data must be properly maintained and the technical infrastructure must be constantly monitored.

The most common security problems encountered in mobile communications are (Boudriga, 2009):

- the communicating parties are not sure of each other's identity: when communicating parties who know each other can identify each other by email address, voice, but beyond that, the system usually lacks authentication, many will easily accept any identifier,
- it is easy for a third party to intercept your communications, because although the standards for communications provide some protection against targeted interception, they do not,
- the billing records kept by the service provider contain a lot of confidential information that can easily be leaked: identification numbers of the communicating parties, time and place of communication, etc.

Often, however, the security of mobile communications is affected by factors that are independent of the developers and operators of the system, because the services are often used by users who

- are not aware of basic safety issues,

- do not understand the basic security risks,
- do not have the right skills,
- do not have the means to protect themselves.

There are several ways to secure mobile systems. We distinguish between security at the network level, transport level and application level.

Security at the network layer is transparent to end users and applications. It offers general purpose security solutions with filtering options, for example, you can set to allow only selected traffic to be accessed. It is part of the operating system, so to modify it, the operating system must be modified.

Security at the transport layer is primarily used to implement security for web transactions.

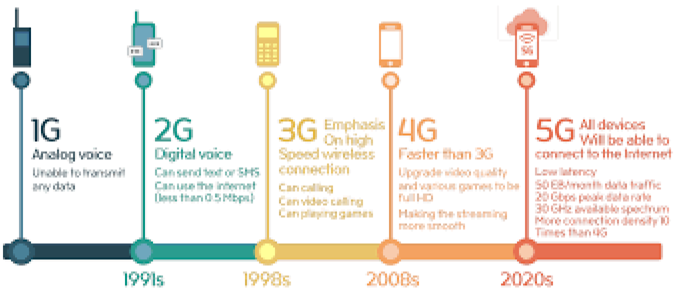
In application layer security, services are embedded in a specific application. The advantage is that the service can be tailored to the specific needs of the application.

Another security problem is that when messages are transmitted, they are not protected against unauthorised copying. Copyright protection can be ensured by embedding watermarks (special patterns). Watermarks can be used to prove ownership, identify the infringer, trace the distribution of the message/document or simply inform users of the rightfulness of the data.

1.3 MOBILE NETWORK TECHNOLOGIES: 2G, 3G, 4G, 5G AND FUTURE DEVELOPMENTS

An important feature of wireless networks is the mobile service, which means that communication can be implemented anytime, anywhere, and users can even request roaming services autonomously (Boudriga, 2009). The development of mobile communication technology has led to increasing data transmission speeds, which nowadays, even for complex applications, often approach the speed of fixed networks:

Since the first switchover from analogue 1G data transmission in 1981 to digital 2G transmission in 1992, new generations of mobiles have appeared every ten years or so. A new mobile generation represents a change in the fundamental nature of mobile service, where new technology is not always backwards compatible. A new generation means higher bit rates, new and wider frequency bands and more simultaneous data transmission capacity.



source: https://www.linkedin.com/pulse/1g-2g-3g-4g-5g-wireless-phone-technology-explained-meaning-samad

Mobile communications are based on the GSM (Global System for Mobile Communications) standard, developed by the European Telecommunications Standards Institute (ETSI) for cellular networks. In cellular networks, data to and from end points is received and transmitted over a wireless link. The network is distributed over a terrestrial area called cells and each cell is served by at least one, but usually three, transceiver base stations. A cell uses a different set of frequencies from neighbouring cells to avoid interference and ensure quality of service. Portable transceivers (mobile phones, laptops, etc.) communicate with each other and with fixed transceivers via base stations (www.tell.hu, 2023).

The first GSM network, 2G, which was used between 1992 and 2001, still offered very slow data rates (9.6-14.4 kb/s). It initially promised a very high theoretical bit rate (172 kb/s), but the maximum bit rate achieved in practice was only 45 kb/s. It allowed users to call each other on the phone, send SMS (Short Message Service) and MMS (Multimedia Messaging Service) messages to each other.

Low data traffic devices, such as payment terminals, cash registers, legacy phones, IoT devices, smart meters, eCall systems, vehicle trackers, are still widely using 2G technology. These systems have thus been able to avoid newer technologies with high usage costs. It is not even possible to eliminate 2G services altogether, as this would risk that devices with only 2G infrastructure would not be able to connect to the appropriate service providers, for example in an emergency the device owner would be unreachable or unable to contact the appropriate authorities.

UMTS (Universal Mobile Telecommunications System), the 3G network, whose widespread use dates from 2001 to 2008, achieved higher data rates, typically 384 kb/s, even though theoretically 2 Mb/s was announced. However, the actual performance of UMTS under real-world conditions with high network loads was variable. The 3G service provided Internet browsing, music listening, video and music downloading, streaming and navigation. Today, it is no longer economical to maintain 3G infrastructure, which is why devices that cannot connect to the next generation 4G and 5G networks are switching back to 2G.

4G technology has been available since 2008, while 5G has been in use since 2018. Both can handle much higher data traffic and are more secure.

4G technology offers mobile web access, gaming services, high-definition mobile TV, video conferencing, 3D TV, etc. The latest standards offer upload speeds of 150 Mbps and 50 Mbps compared to previous technologies.

The 5G standard has 3 levels, the weakest being Low Band, followed by the medium Mid Band and the strongest being High Band. The Low Band offers speeds 20-30% faster than 4G and uses the same 600-900 MHz frequency range as 4G. The Mid Band offers data speeds six times faster than 4G, from 100-900 Mbps. It is the most widely used service, and is the most commonly deployed in metropolitan areas. High Band can also increase the medium band level tenfold. It uses frequencies between 24 and 47 GHz and often reaches download speeds of up to Gbit/s, similar to fixed services. Due to its high deployment cost, it is only deployed in dense urban environments where crowds gather, and therefore not ubiquitous due to incomplete coverage.

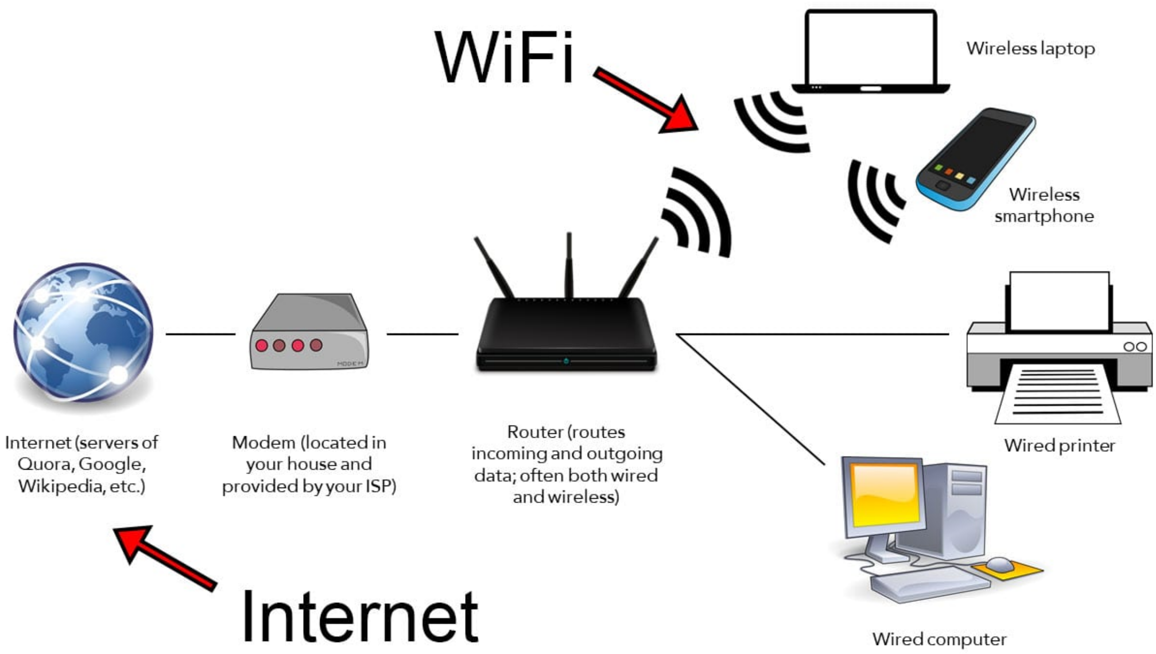
A new generation of mobile services usually requires an update of the software of your mobile device, a change of network settings or a device replacement.

Additional wireless communication systems are in use to provide wireless communication between devices in smaller areas. These include satellite-based systems, wireless local area networks (WLANs) and wireless personal area networks (WPANs). These networks provide high data transmission speeds.

1.4 MOBILE CONNECTIVITY

Wi-Fi

Wi-Fi (Wireless Fidelity) is a family of wireless networking protocols commonly used to connect different devices together or to connect devices to the Internet, allowing data to be exchanged between devices. It is one of the most widely used technologies used worldwide to connect devices to the Internet in homes, small office networks, public places such as hotels, libraries, airports, etc. Wi-Fi is designed to work seamlessly with wired Ethernet. Compatible devices can connect to each other, to wired devices and to the Internet via wireless points. Wi-Fi is a trademark of the Wi-Fi Alliance, which limits the use of the term "Wi-Fi Certified" to products that are compatible with each other:



source: https://www.hellotech.com/blog/what-is-the-difference-between-bluetooth-and-wifi

Different versions of Wi-Fi are defined by different IEEE 802.11 protocol standards and different radio technologies. The available radio band, maximum range and speed also depend on the version. Wi-Fi most commonly uses the 2.4 gigahertz (120 mm) UHF and 5 gigahertz (60 mm) SHF radio bands; these bands are divided into several channels. The channels can be shared between networks, but only one transmitter can transmit on a channel at a time within range.

Nowadays, more and more wireless technologies are being used in communication messaging. NFC and Bluetooth technologies are the biggest players in this field. Both technologies allow two devices to communicate within a short range, ensuring secure data transfer between devices.

Bluetooth

Bluetooth is a wireless technology that allows data exchange between fixed and mobile devices within short range. It is an open source standard. It is named after the Danish King Harald the Blue Tooth, who reigned in the ninth century.

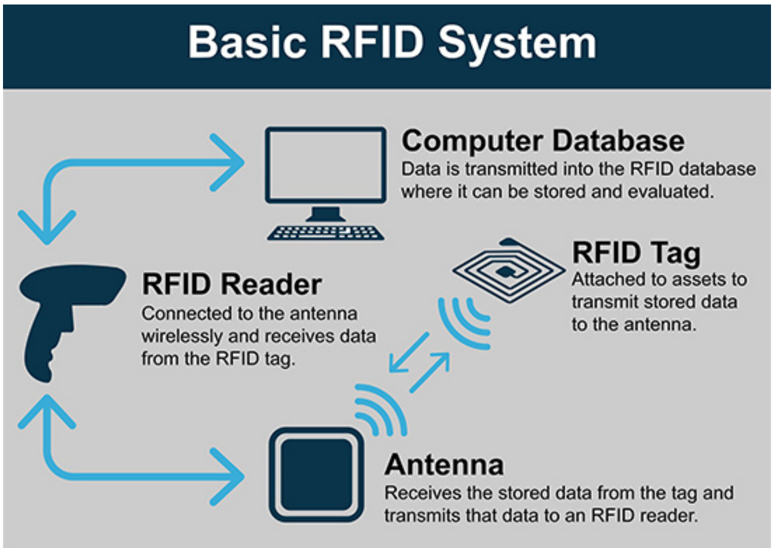
Bluetooth uses UHF radio waves, in Europe and the USA this means the range between 2.402 GHz and 2.480 GHz. It manages a total of 79 dedicated Bluetooth channels with a bandwidth of 1 MHz per channel. It splits the transmitted data into packets and transmits each packet on one of the designated Bluetooth channels.

Many systems use Bluetooth Low Energy (BLE) technology because the technology offers high energy efficiency and performance. Systems using BLE technology can run for months on a single-cell battery alone. Bluetooth-enabled smartphones have also become part of everyday life, and a mobile phone is always at hand so many devices can connect to your mobile phone via Bluetooth. No need to carry additional cards, remote controls or remember PIN codes.

NFC and RFID

Near Field Communication (NFC) is a contactless short-range communication technology. NFC was launched by NXP Semiconductors and Sony as a further development of RFID (Radio Frecquency IDentification) technologies and smart card technologies. Radio Frequency Identification allows devices in close proximity to each other to identify and exchange data over radio waves.

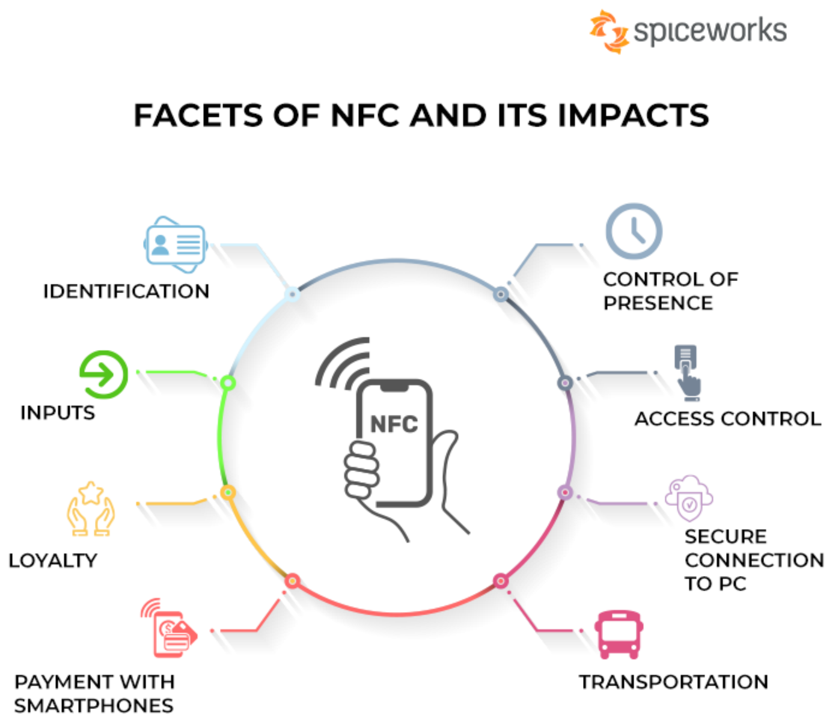
An RFID system consists of three components: an RFID tag/transponder, an RFID reader/interrogator and an application.



source: https://www.bradyid.com/intelligent-manufacturing/what-is-rfid

Operationally, the RFID reader "asks" the RFID tag by emitting a radio wave, and the RFID tag responds by sharing the data it stores with the RFID reader. It can read data from multiple RFID tags at the same time. The RFID reader transfers the data received to a database for storage. The application will process the data based on the data stored in the database. The RFID reader can read both stationary and moving RFID tags. RFID systems are used for asset and location tracking, theft prevention, access control, logistics, animal tracking, etc.

NFC technology is also built around three components. A tag, a reader and the software. But an NFC tag can also act as a reader, and vice versa, the NFC reader can be used as a tag. Therefore, unlike RFID systems, it is suitable for two-way communication, where a fast identification process and data transfer can be achieved between devices that are physically close to each other (1-10 cm). Data from one tag can be read at a time. Often used in contactless payment, smart greenhouses, intelligent transport, smart homes, industrial applications. Its popularity can be explained by its low cost, convenience, reliability and integration with smartphones. At the same time, it can be used to deploy management services due to the information storage capability of NFC tags. For example, NFC can be used to improve the management of production and sales processes in greenhouses. Connected to smartphones, even low-skilled farmers can effectively manage production and sales processes.



source: https://www.spiceworks.com/tech/networking/articles/what-is-near-field-communication/

NFC has three modes: peer-to-peer, read/write and card emulation.

Peer-to-peer mode allows two NFC devices to communicate directly with each other. Communication is bidirectional and standard data structures can be exchanged. In read/write mode, an NFC device can access a passive NFC tag or interact with smart cards.

In card emulation mode, an NFC device emulates a contactless smart card, allowing NFC devices to work with legacy RFID readers.

Like any other electronic device, RFID and NFC devices must comply with various standards and regulations.

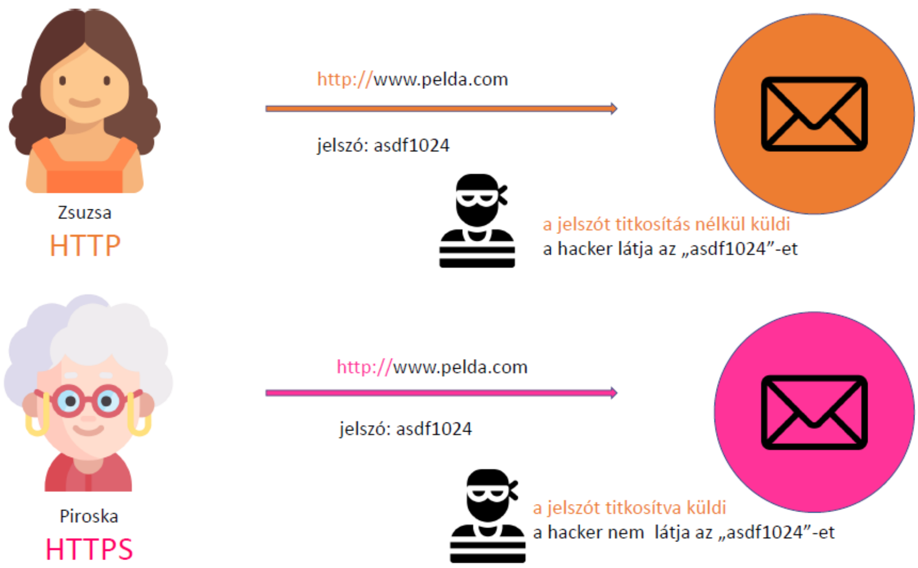
Alternatively, barcode, qr-code, wifi, bluetooth, etc. technologies are used.

1.5 COMMUNICATION PROTOCOLS IN GREENHOUSES

HTTP

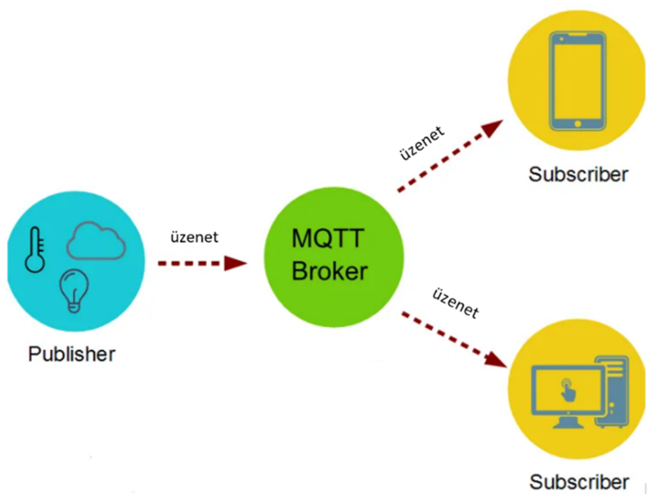
Hypertext Transfer Protocol (HTTP) describes the basics of web communication, the basis for all computer data exchange between a client and a server. For example, the client, a web browser, makes requests that are served by the server, the recipient. Requests can come from the client via text input, mouse clicks, screen taps. The protocol handles hypertext type documents, which means that references can be made in the documents through which the client's requests are fulfilled using various resources. It does not use encryption or authentication and is vulnerable to multiple attacks, but is fast due to the lack of security settings. It is generally used for information sharing. It is not expensive to maintain.

HTTPS is a secure version of HTTP, (httpwg.org, 2023), is not a standalone protocol, runs on top of HTTP and uses the TLS/SSL standard for security. It assures the user of the confidentiality and integrity of the communication and that the website being visited is authentic. However, secure communication can only be achieved if appropriate encryption packets have been selected and the authenticity of the server has been verified. Built into all modern web browsers, its use depends on the web server. It is protected against multiple attacks. Slower than HTTP due to the security settings used. It is mandatory for websites handling sensitive data (passwords, card details, etc.). It is expensive to maintain,



MQTT

Message Queue Telemetry Transport (MQTT) is a lightweight, open, free and easy to implement protocol for publish/subscribe communication between a client and a server. These characteristics allow it to be used in restricted environments such as M2M (Machine to Machine) communication or in IoT (Internet of Things) contexts where only a small amount of code sequences can be processed. It has been designed to work efficiently in low bandwidth, low battery usage and unstable connections. The messages are published by the sender (publish), but it is not necessary to know who has received or subscribed to the messages. Subscribers receive all messages via an MQTT broker.



CoAP

Constrained Application Protocol (CoAP) is a web transport protocol that can be used for restricted nodes and restricted networks. The nodes often have 8-bit microcontrollers, small amounts of ROM and RAM, while the network is often a low-power, wireless, personal network with frequent losses, packet errors, and a typical transfer rate of 10 kbps. The protocol is designed for machine-to-machine (M2M) applications, such as smart energy apps or building automation (datatracker.ietf, 2023).

Between application endpoints, CoAP provides a request-response type interaction protocol, supporting built-in discovery of services and resources, key web minds such as URIs and web media types. It is characterized by very low overhead and simplicity in constrained environments. It has been designed to be able to easily connect to HTTP, but also to meet specific needs such as unicast and multicast request forwarding, or asynchronous messaging.

AMQP

The Advanced Message Queuing Protocol (AMQP) is an open source standard for asynchronous messaging in wired networks. It is an Internet Protocol Application Layer protocol used by middleware. It features message orientation, message queuing, routing (including point-to-point and publish-subscribe), reliability and security. AMQP sends data as a byte stream and can therefore interoperate with any device that can generate and interpret this type of data, (amqp, 2023).

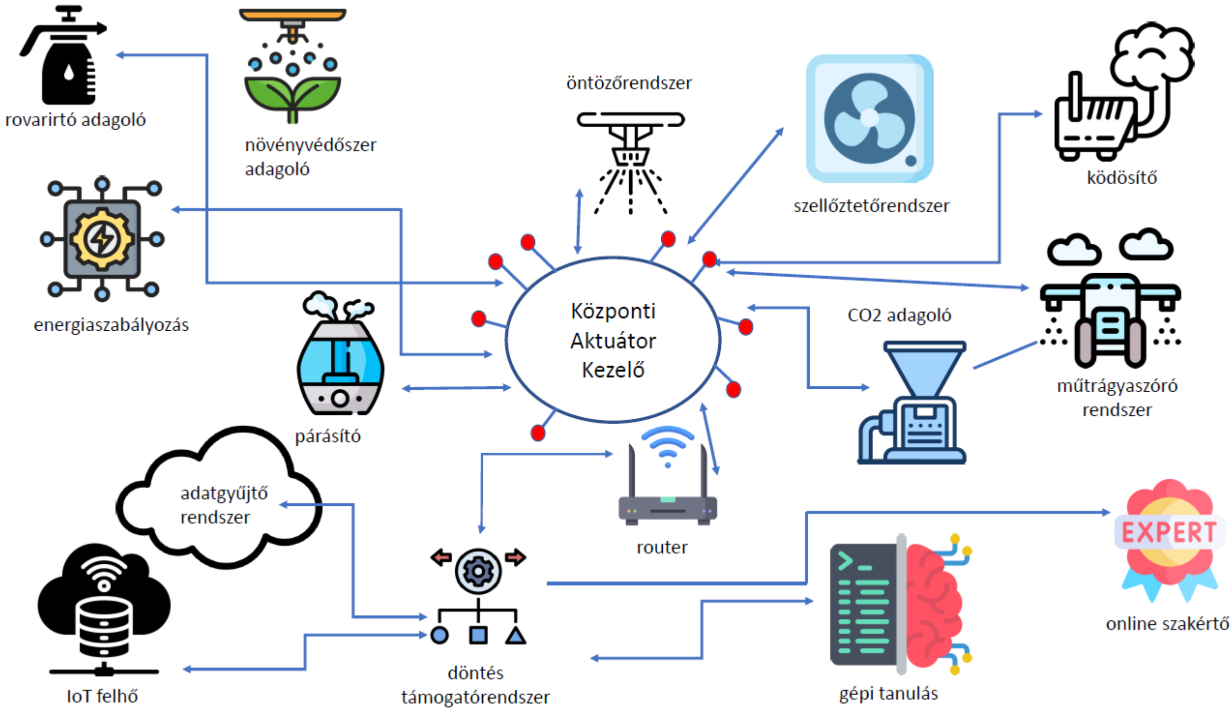
AMQP is designed to efficiently support a wide range of messaging applications and communication patterns. It provides continuous, message-driven communication, with three options for message delivery: at most once, at least once and exactly once. It also provides SASL and/or TLS based authentication and/or encryption. It assumes that a trusted transport layer protocol such as Transmission Control Protocol (TCP) is running in the background.

It is defined in the AMQP specification:

- the type system,
- the symmetric and asynchronous protocol for transferring messages from one process to another,
- the standard and extensible message format,
- a set of standard but extensible messaging options.

1.6 THE IOT (INTERNET OF THINGS)

The Internet of Things (IoT) is a network of physical objects accessible via the Internet. These objects are in constant contact with the external environment, with each other or with the user, using various technologies. The IoT is commonly seen as the third stage in the evolution of the Internet. In the 1990s, the Internet had around 1 billion users, mobile communications in the 2000s connected a further 2 billion users, and by 2022 the IoT was able to connect 35 billion 'things' via the Internet. These include smart watches, sensors in cars, greenhouses, etc... All because the reduction in the cost of sensors and processing power, the low cost of the hardware and software needed to connect devices, and the increase in bandwidths have made it possible to connect "things" in a simple and efficient way, (Banafa, 2023).



The IoT has features that make it significantly different from the regular Internet, such as sensing, efficiency, networked devices, specialised operations and ubiquity. These features could change the direction of technological developments, with significant implications for technology companies. For example, the shift from the former wired to mobile internet has shifted the focus from Intel to Qualcomm and from Dell to Apple.

Several technological changes have enabled the IoT to spread, including:

- cheap sensors: the price of sensors has fallen by an average of 60 cents from \$1.30 over the past 10 years,
- cheap bandwidth: the cost of bandwidth has fallen nearly 40-fold in the last 10 years,
- low-cost processing: processing costs have fallen by almost 60 times in the last 10 years, allowing a device to process data generated and received in addition to connecting,
- smartphones: smartphones act as remote controls or hubs in connected homes, connected cars, greenhouses, or health and fitness devices,
- wireless coverage: the extensive Wi-Fi coverage means that wireless connectivity is available at a very low cost,
- big data: IoTs generate large amounts of unstructured data, which is crucial to analyse,
- IPv6: IPv6 is the latest Internet Protocol (IP) standard that supports 128-bit addresses, as opposed to IPv4 which could only handle 32-bit addresses and has been exhausted by connected devices worldwide. 128-bit addresses, however, translate into approximately 3.4 × 1038 addresses - enough to handle every IoT device imaginable.

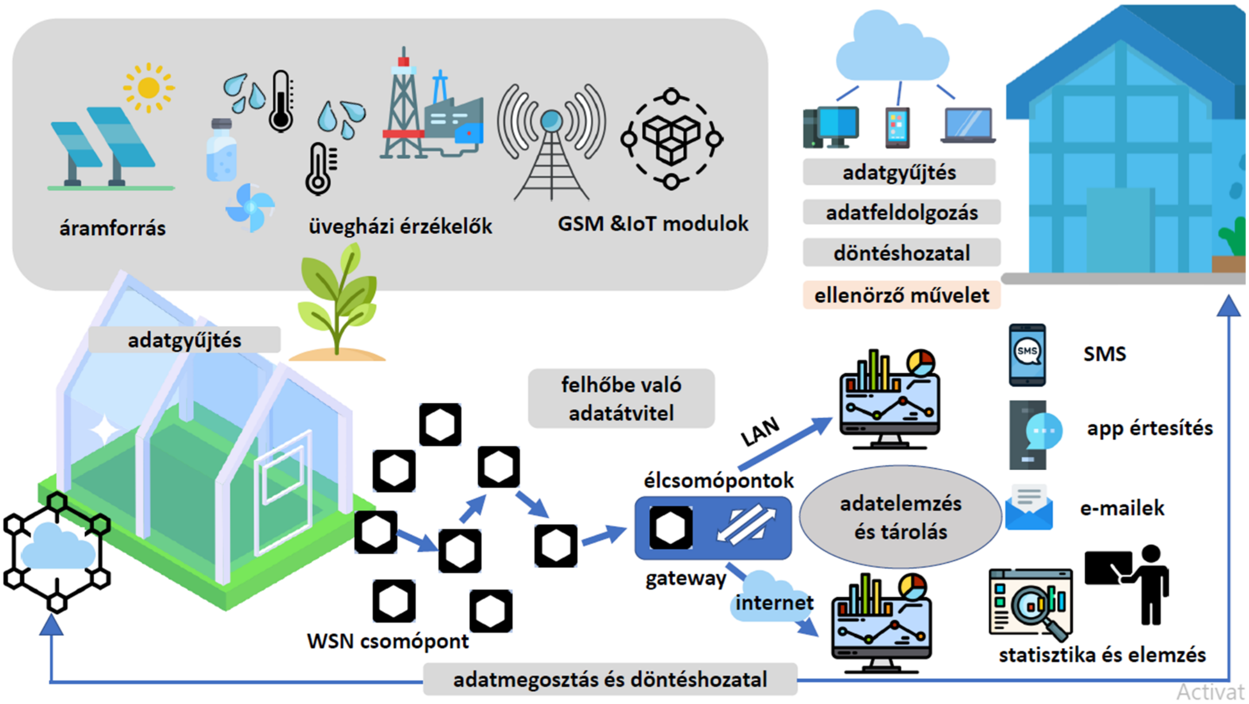
One of the downsides of IoT is that it is difficult to draw the line on privacy and security issues. Smart devices handle a lot of personal data and information about the user, and misuse of this data can cause great harm. Another disadvantage is that most devices cannot communicate only with other devices from the same manufacturer. It is true that the AllJoyn Open Source Project, (openconnectivity, 2023) is trying to ensure that devices from different manufacturers can be connected, but IoT technology is still a long way from developing a unified system.

1.7 GREENHOUSES AND MOBILE COMMUNICATIONS

The world population is likely to reach 9.7 billion by 2050, which will also lead to an exponential increase in food demand. This could lead to a number of problems such as water and air pollution, greenhouse gas emissions and global warming. These problems highlight the need to develop sustainable solutions for food production. The deployment of precision farming greenhouses could be a key to solving these problems.

The mobile control systems installed in greenhouses are fully capable of providing integrated control of temperature, humidity, irrigation, fertilisation, CO2, light and shade levels. Precise control of the cultivation operation allows farmers to achieve greater savings in energy, water, chemicals and crop protection products. Mobile control generally promotes greater operational consistency, scheduled production, higher product quality and environmental cleanliness, (Manohar & Igathinathane, 2007).

In a greenhouse, a single computer can control hundreds of devices (ventilators, heaters, fans, hot water mixing valves, irrigation valves, curtains, lights, etc.) and can process thousands of input parameters, such as indoor and outdoor temperature, humidity, wind direction, wind speed, CO2 level, etc. Mobile systems can receive signals from all the sensors installed and send commands to each device at the appropriate intervals. At the same time, a computer system can collect and record data from various external parties, which, once processed, allow the farmer to know all the factors affecting the quality and quantity of the product:



Systems can produce data visualisations (graphs, reports, summaries) of past and present environmental conditions, which present the evaluated data in a more transparent way.

Even with the proliferation of computerised systems, it should be remembered that the success of crop production depends first and foremost on the farmer's knowledge of crop management. These systems can help, first and foremost, by making greenhouse production more precise, and are only as effective as the software they run correctly and the digital competence of the farmer operating the system.

In addition to the advantages of computer systems, it is also worth considering the disadvantages:

- high initial investment costs,
- requires skilled system operators, both digital and mechanical,
- the number of maintenance, care and precautionary measures may be higher,
- for small-scale and seasonal production is not always economical.

In terms of computing technologies, the following can be applied to greenhouse operations: wireless sensor networks (WSN), Internet of Things (IoT), artificial intelligence (AI), space technologies, remote sensors, computational algorithms, blockchain technology, big data, and radio frequency identification (RFID). These technologies can be used to analyse, generate, receive, transmit and process data.

And microchips, sensors, positioning systems (GPS systems), computer software, communication systems, internet protocols, meteorological data are the tools that provide the data processing for crop production (Mottram, 2022).

The invention of transistor switches, and later silicon etching techniques and the advent of **microchips, enabled the** emergence of today's electronic and digital devices, and their dramatic reduction in size and production costs has led to their widespread use in various sectors of agriculture, such as precision greenhouse cultivation.

The emergence of various sensors and **detectors** provided the detection and monitoring of data such as speed detection, airflow, humidity, animal and plant disease characteristics, etc.

Global Positioning Systems (GPS systems) were originally developed by the US military in the 1970s. These and more recent global navigation satellite systems have made it possible to determine positional data within a few metres, which can be used for vehicles in the field, but also for locating plants in open or confined areas.

Computer software are applications that can analyse digital images, multimedia content, build models, explain relationships, etc. They can be used to recognise plants, detect pests, identify physiological stages, etc. Data were first digitised in the 1950s, but soon afterwards software was developed that allowed structured, systematic processing of large amounts of data. All current databases store huge amounts of searchable and analysable data.

Communication possibilities have changed dramatically with the advent of the Internet and then mobile devices. Every digital object (text, video, image, sound), e-mail and web page travels over the Internet as a series of packets, each of which can be precisely identified by the Internet Protocol standard, knowing where it comes from and where it is being transmitted. The World Wide Web provides a Uniform Resource Locator (URL) anywhere on the Internet so that these digital objects can be easily linked and transmitted.

In developed countries, modern **meteorology** can provide detailed weather forecasts down to 1 km resolution and predict the weather up to 7 days in advance. This has a major impact on the planning and execution of operations in greenhouses, significantly reducing the risks from weather-related hazards.

A greenhouse farmer's network of contacts has a big impact on the business success of the greenhouse. Direct, fast and regular communication with different people is facilitated by the Internet and mobile communications, but you need to know how to use them. In addition to customer contact, advertising services, customer management and information services may also need to be included in business policy. In the case of suppliers, GPS technology can be used to make delivery logistics easier. In dealing with different agencies, the appropriate use of software can ensure two-way data provision and availability of specifications. With the right services from financial institutions, mobile payments, dues payments and internet banking can be made easy. Advocacy organisations can provide quick access to information, up-to-date information and advice.

Mobile applications include applications for production management, process control, product tracking and quality assurance.

A farmer running a greenhouse has to take several data into account when deciding on operations on the farm. This is usually raw data from sensors on tools and machines:

- crop and GPS data: data correlated with GIS information from drones,
- market and pricing data from third-party cloud servers to help you build a picture of potential crop value and demand,
- Internet weather forecast data (temperature, wind speed, wind direction, precipitation, humidity, air pressure, etc.),
- data from sensors that measure local environmental conditions (current weather data, soil condition data, crop data, image and video data indicating plant condition/disease,
- Data on the water supply in the area via the Internet,
- Price information on agricultural products via the Internet in national and international contexts.

1.8 MOBILE COMMUNICATION APPLICATIONS IN GREENHOUSES

There are now a number of sensors and tools on the market to support farmers to build smart greenhouses on their own, even on their own. Current digital technology can be used to monitor soil quality, for example, and the systems also offer solutions to help farmers avoid soil degradation, (S. Bharati, et al., 2023). IoT technology enables soil management, with a focus on soil water retention, texture and absorption rate. They can help avoid excessive fertilizer use, reduce compaction, salinization, acidification, pollution and erosion. For example, serious soil analysis can be carried out with the Labin-a-Box soil analysis toolkit from AgroCares (AgroCares, 2023). Any farmer can use the Labin-a-Box to analyse 100 samples a day without having to visit a laboratory with the samples taken.

In 2009, the Soil Moisture and Ocean Salinity (SMOS) satellite was launched, which provides maps of global soil moisture every day or two (earth.esa.int, 2023). It uses remote sensors to collect soil moisture data on a regular basis, which helps to analyse droughts in different areas.

In 2014, Spanish researchers used the SMOS L2 system to assess the Soil Water Depletion Index (SWDI). They also used the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor to scan different soil properties to quantify the risk of soil degradation in sub-Saharan Africa. Additional sensors and vision-based technology were also used to determine the distance and depth required for effective seeding.

IoT-based smart devices such as wireless sensors, drones and robots can accurately detect crop pests, allowing farmers to drastically reduce pesticide use. Contemporary IoT-based pest management offers real-time monitoring, disease forecasting and modelling, making it more effective than traditional pest control. State-of-the-art pest and disease detection techniques depend on the image processing technology of the system. Raw images are collected in the agricultural field using remote sensing satellites or field sensors. The images collected usually cover large areas and can be processed with good efficiency at low cost. There are also field sensors that can collect samples of crop conditions and the presence of pests at all stages of the crop cycle. IoT-based systems can collect, count and describe pest species and then analyse them in detail using a cloud service. Such an IoT-based pest monitoring system can minimise overall costs while helping to restore the natural climate.

IoT-based fertilisation technologies accurately measure fertiliser demand with minimal labour. For example, the Normalized Differential Vegetation Index (NDVI), based entirely on the reflectance of visible and near-infrared light from vegetation, uses satellite imagery to assess crop condition, measure healthy yields, and measure vegetation. It also helps to assess soil nutrient levels. These measurements can significantly increase the efficiency of fertilizer use while avoiding environmental side effects. Geo-mapping, GPS accuracy, autonomous vehicles and variable rate technology (VRT) are contributing to IoT-based smart fertilization.

IoT-based technologies can also be used effectively for yield monitoring. Suitable sensors can be installed on any harvesting computer and the data can be processed, for example, via the FarmTRX mobile application (farmtrx, 2023). The application can be used to generate high-quality yield maps that can be exported by the farmer to other farm management tools for further analysis. Satellite imagery is also used to monitor yields on large farms. For example, in Myanmar, Sentinel-1 interferometric images have been used to determine yields of rice crops; colour (RGB) depth photographs have been used to track fruit stages in mango fields; optical sensors have been used to measure shrinkage of papaya during drying.

Crop water stress index (CWSI) based irrigation management is another application of IoT-based strategies. Irrigation is based on predictions, which can lead to significant improvements in crop yields. CWSI calculation requires monitoring both crop yield and air temperature at different times. In a wireless sensor-based monitoring system, all field sensors are connected and the measured data are transmitted to a processing system, where the data are analysed using appropriate software. Satellite images and meteorological data are also incorporated into CWSI models to determine water demand. Exclusive irrigation index values are generated for each site. CropMetrics' variable rate irrigation (VRI) method determines the amount of water needed based on soil and topography conditions (cropx, 2023).

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2. Greenhouse automation, sensors, robotics

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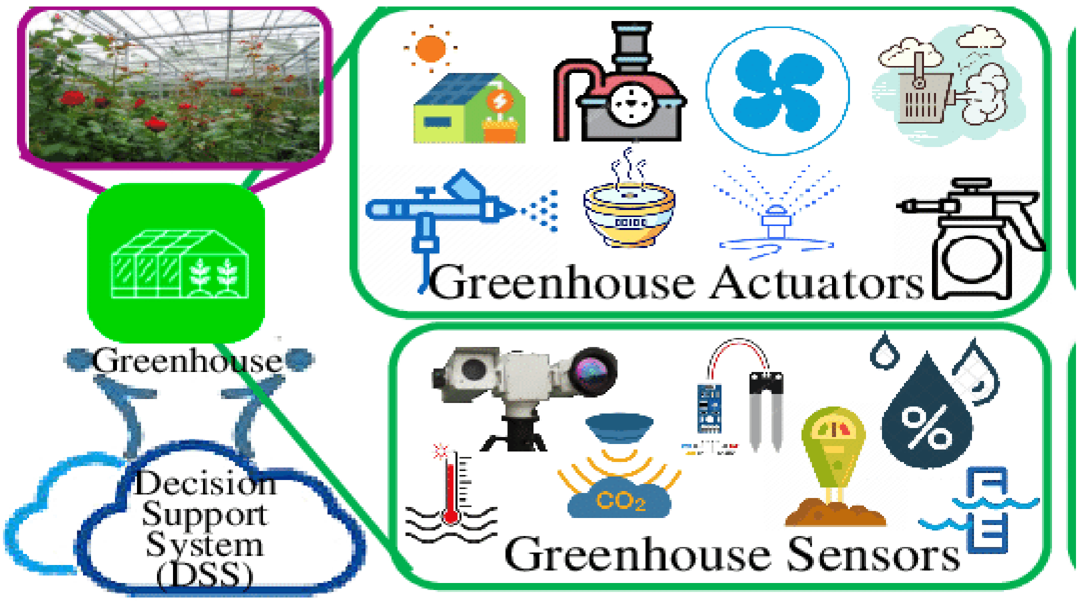
2.1 INTRODUCTION

The combination of automated sensors, robotics and artificial intelligence is revolutionising crop production. Properly designed and integrated systems will enable better monitoring of crops, early detection of diseases and pests, and optimal growth and production. Steps towards sustainable agriculture, facilitated by automation and robotics, will contribute to maintaining food security and protecting the environment.

2.2 AUTOMATED MONITORING AND CARE OF PLANTS

In the field of agricultural production, automation, sensors and robotics are playing an increasingly important role in increasing efficiency and achieving sustainable production. Automated monitoring and care allows continuous monitoring of plant health and optimal growing conditions. In this paper, we describe the use of automated sensors for monitoring and diagnosing plant health, early detection of plant diseases and pests, and the role of robotic care systems and artificial intelligence for optimal plant growth and cultivation. Figure 2.1 illustrates the units used in an automated greenhouse:



Source : https://www.researchgate.net/figure/IoT-Enabled-Greenhouse_fig1_348989431
Figure 2.1 Main units used in an automated greenhouse

Using automated sensors to monitor and diagnose plant health

Automated sensors are a key tool in modern agriculture, helping farmers to monitor and care for crops more accurately. The following is an overview of the most important sensors:

- **soil moisture sensors** are able to continuously measure soil moisture content, **ensuring that irrigation schedules are optimised, preventing over- or under-irrigation, promoting sustainable farming and ultimately increasing agricultural productivity, minimising water wastage.** Among the older, simpler technologies we can mention ***tensiometric***, ***resistive*** **and** ***capacitive*** **soil moisture meters. These have the advantage of their relative simplicity of construction and low cost, but are now being pushed out of modern smart metering systems because of their measurement speed, limited applications and low accuracy. The most accurate and reliable soil moisture sensing known today is** based on the principle of time-domain reflectometry (TDR), which can be used to measure moisture content indirectly based on the correlation with the electrical and dielectric properties of the soil. The principle of this measurement is to inject a very fast rise time (about 200 ps) electrical pulse into a probe guided in the soil. The propagation speed of the pulse is closely related to the moisture content of the soil. An example of a time-domain reflectometry-based instrument is the John Morris Group's TDR 350.

- **temperature and humidity sensors** measure environmental conditions and help create the ideal microclimate for plants. This data is particularly important in greenhouse environments, where temperature and humidity control is vital to the success of the crop. Classical air temperature and relative humidity sensors have now been replaced by integrated smart sensors that convert and process noise-sensitive analogue signals locally and communicate with central measuring systems in the form of a digital signal. A very good example is the SHT4X, one of the many smart sensors from the Swiss company Sensirion. One of the strengths of this device is that 128 sensors can be connected to a pair of sensors via the I2C communication bus and protocol, enabling the principle of multipoint measurement in a simple and cost-effective network.

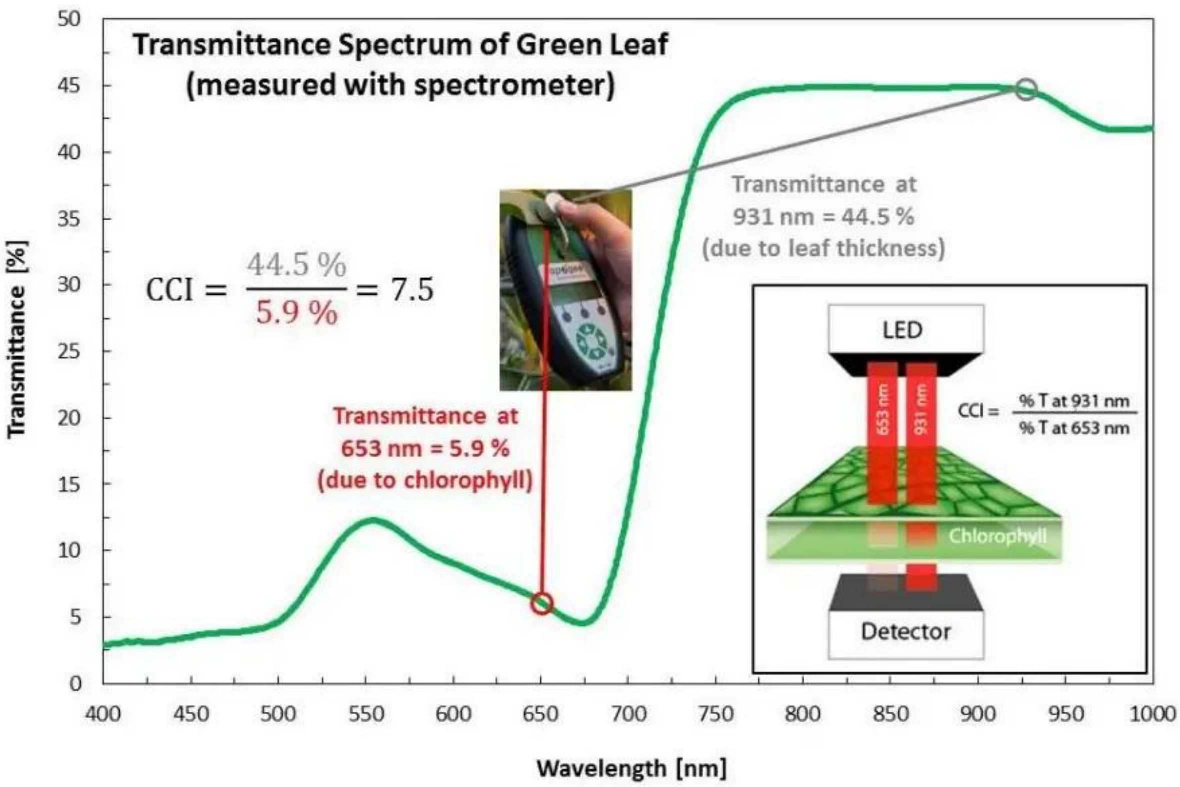
- **photosynthetic active radiation** (PAR) sensors measure light intensity, which is critical for photosynthesis and nutrient production in plants.

Accurate measurement of photosynthetic active radiation helps to achieve optimal plant growth and yield. The sensor can be used to measure Photosynthetic Photon Flux Density (PPFD) over plant canopies in outdoor environments, greenhouses, growth chambers, and in reflected or under canopy (translucent) environments. Instruments from the US company Apogee Instruments are considered industry standard, including the PPFD Quantum SQ-500 sensor family.

Source : https://www.amazon.ca/Apogee-Instruments-MQ-500-Full-Spectrum-Quantum/dp/B09KWQJ8XP?th=1

- **the chlorophyll concentration sensor gives the** concentration in the leaf in absolute units - µmol/m2. It can be used to assess nutrient status, to estimate plant stress and to optimise harvesting. Despite providing very important plant life information, its relatively high price means that it is not yet widely used. The Apogee MC-100 chlorophyll concentration meter and the measurement method and principle are shown in the figures below:

Source : https://www.apogeeinstruments.com/mc-100-chlorophyll-concentration-meter/



Source [: https://manuals.plus/apogee/mc-100-chlorophyll-concentration-meter-manual#axzz8QqVt1E8l](https://manuals.plus/apogee/mc-100-chlorophyll-concentration-meter-manual#axzz8QqVt1E8l)

Early detection of plant diseases and pests using automated computer vision systems

Source [: https://phenospex.com/products/plant-phenotyping/planteye-f500-multispectral-3d-laser-scanner/](https://phenospex.com/products/plant-phenotyping/planteye-f500-multispectral-3d-laser-scanner/)

With dwindling natural resources, one of the biggest problems in agriculture is that yields are struggling to keep up with the world's population growth. The main challenge is to increase productivity regardless of adverse environmental factors. Modern precision agriculture uses the latest technological advances to improve productivity.

The automated disease detection system provides the farmer with an immediate and accurate diagnosis of plant disease, speeding up the diagnostic process. Automating the disease detection system is critical to speeding up crop diagnosis and intervention.

Nowadays, in agriculture, image processing has become an essential application and one of the fastest growing subjects of study in the field. A wide range of industries, including agriculture, have found image processing to be a useful tool for data analysis. Data is collected using cameras, aircraft or satellites and computer image processing algorithms are used to process and analyse the images. An automated leaf disease detection system for precision farming uses image acquisition, image processing, image segmentation, feature extraction and machine learning techniques.

Many of the problems facing agriculture have been greatly simplified thanks to recent developments in image capture and data processing technologies. Images can be used to detect diseased leaves, stems and crops, thereby quantifying the area affected by disease.

Figure below illustrates the complex recording system of a smart greenhouse:

Source *: https://phenospex.com/products/plant-phenotyping/planteye-f500-multispectral-3d-laser-scanner/*

Smart greenhouse complex recording system

The University of Minnesota pilot scheme can be seen HERE.

Data pre-processing is an important part of any computer vision system. To achieve accurate results, any background noise must be filtered out before extracting features. To do this, the colour image is first converted to greyscale and then a Gaussian filter is used to smooth the image. The Otsu thresholding algorithm is then applied to the binary version of the image. A morphological transformation is then applied to the binarized image to close small holes in the foreground.

After the foreground is detected, the bitwise AND operation is performed on the binary image and the original color image to obtain an RGB image of the segmented leaf. After segmenting the image, the system extracts the shape, texture and color from the image. The outlines are used to calculate the area of the leaf and the circumference of the leaf. Contours are the lines connecting all points along the edges of objects of the same colour or intensity. We also estimate the mean and variance of each channel in the RGB image. To calculate the amount of green colour in an image, the image is converted into an HSV colour space and then extract the texture and color features from the grayscale co-occurrence matrix (GLCM) of the image.

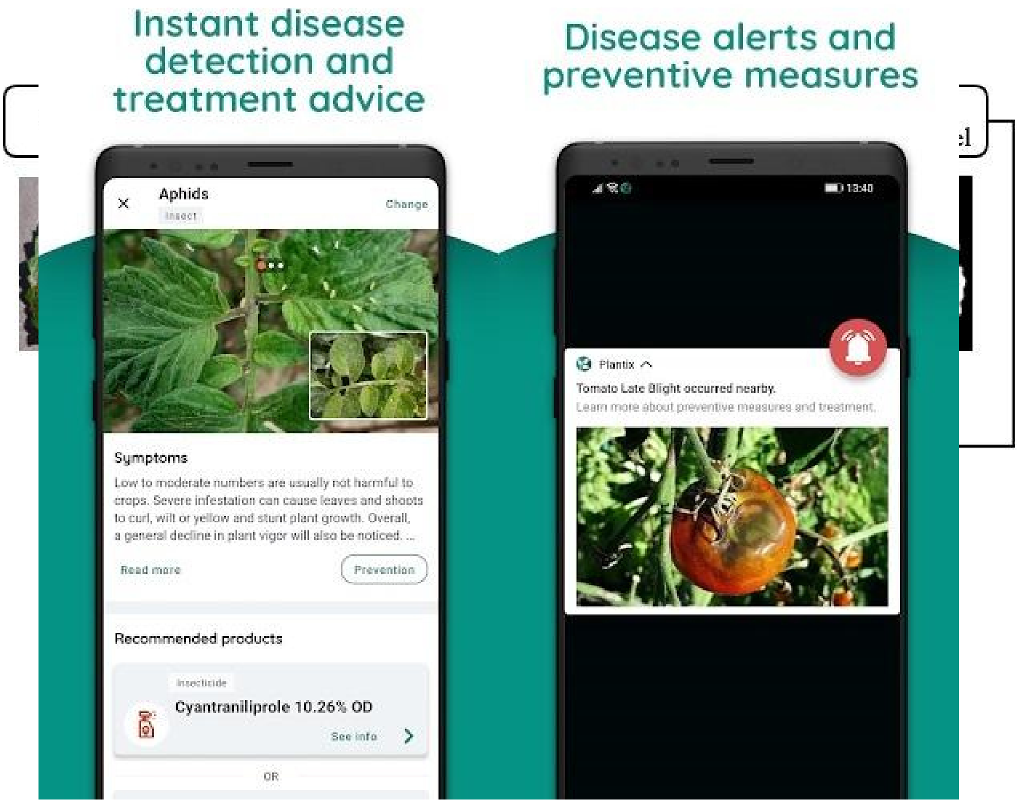
Once all the features have been extracted from all the images in the dataset, another important step in machine learning is feature selection.

The characteristics are selected based on the correlation between the variables and the target variables. For example, in the case of apple disease prediction, the correlation between the green part of the leaf characteristic and the green part of the leaf is very high, i.e. the two variables are interdependent. After selecting the most salient features, the data are now analysed into machine learning classifiers to find patterns in the data. Among several classification algorithms, for example, the random forest classifier can be used in combination with decision trees to achieve higher accuracy. After running the complete set of operations, high accuracy diagnostics can be obtained for continuously expanding plant types.

Based on current reported results, computer vision-based systems can detect and indicate, for example, apple diseases with 93% accuracy and potato diseases with 98% accuracy.

A possible practical implementation can be seen in the following film HERE .

One notable example is Plantix, a smartphone application based on the Android operating system, which detects plant diseases and pathogens based on a photo taken and uploaded with the user's own camera and provides recommendations for intervention. It should be noted that, due to the limitations of the database used and the lack of specialised knowledge of the development team, this application can be considered as amateur level. A demonstration film of the application is available HERE.



Source : https://cafebazaar.ir/app/com.peat.GartenBank.preview?l=en

At the same time, world-renowned companies in the industry are also developing similar applications for professionals, aimed at making a profit.

Robotic care systems and artificial intelligence for optimal plant growth and cultivation

Source [: https://mezogazdasag.ma/mesterseges-intelligencia-a-mezogazdasagban/](https://mezogazdasag.ma/mesterseges-intelligencia-a-mezogazdasagban/)

Robotic care systems and artificial intelligence (AI) are revolutionising crop production. Smart robotic care systems are able to autonomously perform various tasks on plants.
For example, robots can precisely prune plants according to their growth stage and needs. This allows plants to grow and fruit optimally. The use of artificial intelligence helps robots to learn, so they become more accurate at performing tasks over time.
The concept of precision agriculture is based on combining technology and data to optimise agricultural production and minimise environmental impacts. Artificial intelligence in this context enables deeper analysis of data and support for farming decisions.

Artificial intelligence can help farmers get real-time information on soil conditions and crop health:

- Sensors and IoT (Internet of Things): smart sensors measure soil moisture, pH and other key parameters. IoT devices allow this data to be transmitted to central systems.
- Drones and satellite imagery: these devices take pictures of the land, allowing early detection of plant diseases, nutrient deficiencies or pests.
- AI models for data analysis: the collected data is analysed by AI algorithms to identify patterns, make predictions and optimise management.

Precision agriculture is being radically transformed by artificial intelligence. AI will enable farmers to farm their land in a more sustainable, efficient and environmentally friendly way. This development will not only reduce production costs, but also minimise environmental impacts and improve global food security.

In recent years, artificial intelligence (AI) has exploded in agriculture, allowing the sector to reach new heights. However, like all technologies, AI has its challenges that the agricultural sector faces. The potential challenges and added value of AI in agriculture include:

- Added values: productivity gains, reduction of inputs, minimisation of environmental impact, etc.
- The challenges of AI systems are: high upfront costs, accurate data collection and processing, data security and protection, lack of skilled professionals and last but not least ethical and security concerns.

While AI offers huge opportunities for agriculture, it is important that farmers, decision-makers and industry professionals are aware of these challenges. With a proactive approach and proper training, the industry can reap the benefits of AI while managing potential risks and concerns.

In one of the lectures of the Hungarian Science Festival 2023, organised by the Hungarian Academy of Sciences, you can follow a series of interesting presentations on *Sustainable agriculture: precision farming, large-scale digitalisation, artificial intelligence.*

2.3 GREENHOUSE ROBOTS AND SELF-DRIVING VEHICLES

Automation and robotics are playing an increasingly important role in crop production, especially in greenhouses or greenhouses. Greenhouse robots and self-driving vehicles offer solutions to labour shortages and reduce labour costs, while also significantly increasing the efficiency and productivity of crop production. In this paper, we will elaborate on the use of robotic systems in greenhouses, the use of self-driving vehicles and drones for watering, spraying and tending plants, and the benefits of robotics in crop production.

Using robotic systems in greenhouses to reduce labour shortages and labour costs

In crop production, labour shortages can be a critical problem, especially for manual tasks such as harvesting, spraying or fertilising. Robotic systems offer an effective solution to this problem. Robotic machines can perform these tasks autonomously, significantly reducing dependence on human labour.

Greenhouse robots ensure quality work with their precision and reliability. Automated harvesting robots, for example, enable precise and timely harvesting of crops, optimising yields. This not only reduces labour costs, but also improves the quality and quantity of the harvest. Not insignificantly, the intertwining of robotics and regenerative agriculture enables the promotion of organic farming. With the help of robots, chemical use and environmental impact can be minimised, while yields and soil quality can be increased.

Use of self-driving vehicles and drones in plant care

Self-driving vehicles and drones are extremely versatile in crop production. Self-driving tractors and robots can follow crop beds along a designated path, while drones can monitor and care for crops from the air.

The use of self-driving vehicles and drones in watering and spraying crops allows precise and efficient work. Automated systems minimize the use of chemicals or water thanks to precise GPS control, reducing environmental impact and costs.

Aerial surveillance by drones allows fast and efficient inspection of plants in large areas that are difficult to reach manually. Drones can monitor whole plants or even their leaves with a camera, helping to detect disease or pests early, before they become widespread.

- Robotic pollination of plants

The lack of natural pollinators worldwide threatens global food production. According to the US Department of Agriculture's Forest Service, about 80% of flowering plants are fertilised by animals, meaning that without pollinators, many plants cannot reproduce, bear fruit or mature seeds. Researchers at West Virginia University are developing robotic pollinators to address this pressing problem.

Source : https://www.biokontroll.hu/wp-content/uploads/2022/08/Biokultura_2022-2-3_oldalpar-ban.pdf?x18764

A six-armed robot called StickBug, which resembles a batshit and can pollinate a variety of plants, has been created by a team led by *Yu Gu,* an associate professor in the Department of Mechanical and Aerospace Engineering at West Virginia University. The development was supported by a $750,000 grant from the US Department of Agriculture. StickBug first surveys and maps the environment and then maps plants in great detail. It then knows exactly where the flowers are and which ones need pollination, and uses this information to create a work plan. It then approaches the plants one by one and uses the moving arms to pollinate them.

The actual pollination efficiency of StickBug will be evaluated in greenhouses at West Virginia University, where blackberries and tomatoes are grown. These species were chosen because they are both very popular in the US and have significant economic value. According to Yu Gu, tomatoes are probably one of the most important crops grown, but nowadays they need help to pollinate. Moreover, tomatoes can be grown all year round, so the robot can be tested continuously. The ultimate goal is to put these developments into practice and develop a platform for robots that can be widely used in agriculture. Find out more about how the robot works here.

Robotic inspection and spraying of plants

Spraying chemicals is also a common practice in greenhouse plant protection. This operation is essential, but it can cause some problems, such as human and environmental damage from pesticide overdosing. Recently, researchers have focused on precision agriculture to make it smarter. They use sensors to detect the leaves of plants and spray them only when necessary. In this way, the dosage of chemicals can be kept under tight control.

Nowadays, advanced applicability trials are being conducted with automated spraying robots using artificial intelligence-based image processing systems. These robots can detect weeds in the soil or signs of infestation on plants and spray herbicides or pesticides with minimal human supervision. Consequently, the robotisation of these operations can reduce costs and increase environmental and human safety.

Among the many manufacturers, the Chinese company XAG, working on the challenges of Agriculture 4.0, has some notable robots for automatic spraying, rolling and flying. The R150 unmanned guided vehicle (UGV) is designed for next-generation farming with unmanned systems. With powerful scalability and multiple modes of operation, it is the first mass-produced agricultural robot platform of its kind. From precision crop protection to field scouting to agricultural material handling, it offers ground autonomous solutions. You can see the robot in action in Hungary spraying an indoor cabbage crop **here**. The manufacturer's website is available **here.**

2.4 INTERACTION AND COOPERATION OF INTELLIGENT SYSTEMS

The interaction and cooperation of intelligent systems in agricultural production is a key factor in achieving efficient, sustainable and effective crop production. The interconnection of automated systems, sensors and robots allows for the joint collection and analysis of data, providing important information about the condition of crops and the growing environment. In this paper, the benefits of intelligent systems collaboration in crop production are presented.

Connecting sensors, robots and automated systems to collect and analyse data together

The interconnection of automated systems, sensors and robots allows the integration of information from different data sources. Sensors continuously collect data on plant and growing environment parameters, such as soil moisture, temperature, humidity, light intensity, etc. Automated systems and robots perform tasks such as irrigation, spraying or harvesting.

Integrated data collection and analysis allows farmers or agronomists to get a comprehensive picture of the health of crops and the growing environment. By analysing the data, smart systems can instantly identify problems or anomalies and send alerts so that appropriate action can be taken in a timely manner.

Intelligent decision-making and adaptive control in complex crop production environments

The integration and analysis of data supports intelligent decision making and adaptive management in the crop production environment. Automated systems can learn from data and adapt to changing conditions, enabling optimised operations.

For example, automated irrigation systems make intelligent decisions by analysing soil moisture sensor data. When soil moisture levels drop to critical levels, the intelligent system automatically triggers the irrigation system to ensure optimal water supply to the plants. This minimises the waste caused by over-irrigation and the harmful effects of excessively dry soil.

Cooperation between automated systems and robotics for efficient workflow and resource utilisation

Automated systems and robotics work together effectively to help optimise workflows and available resources. Robots that communicate and collaborate with each other can distribute tasks and work together efficiently throughout the growing process.

For example, a self-driving irrigation system and a self-propelled spraying robot can work together to optimise irrigation and spraying according to the needs of the plants. Sensors continuously monitor soil moisture and plant conditions, and the robots use the data to decide on the optimal operations. This minimises the waste of resources and increases the efficiency of cultivation.

2.5 GREENHOUSE DRONES AND DRONE-BASED TECHNOLOGIES

Drones and drone-based technologies are also becoming more widespread and useful in agriculture, especially in crop production. Drones in greenhouses offer particular advantages in supporting cultivation processes, monitoring crop condition and quality, and facilitating precision farming. In this paper, we will elaborate on how drones and drone-based technologies are helping to promote efficient and advanced crop production.

The use of drones in greenhouses to support growing processes

Greenhouse drones are great tools to support crop production processes. Self-guided drones can precisely follow designated paths between plant beds and perform various tasks automatically. For example, spraying drones can spray crops efficiently, minimizing chemical use and human labor.

Drones allow for a higher level of monitoring and surveillance of plants. Camera-equipped drones allow farmers and agronomists to easily monitor crop growth, development and potential problems such as the presence of diseases or pests.

Using drones to monitor crop health and quality

The drones' cameras and sensors allow continuous monitoring of crop condition and quality. Drones equipped with multispectral cameras are able to capture images of crops in different spectral bands. This makes it possible to assess the stress levels, nutrient supply, water requirements and the presence of diseases.

With the help of drones, farmers can detect stressed crops and potential problems in time to take immediate action to restore them. In addition, drones can predict crop quality, which can help produce better products and achieve better market prices.

Drone-based data collection and image processing for precision farming

Drone-based data collection and image processing enables precision farming in agriculture. Data collected by drones is analysed by image processing algorithms and provides detailed information to farmers.

Accurate soil moisture, nutrient supply and plant health data help farmers make better decisions. Precision farming can minimise chemical and water use, reducing environmental impact and costs. And more accurate nutrient and water supply increases productivity and crop quality.

Human-robot interaction and ethical issues

The rise of automation and robotisation in agriculture opens up the possibility of human labour and robots working together in crop production. However, technological advances and the use of artificial intelligence also raise some ethical questions. In this essay, we present the benefits and challenges of human-robot interaction in agriculture, as well as ethical considerations related to the use of robotics and artificial intelligence.

- Human workers and robots working together in greenhouses

Human-robot cooperation in greenhouses offers many advantages. Robots and automated systems can perform difficult and monotonous tasks, reducing the burden on human labour. Freeing human labour from such tasks allows people to focus on their expertise and higher-level tasks such as decision-making or technical supervision.

Human-robot cooperation also increases efficiency. Humans and robots work in complementary ways to optimise crop production processes, improving productivity and crop quality.

- Ethical considerations in the application of robotics and artificial intelligence in agriculture

The use of automation and robotics in agriculture raises ethical questions. One important consideration is the situation of the labour market and workers. The replacement of human labour by robots and automated systems may lead to unemployment among agricultural workers and thus to social inequality.

In addition, ethical issues include data protection and privacy in the use of AI. Sensors and data collection systems continuously monitor the condition of plants and the growing environment, but this data can also contain personal and sensitive information. It is important to consider data protection measures to ensure that the data of growers and farm businesses is protected.

- The role of human labour and skills in the automation and robotisation of crop production

Human labour and skills remain critical to the automation and robotisation of crop production. Human expertise is essential for the optimal functioning of automated systems and robots. Skills enable robots and systems to be set up and monitored efficiently and to intervene when necessary to solve problems.

Human labour and expertise are also critical in addressing ethical issues. Humans must be prepared to deal with the use of robotics and artificial intelligence in agriculture with appropriate ethical considerations. It is important that farmers, agronomists and agricultural workers are aware of the benefits and challenges of automation and robotisation and use them responsibly.

2.6 ECOSYSTEM SERVICES AND SUSTAINABILITY

The rise of automation and robotisation in crop production is affecting ecosystem services and biodiversity. It is important to recognise the sustainability challenges and opportunities facing agriculture. In this paper, we present the impact of automated crop production on ecosystem services and biodiversity and focus on the balance between economic efficiency and environmental sustainability in greenhouses.

Impact of crop automation on ecosystem services and biodiversity

Automated crop production can affect ecosystem services and biodiversity. The precision operation of automated systems and robots enables more accurate and less resource-intensive cultivation, such as optimal irrigation and spraying. This can reduce soil erosion and environmental stress, with positive impacts on ecosystem services.

However, automation can sometimes lead to a loss of biodiversity. One-sided cultivation methods and large-scale production practices can reduce ecosystem diversity if appropriate sustainability measures are not applied.

Sustainability challenges and opportunities in automated crop production

Automated crop production poses a number of sustainability challenges. The more efficient use of resources (water, energy, chemicals) makes it possible to reduce environmental pressures. However, the introduction of robotics and automation can be costly and this can make it difficult for smaller farms to access the technology.

Sustainability options include the use of intelligent decision-making and adaptive control to optimise operations based on environmental conditions and crop needs. To promote sustainability, automated crop production must balance economic efficiency with environmental sustainability.

Balancing economic efficiency and environmental sustainability in greenhouses

Automation and robotisation in greenhouses can promote both economic efficiency and environmental sustainability. Automated systems can reduce labour costs and increase productivity, improving economic outcomes. Precision operations allow for more efficient use of resources, thus reducing environmental pressures.

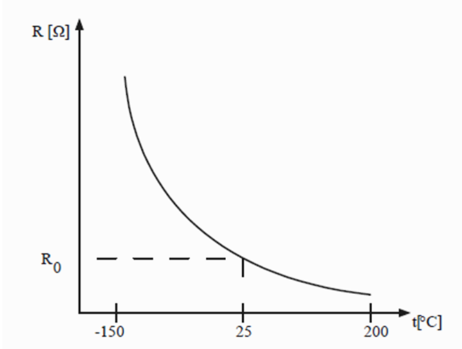
But finding the balance is a challenge. Maximising economic efficiency does not always go hand in hand with environmental sustainability. For example, excessive use of chemicals can damage soil quality and ecosystems, in addition to the economic benefits. This is why smart and responsible automation and robotisation that takes into account both economic and environmental aspects is important.

2.7 SENSORS USED IN GREENHOUSES, AGRICULTURE

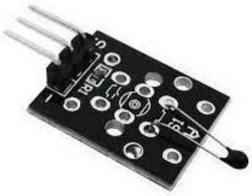
Given that the sensors used in agriculture can be diverse in their design, we provide some insight into the principle of operation of these sensors for a better understanding, but also some examples that can be used in professional or even hobby level horticulture, the examples are not exhaustive in this respect.

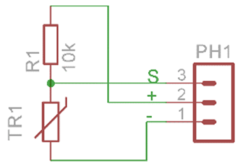
Analogue temperature sensor

Let's look at a concrete, simpler example of a temperature measurement, which is traced from sensing through signal processing to the display of the information. In our example, the sensing element is an NTC type thermistor. The best approximation of the thermistor's temperature dependence is given by the Steinhart-Hart equation. The input of the sensor is the temperature and the output is the value of the electrical resistance.

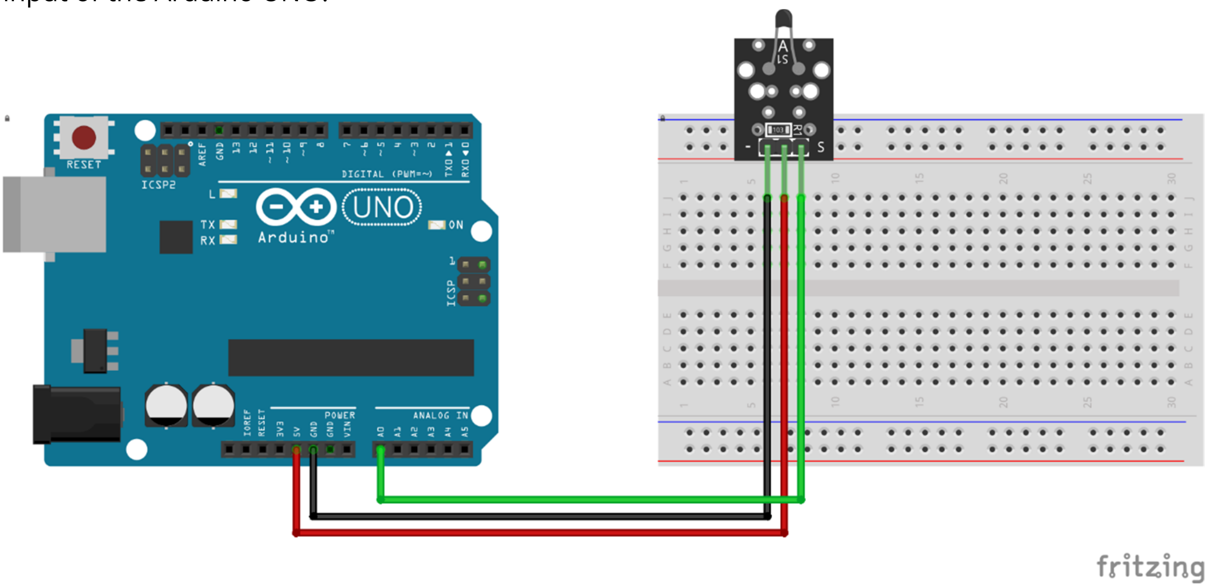


This sensing element (thermistor) is connected to a voltage divider circuit of another with resistance.





The voltage divider circuit is powered by +5V, with an analog voltage output connected to an analog input of the Arduino UNO.

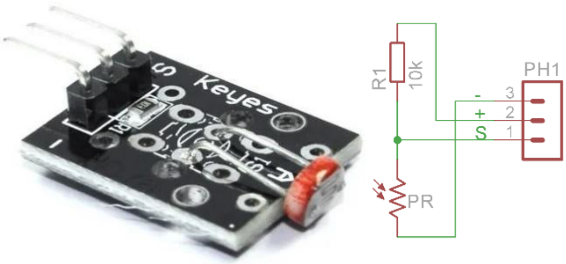


The analogue-to-digital conversion is done in the Arduino UNO, which runs a program. The task of the program is to perform the analog-to-digital conversion in a cyclic manner. The result of the conversion is a numeric value that is passed through a digital signal processing process. During the signal processing, mathematical calculations, taking into account the value of the resistor used in the voltage divider and the static characteristics of the sensor, allow the temperature value in Celsius or Kelvin to be calculated accurately. The result is transmitted via the USB port to a computer, which displays the displayed information.

In the following, we will introduce some more sensors whose processing process may be slightly different, or not discussed in so much detail.

Photo gallery

It is used to detect illumination, the resistance decreases as the illumination increases, but it is also sensitive to the wavelength of light. The figure below shows a photo-resistive sensor and its circuit diagram.

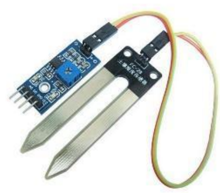


Likewise, **photodiodes**, **phototransistors** and sensors based on these elements are used to detect light.

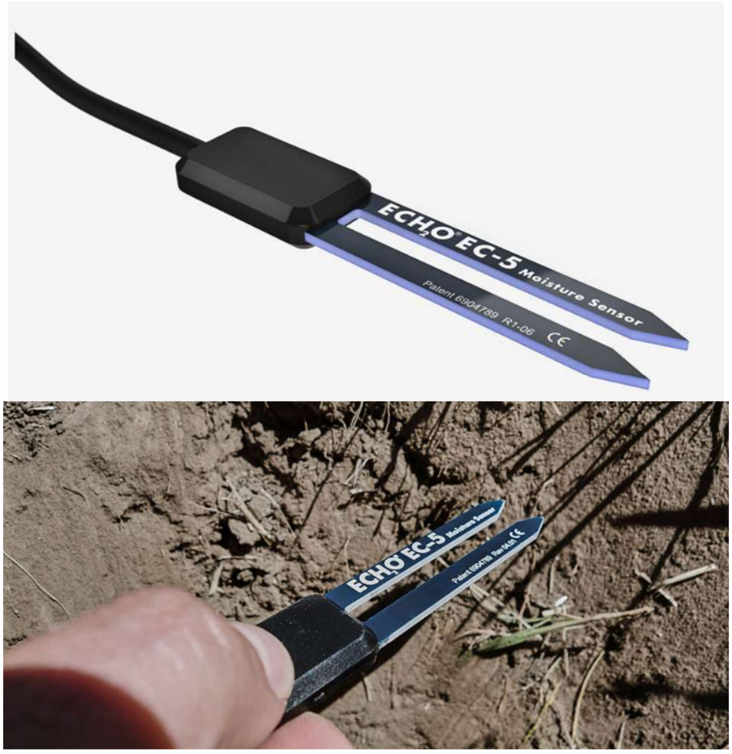
Soil moisture sensor

Moisture meters are used in agriculture, in the cultivation of plants and flowers, where soil moisture is measured and the amount of water applied is controlled depending on the measured values, using automatic irrigation systems. In the case of resistive humidity sensors, the resistance decreases and the conductivity increases as the humidity increases.

In the case of capacitive humidity sensors, the dielectric between the two armatures changes in response to humidity, e.g. when measuring soil moisture, the dielectric may be wet soil.



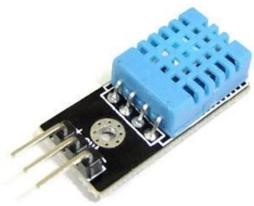
Source : https://ardushop.ro/ro/home/44-modul-senzor-umiditate-sol-higrometru.html



Source : https://www.metergroup.com/en/meter-environment/products/ech20-ec-5-soil-moisture-sensor

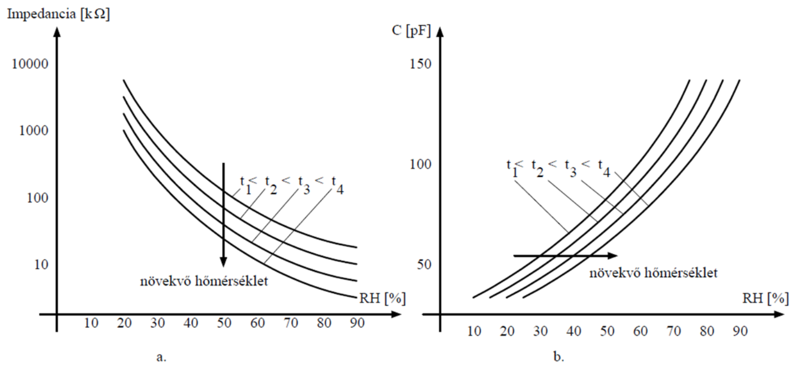
Temperature and humidity/humidity sensor

Water is almost ubiquitous and comes in many forms: drops, vapour, grit, snow, mist. Vapour in air or any other gas is usually called moisture. Absolute Humidity - gives the mass of water in a unit volume of gas.



Source : https://ardushop.ro/ro/electronica/619-modul-senzor-temperatura-i-umiditate-digital-dht11.html

The figure shows the typical static characteristics of moisture meters based on resistance (impedance) and capacitance changes.



Both characteristics are temperature-dependent, and it is no coincidence that most humidity sensors in integrated circuits also include temperature sensors.

Raindrop sensor

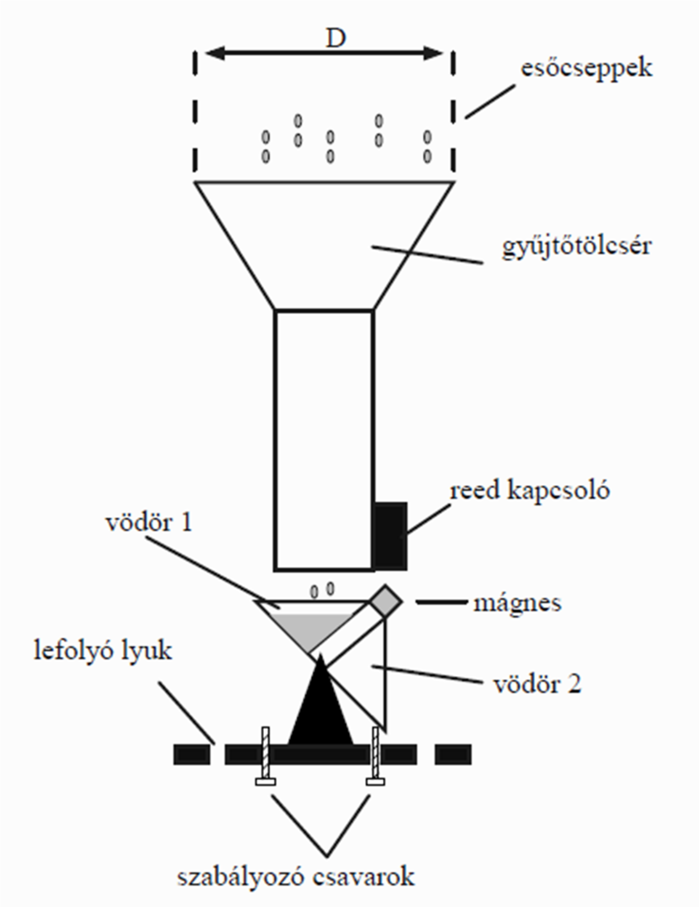
Raindrop sensors mostly detect the presence of rain, but provide little information on the amount of rainfall. The design of such a raindrop sensor is shown in the figure below.

Source : https://ardushop.ro/ro/home/130-senzor-picaturi-de-ploaie.html
User Guide: https://www.youtube.com/watch?v=uDdiMMdVb90

Precipitation sensor

Precipitation measurement is mainly important from a meteorological, agricultural point of view, and the weather in a given geographical area plays a decisive role in its formation. It may be liquid (rain), solid (snow, sleet, hail) or mixed (hail). **Precipitation is** measured in mm, which is the number of litres of precipitation per 1 m2 of area (1 *l of precipitation* falling on 1 m^2 = *1*dm^3 of area *h* = 1 mm of precipitation height). The intensity of precipitation is given by the amount of precipitation falling during a unit of time.

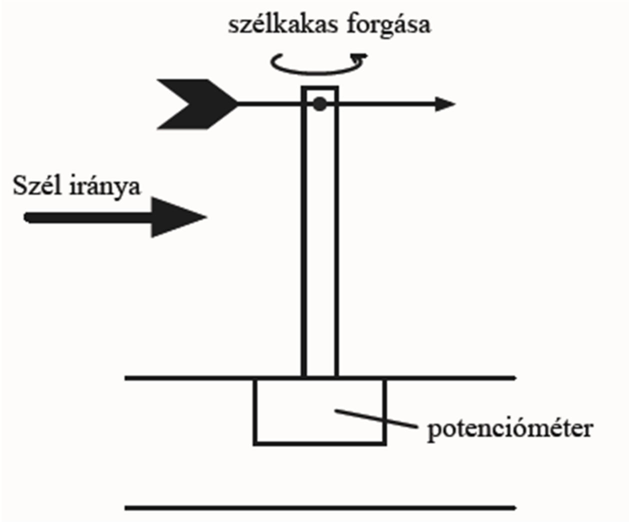
The tipping bucket method is very common and is shown in the figure below. The tipping bucket consists of a collection funnel with a diameter D, which allows the collection of raindrops over a large surface area. Minél nagyobb az átmérő, annál hatékonyabban gyűjti össze a szórványosan eső esőcseppeket. csapadékot is pontosabban tudjuk érzékelni, ugyanakkor az összegyűjtött csapadék mennyisége is növekszik, ezáltal a tölcsér alján elhelyezett vödrök is hamarabb megtelnek, növelve az érzékelés felbontását, mely a gyűjtő vödrök méretétől is függ. Buckets 1 and 2 (left and right) will fill and empty sequentially as the rain fills them as a consequence of gravity. While one is being filled, the other is being emptied (and vice versa). The adjusting screws allow you to control the amount of emptying and the angle of tilt to ensure that the buckets are emptied. At the top of the tipping mechanism is a permanent magnet, while at the bottom of the hopper is a fixed Reed switch. When the permanent magnet comes close to the reed switch, the latter's contacts close (bucket 1 fills), and when bucket 2 fills, the reed switch is removed from the immediate field of the permanent magnet and the contacts disengage. These state changes can be easily counted by a program running on an embedded system using a simple signal conditioning electronic circuit and from there, taking into account the volume of the bucket and the time elapsed while counting the empty buckets, the intensity of the precipitation can be obtained by mathematical calculations.



Measurement of wind direction

A wind box is typically used to measure wind direction. Officially, this is usually placed at a height of 10 m. A wind vane is a device placed on the ground perpendicular to a pole. This arrangement allows the wind to cause the wind vane to always turn in the current wind direction around the axis defined by the pole. It thus indicates the current wind direction in two dimensions.

In a simple embodiment, a rotary potentiometer is used, where the cursor moves parallel to the axis of the wind vane. As a result, the position of the potentiometer cursor changes as the environmental parameters are measured, i.e. as the wind direction changes. Thus, the measured resistance value changes between one end point and the position determined by the cursor. The change in the resistance value causes an electrical voltage/current change in the electronic circuitry which, after analogue-to-digital conversion of the information, can be used to accurately determine the wind direction value in the digital system during signal processing.



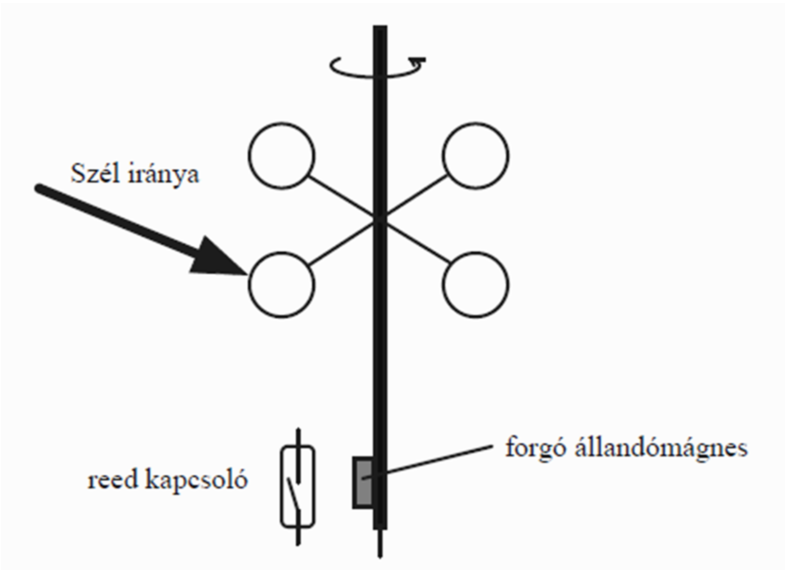
Wind speed measurement

The wind flow velocity is caused by the movement of air from high to low pressure, usually due to changes in temperature. The greater this pressure difference between two points in the atmosphere (pressure gradient), the greater the wind speed (from the higher pressure point to the lower pressure point) will be to compensate for this difference.

Measuring wind strength on the Beaufort scale:

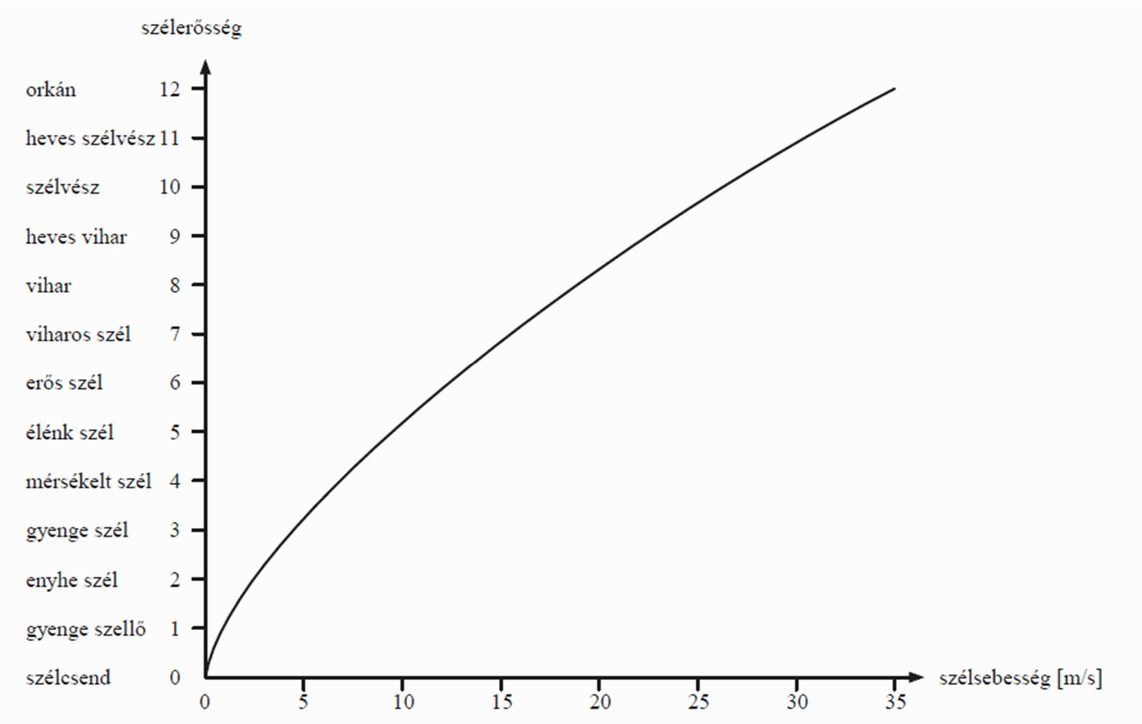
Several wind measurement systems are used to measure wind speed. One approach is the propeller solution, in which a propeller is placed on the nose of the wind vane and the rotation speed of this propeller increases with the wind speed. This rotation speed is measured by different methods.

Another, and perhaps the most common, method is to use a spoon wind gauge. In this case, a 3 or 4 spoon device is placed on the axis of the wind vane. The spoons rotate depending on the wind speed, and this rotation speed is measured.



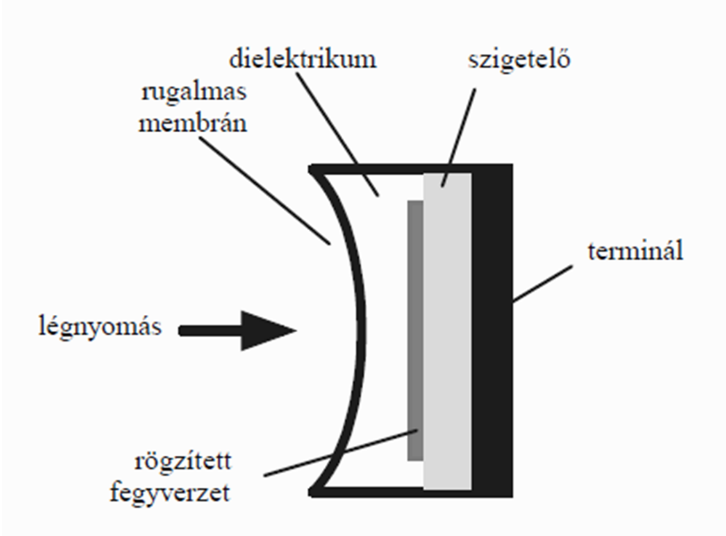
In both cases, the wind speed is related to the rotation speed, which is measured by some optical or magnetic method.

There are also solutions that do not include rotating parts that are subject to mechanical wear. These include hot wire anemometers or methods using the propagation speed of sound waves. In the latter case, ultrasound is excited in a range inaudible to the human ear, which allows not only the speed of the wind but also its direction to be determined. Three ultrasound transceivers are placed 120 degrees apart in a virtual circle and transmit signals to each other in turn. Given that the ultrasound speed and the wind speed are vectorially additive, by measuring the propagation time of the sound waves and knowing the exact distance between the transceivers, the wind direction and wind speed can be calculated mathematically.



Measuring barometric pressure

The weight of the air molecules around us per unit area is called air pressure. Air pressure measuring devices are also called barometers. Air pressure varies with altitude. One of the most common methods of measurement is the capacitive method, whereby the capacitance of a capacitor, which is measured, changes in response to the air pressure. In general, the two armatures of a capacitor are a fixed and a flexible membrane, with a capacitance formed by the action of a dielectric between them. Under the effect of air pressure, the armament created by the flexible membrane moves closer or further away from the fixed armament, thereby changing the capacitance of the capacitor.



Another sensor often used to measure air pressure is the piezoresistor.

There are so-called meteo stations, which integrate most of the listed environmental parameters into a single system, or can measure several parameters.

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3. Micropropagation techniques in the laboratory

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3.1 PEST-FREE PLANT PRODUCTION AND MICROPROPAGATION

The importance of micropropagation in pathogen-free crop production

Disease-free crop production is one of the most important challenges for the agricultural economy, as plant pathogens such as fungi, viruses and bacteria can cause serious damage to plant health and production. In traditional propagation methods, pathogens can often be transferred with the plant material, exposing plants to diseases. In addition, plants propagated under inappropriate conditions are more susceptible to the spread of pathogens and diseases.

Micropropagation is an innovative technique that allows pathogen-free plant propagation. This method relies, among other things, on the propagation of microscopic parts of plant tissue and the totipotency of cells under laboratory conditions. The procedure usually involves taking pieces of plant tissue from the healthy part of the parent plant, mainly from shoot tips, such as buds. These tissue fragments are grown in a sterile environment on nutrient-enriched media where new plants are formed.

The advantage of micropropagation is that the propagated plants can be completely free of pathogens that may be present in the parent plants. As a result, pathogen-free plants are healthy, vigorous and, under the right conditions, can have better yields. In addition, micropropagation allows plants to be propagated very quickly and efficiently, regardless of the weather, and can therefore result in economical and sustainable crop production.

source: ChatGPT 4.0 DALL-E

Laboratory conditions and hygiene requirements for pathogen-free propagation

Laboratory conditions and careful hygiene protocols are essential for successful micropropagation. The laboratory operates in a sterile environment that minimises the presence of pathogens and other contaminants. Laboratory staff wear special clothing, including gloves and masks, to prevent contamination and contamination by pathogens.

The culture media on which the plant tissues are propagated are strictly sterilised and enriched with nutrients and synthetic hormones to ensure the proper development of the plants. Tools such as scissors, scalpels and glassware are completely disinfected to avoid the spread of pathogens among the propagated plants.

Continuous monitoring and maintenance of the laboratory environment is essential for pathogen-free propagation. Air conditioning and ventilation systems ensure that the correct temperature and humidity are maintained. Regular disinfection and cleaning ensure that the laboratory is kept clean and sterile.

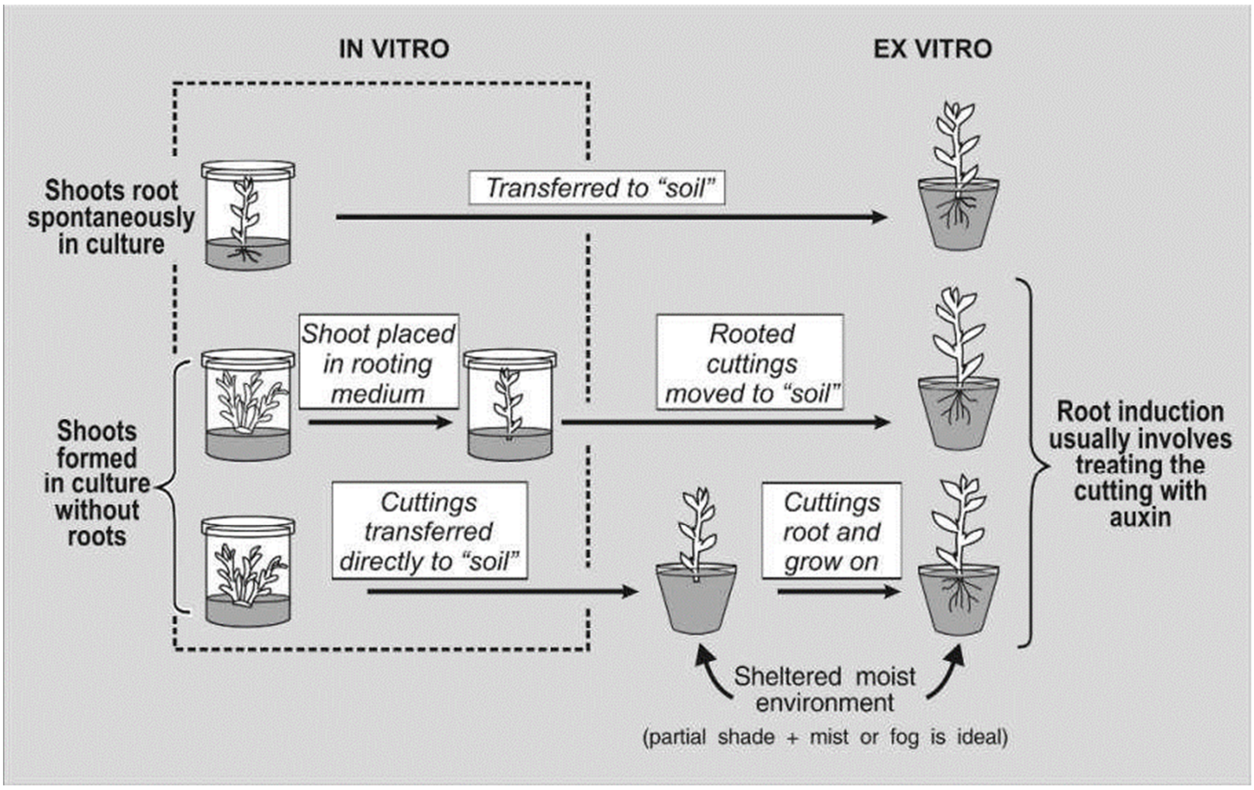
Identification of pathogens and preventive treatments during micropropagation

Although micropropagation takes place in a laboratory environment, it is important that plant parts are selected from mother plants that are free from pathogens and diseases. Preliminary plant health testing and screening for pathogens is an important step in ensuring successful micropropagation. If the plants show symptoms of pathogens, appropriate preventive measures should be taken, such as removal of infected parts or quarantine of the plants.

During micropropagation, plants are regularly checked for plant health In the event of any infection being detected, the affected plants are immediately isolated and treated to prevent the spread of infection.

Overall, micropropagation is one of the most important tools for pathogen-free plant propagation, allowing plants to be propagated free of pathogens and pests, and quickly and productively. Strict adherence to laboratory conditions and preventive measures against pathogens are key to ensuring a successful micropropagation process. Pathogen-free plant propagation can lead to sustainable and efficient agricultural practices, contributing to the development of global food supply and agricultural production.

3.2 IN VITRO PROPAGATION METHODS AND THEIR APPLICATION



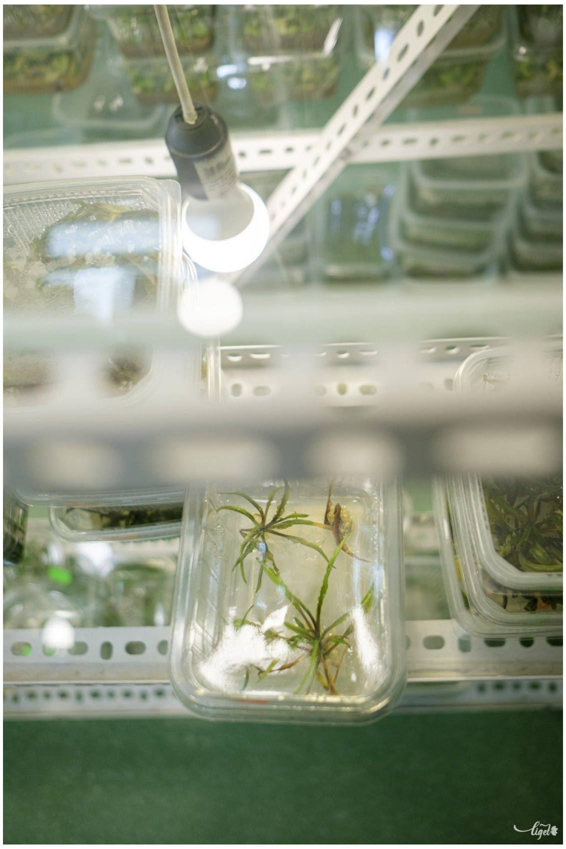
Source : https://docplayer.hu/93231435-Disznovenyek-mikroszaporitasa-dr-mosonyi-istvan-daniel.html

Preparation of tissues and other explants for in vitro propagation

In vitro propagation methods have brought major breakthroughs in agriculture and plant biotechnology, allowing plants to be propagated efficiently and rapidly in the laboratory. *In vitro* propagation is based on tissue culture techniques, where tiny tissue particles of plants, called explants, are placed in nutrient-rich media and given optimal growth conditions. Explants can be, for example, buds, leaf fragments or other tissue parts.

When testing plant parts and tissues, the selection and preparation of suitable explants for in vitro propagation is a key step. The explants are separated and prepared under sterile conditions to minimise the presence of pathogens and contaminants and to prevent the possibility of contamination. The explants are then sterilized, usually in sodium hypochlorite solution and/or ethanol, to ensure that they are completely free of pathogens.

The explants are carefully checked and the most suitable ones are selected for the propagation process. This allows only the healthiest and strongest explants to be used for in vitro propagation and guarantees the successful development of healthy plants in later stages.



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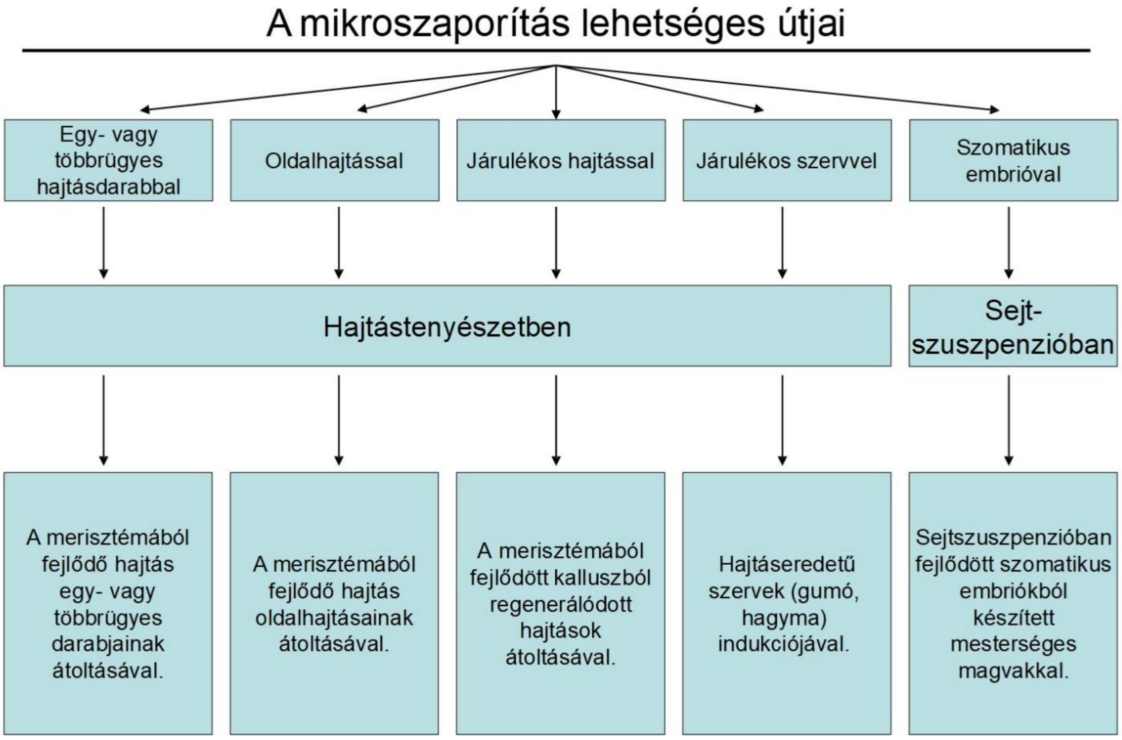
Comparison of different in vitro reproduction techniques



Source: https://docplayer.hu/93231435-Disznovenyek-mikroszaporitasa-dr-mosonyi-istvan-daniel.html

Among the various techniques of *in vitro* propagation, there are a number of options that may be suitable for propagating different plant species and their varieties. Some of them are:

Propagation from shoots: this method is suitable for propagating healthy shoots. The explants are sterilized and then grown on sterile media. This technique is particularly effective for plants that produce vigorous shoots.

Propagation from the stem: in this method, the stem part of the plant is used as an explant. This is used in the production of stem cuttings. The explant is placed on a medium where the plant part develops roots and shoots. This method is particularly useful for propagating trees and shrubs that are difficult to propagate conventionally.

Propagation by division: in this case, the mother plant is divided into several parts and the resulting smaller plant parts are placed separately on the soil. This method is effective for the rapid multiplication of plants and is particularly suitable for plants that are difficult or rare to propagate naturally.

In vitro propagation of rare and endangered plant species

Source : https://kert.tv/novenyek-szaporitasa-gyokereztetes/

In vitro propagation methods are particularly useful for the propagation of rare and endangered plant species that have limited access to protect their natural habitats or are difficult or dangerous to propagate conventionally.

Traditional propagation methods often require significant amounts of plant material, which can be problematic for endangered species. However, with *in vitro* propagation, even a single plant can be sufficient to initiate propagation, and propagation in culture media can achieve rapid and efficient multiplication.

In this way, in vitro propagation methods contribute to the conservation and cultivation of rare and endangered plant species and allow their reproduction without damaging the population or natural habitats.

Overall, *in vitro* propagation methods offer an innovative and effective tool for plant biotechnology and agriculture. The careful preparation of tissues and other explants and the use of different in vitro propagation techniques allow for efficient and environmentally friendly plant propagation, as well as the conservation and multiplication of rare and endangered plant species. Further research and development will provide opportunities to improve and optimise *in vitro* propagation techniques, thus contributing to the sustainable and efficient development of the agricultural economy.

3.3 IMPROVING THE EFFICIENCY AND ACCURACY OF MICROPROPAGATION

Mic-ropro- *paga-tion7.jpg*

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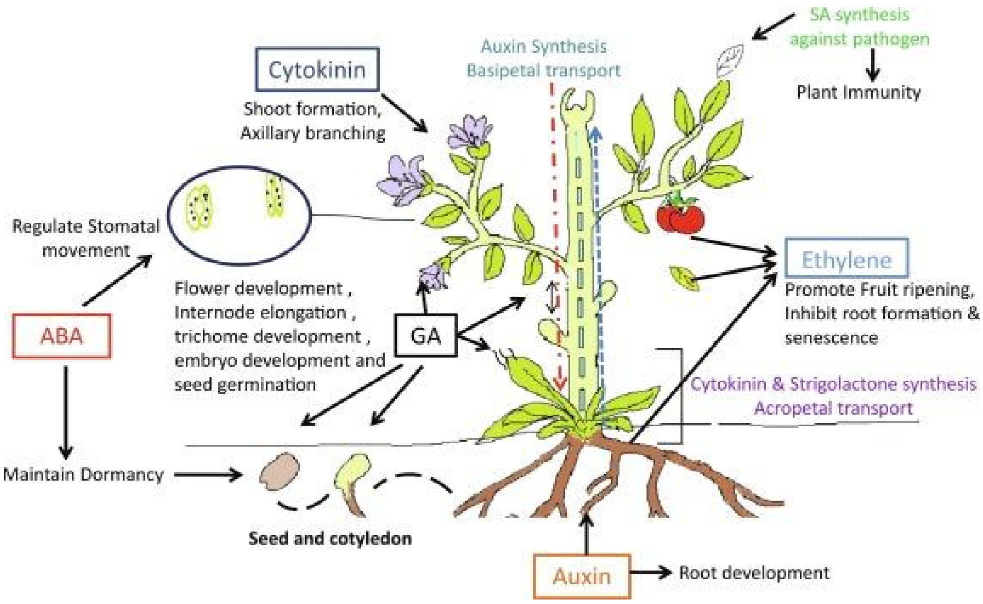


https://www.sciencedirect.com/science/article/abs/pii/B9780323907958000023

In order to increase the efficiency and accuracy of micropropagation, precision computing can be applied as follows:

Hormonal balance and regulation in the reproductive process:

Hormonal balance and regulation is a key factor in increasing the efficiency of micropropagation. Plant hormones such as auxin and cytokinin play an important role in plant reproduction and growth. Adjusting the optimal hormonal balance enables the efficient growth and differentiation of explants and promotes the development of healthy shoots and roots on plants.

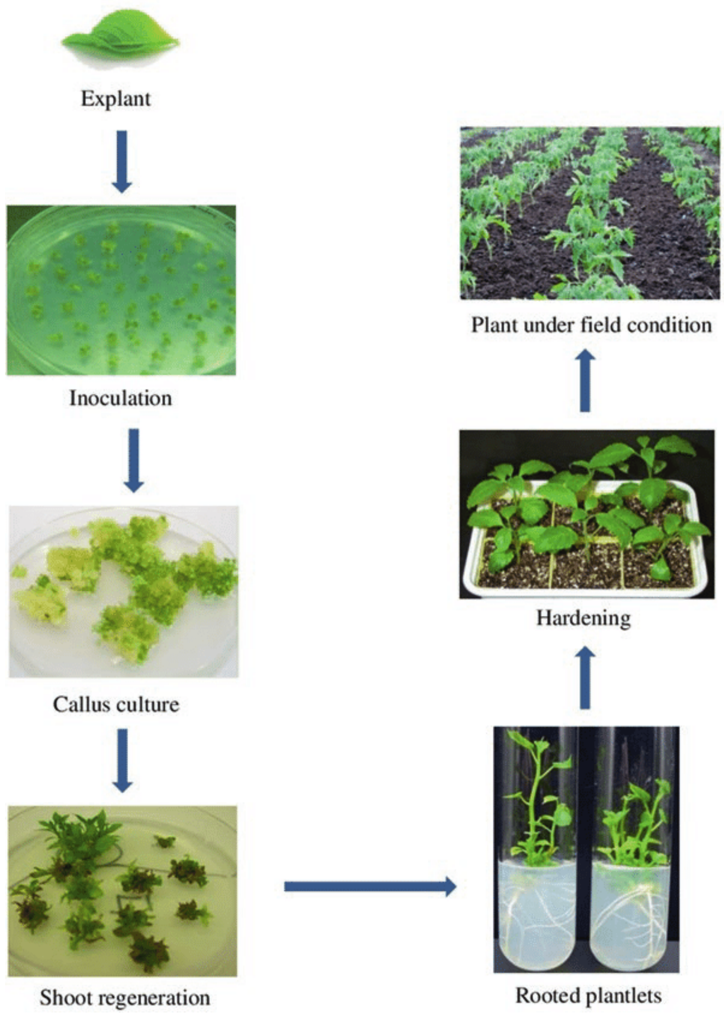
Hormonal regulation requires the use of appropriate concentrations and ratios under *in vitro* conditions to maximise plant growth and reproduction. Hormonal regulation allows tissue differentiation and the development of the appropriate plant organs needed for successful reproduction.

Data collection: data collection technologies can be used to obtain detailed information on the hormonal responses of plants during the reproductive process.

Modelling: the data collected will be used to build models to help understand the role of hormones in plant development.

Regulatory algorithms: developing algorithms to help maintain an optimal hormonal balance to promote healthy plant tissue development.

Optimising nutrients and media for efficiency:



Source : https://www.vedantu.com/question-answer/what-is-micropropagation-class-12-biology-cbse-5f9066d6d519b61dfd600b05

Providing plants with the right nutrients enables healthy growth and development. Soil enriched with the right nutrients promotes rapid and efficient explant growth and the development of roots and shoots.

The pH and composition of the soil also affect plant reproduction and development. Optimal pH and nutrient ratios help minimise the possibility of contamination and improve explant survival rates.

Nutrient management: accurate monitoring and control of the composition of nutrients and media is important for optimal plant tissue growth.

Application of artificial intelligence: artificial intelligence-based systems can be used to optimise the composition of media, pH, temperature and other environmental factors.

Challenges and solutions for genetic stability and clonal breeding:

In clonal propagation, explants are genetically identical to the parent plants, resulting in excellent genetic stability. However, one of the challenges of clonal breeding is the lack of genetic variability, which in the long run can lead to vulnerability of the populations and difficulties in adapting to new environmental conditions.

To improve genetic stability and adaptability, genetic diversity should be introduced into the breeding stock. This can be achieved by introducing new plant material into the breeding process, which can be derived from different parent plants. In addition, genetic variability can be generated in the propagated plant stock through mutation techniques and control of the maturation phase.

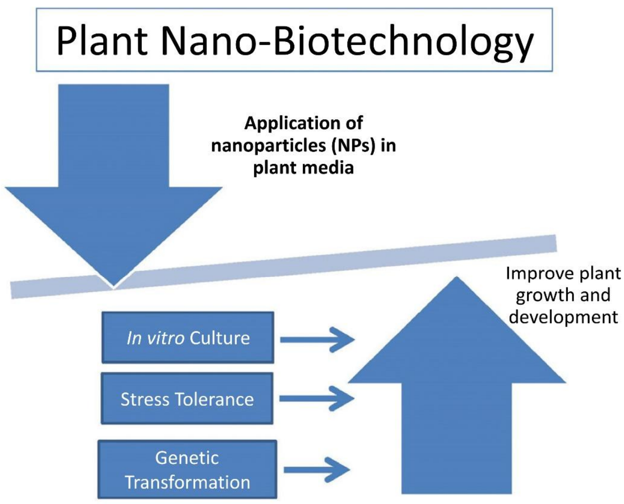
Genetic analysis: genetic sequencing technologies can be used to monitor the genetic stability of plant tissues.

Databases and bioinformatics tools: storing and analysing genetic data with bioinformatics tools can help detect early signs of genetic instability.

Predictive modelling: analysing the relationship between genetic data and plant development can help predict and address challenges in the cloning process.

Overall, to increase the efficiency and accuracy of micropropagation, a number of aspects need to be considered, including regulating hormonal balance, optimising medium and nutrients, and addressing the challenges of genetic stability and clonal propagation. Further research and development offers the potential to further improve *in vitro* propagation techniques and promote sustainable crop production practices in the agricultural economy.

3.4 NANOTECHNOLOGY AND MICROPROPAGATION



Nanotechnology is employed in different aspects of plant biotechnology to foster food security, and produce genetically modified plants that are resistant to environmental and stress conditions.

Source : https://www.eurekaselect.com/article/118920

The use of nanotechnology in micropropagation could represent a major advance and the IT aspects can be integrated into the development of this field as follows:

Application of nanoparticles in micropropagation:

Because of their small size and high surface area, nanoparticles interact very efficiently with other materials, such as plant cells. In micropropagation, the use of nanoparticles allows plant explants to grow and multiply more efficiently. For example, nanoparticles are able to penetrate plant cells and deliver nutrients, hormones and other necessary substances to the cells in a targeted manner, which can accelerate growth processes and improve reproduction rates.

Data collection and analysis: data collection techniques can be used to monitor the effects of nanoparticles on plant cells. These data help to understand the interactions of nanoparticles with cells and their effects.

Modelling: the data can be used to develop models that help predict the behaviour of nanoparticles under different conditions, allowing the optimisation of the propagation process.

Nano-scale The benefits of containers and nutrients in plant cell culture:

The nanoscale containers provide a large surface area for cells, which helps to improve nutrient uptake and optimise growth processes.

In addition, they can also target nano-sized nutrients to cells, thereby enhancing cell growth and differentiation.

Precision dosing: nanotechnology can be used to precisely control the delivery of nutrients and hormones, improving the growth conditions of plant cells.

Simulations and analytics: IT tools can be used to model and analyse the effects of nanocontainers and nutrients, allowing the development of more effective formulations and treatment protocols.

Impact of nanotechnology on reproductive efficiency and phenotype:

The integration of nanotechnology into the micropropagation process can provide significant benefits through precision dosing, more efficient propagation processes and improved phenotypes. Informatics tools such as data analysis, modelling, simulations and predictive analytics are key to exploiting these benefits.

Nanotechnology is an advanced scientific field that deals with the manipulation of materials and structures at the nanoscale. In recent years, nanotechnology has also been used in agriculture, in particular in plant biotechnology, and thus has also found applications in the field of micropropagation. The benefits of nanotechnology and its innovative solutions can lead to more efficient and sustainable micropropagation processes.

However, it is important to note that the application of nanotechnology is still a relatively new and under-researched area, and further research is needed to determine the extent to which it affects the micropropagation process and the phenotype of the resulting plants.

Data mining and machine learning: machine learning and data mining techniques can help to extract relevant information from large data sets, thus identifying the most important effects of nanotechnology on reproductive efficiency and plant phenotype.

Predictive analytics: predicting the effects of nanotechnology interventions can help fine-tune breeding strategies and achieve desired phenotypes.

3.5 AUTOMATED MICROPROPAGATION SYSTEMS

Automated micropropagation systems are innovative solutions that enable the efficient and precise propagation of plants in large quantities, minimising the need for human resources and time. Automated systems represent a significant advance in micropropagation and offer many advantages over traditional manual propagation methods.

The following automated systems are the most commonly used in the micropropagation process:

Light rooms

Source : https://www.darjeelinggardens.com/tissue-culture.html

The light rooms used in the process of micropropagation can be thought of as a special greenhouse, with all the technologies that we will learn about in the other 6 topics in Module 2.

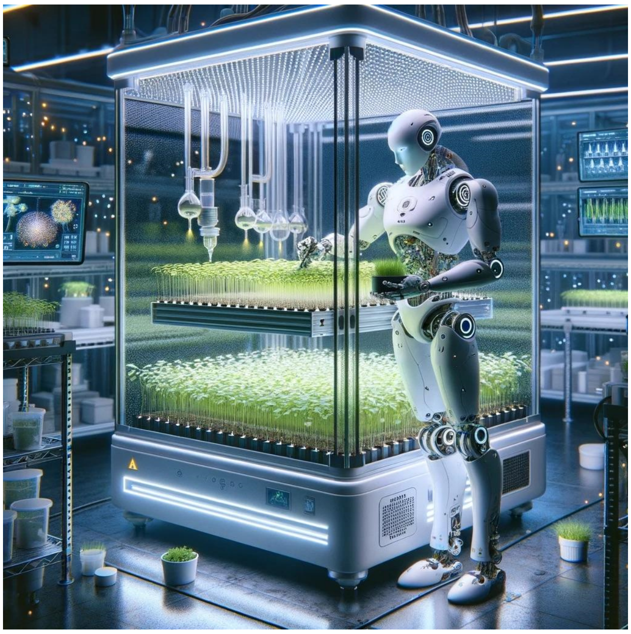
Here is some basic information about the light rooms used in micropropagation:

- Function and purpose: The purpose of light rooms is to provide optimal growing conditions for crops. This includes the right light intensity, light composition, temperature, humidity and other environmental factors that promote healthy plant growth and development.

- Control and Supervision: in artificially lit light rooms, automated systems ensure the control of light intensity, wavelength and spectrum, which are essential for healthy plant growth.
- Light sources: different types of light sources are used in the light rooms, such as fluorescent lamps, LED lamps or special plant growth lamps. These light sources provide different wavelengths of light that affect the photosynthesis and growth of plant cells.
- Temperature control: temperature control is also important in light rooms, as plant growth and development is highly dependent on the ambient temperature. Temperature control devices in the rooms allow researchers to precisely set and maintain the desired temperature.
- Humidity and ventilation:Maintaining adequate humidity and ensuring adequate ventilation are also vital for healthy crop growth. Humidity controls and ventilation systems in light rooms help to optimise these factors.
- Controllability and control: when designing light rooms, special attention is paid to ensuring that environmental factors such as light, temperature and humidity can be accurately and easily controlled. This allows workers to tightly control and regulate the growing environment of crops. Sensors can be used to continuously measure temperature, humidity, carbon dioxide levels and light intensity, providing real-time data on the plant environment.

Light rooms are therefore essential in micropropagation to ensure healthy and controlled growth of plants. These rooms allow researchers to precisely control the environmental conditions required for plant cultures, thus facilitating efficient and successful propagation.

Combining robotic systems and micropropagation



Source: ChatGPT 4.0 DALL-E

In automated micropropagation, the use of robotic systems allows the rapid and accurate handling of explants, planting and automation of the whole process. Robotic systems are capable of high speed and accuracy and can process multiple explants at the same time, allowing for higher volume micropropagation.

The precision and consistency of robotic systems contribute greatly to the reliability and success of the breeding process. Robotic systems are able to plant explants at a consistent distance and depth in the culture medium, minimising the risk of damage and contamination.

The role of artificial intelligence in automated micropropagation

Artificial intelligence (AI) is increasingly being introduced into automated micropropagation systems, further improving efficiency and accuracy. AI allows systems to learn and adapt autonomously to different conditions and changing circumstances.

AI algorithms are able to detect and react appropriately to the condition of plants and intervene in time if any problems or abnormalities occur during the reproduction process. This proactive approach increases success rates and minimises risks.

Optimisation algorithms. AI and machine learning algorithms can help determine optimal growing conditions and automatically adjust light room parameters.

Predictive maintenance: AI analytics can help predict the maintenance needs of your lighting room system, reducing downtime and increasing system efficiency.

Scalability and mass propagation options

Automated micropropagation systems are excellent for scalability and mass propagation. Because robotic systems are faster and more efficient process plants more efficiently, they allow for larger planting sizes and mass propagation.

With the potential for scalability and mass propagation, automated systems can contribute to increasing agricultural production and producing the large quantities of crops needed to maintain varieties. Thus, automated micropropagation systems can contribute to sustainable and efficient agricultural production.

Overall, automated micropropagation systems are revolutionising plant biotechnology and agriculture, enabling faster, more efficient and more reliable plant propagation. The combination of automated systems with robotics and artificial intelligence will enable a significant increase in crop production efficiency and productivity, contributing to sustainable and high quality agricultural production.

3.6 MICROPROPAGATION AND CONSERVATION

The relationship between micropropagation and conservation can be approached from an informatics perspective in the following way:

Micropropagation and conservation of species genetic diversity

Traditional breeding methods are often insufficient to conserve endangered plant species because of a lack of available parent plants or because they take a long time to propagate. Micropropagation allows a significant number of offspring to be produced from a small number of parent plants, thereby increasing genetic diversity and contributing to species conservation.

In micropropagation, explants are grown under sterile conditions to minimise the risk of environmental contamination and ensure the genetic purity of the species. Micropropagation can therefore be an ideal method for the conservation of endangered species that can only be grown under special conditions.

- Genetic databases and bioinformatics: monitoring and analysing the genetic diversity of species is critical. Information technology enables the creation and maintenance of genetic databases to help conserve and monitor genetic diversity.
- Sequencing technologies: modern DNA sequencing technologies can be used to generate detailed genetic profiles that help to preserve genetic diversity and optimise micropropagation processes.

Phenotypic diversity and adaptation in micropropagation

By selecting and processing different explants, micropropagation can be used to create new plants with different characteristics, such as different leaf sizes, shapes or colours.

This phenotypic diversity can be important for the adaptability and survival of a species or breed. Plants with different phenotypes may adapt to different environmental conditions and stresses, so that the plant population produced by micropropagation may be more resistant to changing conditions.

Data collection and analysis: the collection and analysis of phenotypic data helps us to understand the impact of different environmental factors on plant development. This information can be important for the development and maintenance of adaptive traits.

Predictive modelling: IT tools can be used to create predictive models that anticipate the impact of different environmental changes on plant phenotypes. This can help in developing breeding strategies to make plants better adapted to changing conditions.

The contribution of micropropagation to sustainable crop protection and agriculture

Micropropagation has an important role to play in promoting sustainable crop protection and sustainable agricultural practices. Micropropagation allows for healthy and pathogen-free selection of plants, thus minimising the spread of pests and diseases in the propagated crop population.

Pathogen-free micropropagation allows the production of infection-free or resistant crops that require less pesticide application. This reduces the negative environmental and health impacts of chemicals and promotes sustainable agriculture.

In addition, micropropagation offers the possibility of producing hybrids and combining improved plant traits. This can increase the productivity and resistance of the crops grown and reduce the environmental stresses involved in their cultivation.

Overall, micropropagation has great potential for species conservation, contributing to the conservation of endangered plant species and increasing genetic diversity. In addition, it offers the potential to increase phenotypic diversity and improve plant adaptation, which is key to promoting sustainable plant conservation and agriculture.

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4. Greenhouse growing

Author:

• Pék Zoltán - Magyar Agrár- és Élettudományi Egyetem

4.1 GREENHOUSE GROWING, VEGETABLE PROPAGATION

The spread of greenhouse cultivation of vegetable crops, or vegetable sprouting in technical terms, on a factory scale began in Hungary in the 1950s. Initially, this meant exclusively soil cultivation, which was gradually replaced by soil-less (hydroponic) cultivation in high-tech facilities from the 1990s onwards. From the technological point of view, the more environmental factors can be controlled in a growing system, the more advanced it is considered to be, the more precisely it can be controlled, while achieving higher yields and better quality. These growing objectives are best achieved today in vegetable production, in large air-space, climate-controlled greenhouses with biological control and soil-less cultivation (1). It is estimated that less than 0.3% of the world's total agricultural area is covered by some type of growing equipment.

Crop production facilities can be divided into 3 broad categories.

Low technology (small airspace installations)

They are less automated and highly dependent on their environment, usually using a single cover, typically plastic, with passive ventilation (top and side ventilation), without heating, and grown almost exclusively on the ground. For this type of structure, it is very important to know the differences between day and night temperatures due to the lack of heating and inefficient ventilation. They do not provide the microclimate necessary for the year-round cultivation of heat-demanding crops and can therefore be used for temporary cover (foil tunnels) or for growing during frost-free periods. Equipment covered: foil tunnel, foil bed, Soroksár '70 type foil tent without side ventilation, sled foil (**Figure 1**).

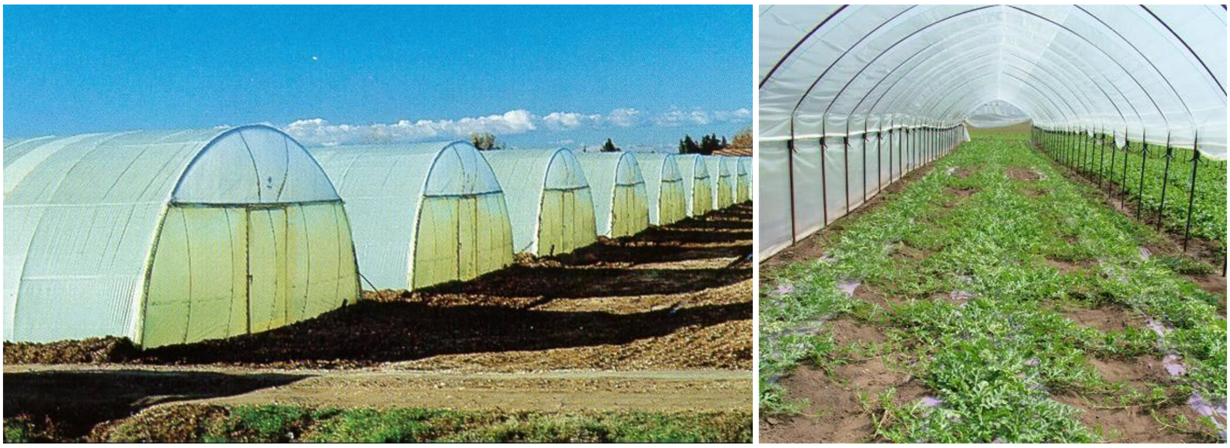


Fig. 1 Foil tunnel, foil bed, Soroksár '70 type foil tent, sledge foil

Medium technological level (heated and unheated equipment)

Typically plastic-covered units, which are already equipped with climate control (emergency heating, heating, side and/or roof ventilation), programmable irrigation with or without soil (hydroponics). Productivity and quality are generally higher than the previous technology and temperature control is usually very simple. It cannot yet compensate for extreme external temperatures and is therefore not suitable for continuous year-round production. The installation of side vents can be retrofitted, so that existing lower quality equipment can be upgraded.

High technological standards (heated high air volume equipment)

Typically large airspace installations (average ceiling height > 3 m), with a single layer of glass (4-6 mm thick), for plastic, several layers (0,04-0,3 mm thick). To optimise the use of space, rolling tables are often used in the production of ornamental plants and propagating material. These special tables are usually equipped with a tidal irrigation system (see 4.5).

Raising *Phalaenopsis on a* roll-top table and pots with tidal irrigation

Facilities with fully automated climate control (highly independent from the outside weather), computer-controlled irrigation, CO_2 fertilisation, almost exclusively micro-irrigation. For this purpose, they have sensor-controlled irrigation and ventilation systems, shade nets for light (and climate) control, usually soil-less cultivation (except for organic cultivation). The greenhouse reacts instantly to changes in the external environment by means of external climate sensors. With these systems, the grower can optimise plant growth, maximise yield and crop quality.

Large airy plastic-covered greenhouse and glasshouse

Vertical farm

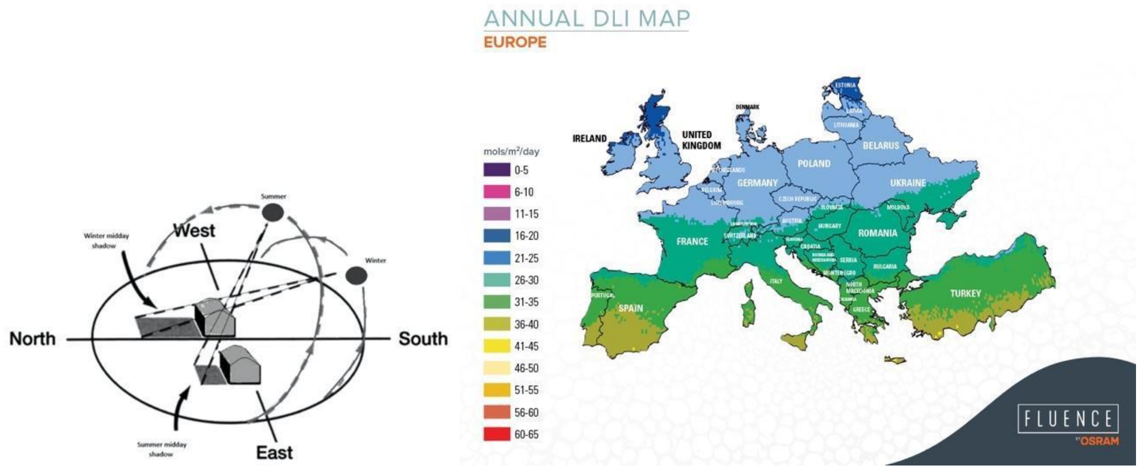
One of the fastest growing and most intensively researched topics in greenhouse production today, and one of the most important, is the topic of vegetable crops grown in fully enclosed and automated production facilities, the so-called Vertical Farm (Plant Factory). This would not have been possible without the development of LED lighting, whose energy efficiency allows its economic application in production and food production in places where it was not possible until now due to lack of light (barren areas, Arctic, space vehicles).

Vertical farms from Aerofarms (New York, USA) and VegetaFarm (Haneda, Japan)

Not only in vegetable production, but in almost all sectors of horticulture, the demand for manual labour is high, which nowadays presents practising horticulturists with an almost insurmountable challenge. One solution to this problem is the development of robots for agro- and phytotechnical work in the field of precision farming.

4.2 BASICS OF CLIMATE CONTROL FOR PRODUCTION EQUIPMENT

The climate control of a production facility can be designed in relation to the geographical location (latitude) and microclimate of the implementation. The former determines the maximum/minimum angle of incidence of the sun's rays and, through this, the maximum and minimum day length (summer/winter solstice) and the theoretical expected daily solar radiation energy (Daily Light Integral, DLI).



The angle of incidence of the sun at the summer and winter solstices and Europe's DLI skyline

The latter is also strongly influenced by the microclimate of the area, which, in addition to the basic climate classification, is influenced by the local topography and other surface features. Growing facilities in the temperate zone are designed so that the rows of crops grown in them, generally oriented east-west (2).

High-tech equipment, which can therefore be implemented at the highest cost, must also be equipped with external meteorological sensors to protect the crop and equipment against extreme climatic events (wind, precipitation).

The climate control, which is highly dependent on the technological level of the plant, is based on data measured and transmitted by sensors, which are usually used by a control software to develop the optimal climatic and edaphic conditions for the specific technological version of the vegetable crop.

(For more information, see chapter 2).

4.3 GROWER CONTROL IN PRACTICE: THE PRIVA OPERATOR

To create optimal growing conditions, it is essential that all systems work together seamlessly, coordinated by the intelligent controller. This operations centre is the basis of the control system, to which several systems are connected. The more intelligent the controller, the better the processes achieve an optimal balance.

Temperature, humidity, CO_2 concentration, nutrient and water supply are optimised according to the amount of light irradiated, adapted to the needs of the crop. The control system continuously monitors the greenhouse growing conditions, such as ventilation, heating, shading, CO2 levels, fans, humidity, lighting, boilers, irrigation, nutrient solution and drainage water reuse, 24 hours a day, using data from sensors. All commercially available control systems have the necessary control options, as well as a graphical interface that can be accessed via a mobile client.

Graphical user interfaces for the Priva Operator greenhouse control system

4.4 GROWER CONTROL IN PRACTICE: GREMON SYSTEMS

All the major greenhouse control systems available in Hungary have sensor-controlled climate control and modules for optimal water and nutrient supply to plants.

Unlike the previous one, Trutina is a Hungarian solution developed by Gremon Systems, which can be used even for soil cultivation. In addition to the basic services, it also provides real-time monitoring of plant biomass (with an accuracy of 1 gram), based on the use of specially developed plant scales. The scales can be retrofitted in the crop and the number of sensors can be extended. It continuously monitors the biomass evolution and automatically warns when the tray weight decreases. By continuously monitoring irrigation water/fertilizer solution, it optimizes irrigation strategies to save water and fertilizer. Thanks to the client software, you can also monitor the process on your smartphone. Its alert system automatically sends a message when irradiation, temperature, nutrient EC, drainage water, bowl weight, root medium parameters reach undesirable values.

Gremon Systems, Trutina Greenhouse Control Software graphical user interface and sensors for measuring plants

Tungsram Agritech's Power Grow system can be used exclusively to control the company's proprietary vertical farm, which is unique in that it is completely closed. It is based on fully artificial lighting, using proprietary LED lamps to set specific lighting recipes. The lamps emit light not only in the photosynthetically active spectrum (PAR) but also in the ultraviolet range, which can be used to produce similar effects as in the open air under natural lighting conditions. The full potential of varying the ratios of the different wavelengths has not yet been scientifically investigated, so it is not surprising that several universities and research institutes are using their systems to study the effects of light on plants.

4.5 SOILLESS GROWING SYSTEMS

The cultivation of a plant species on a given soil over several years is called monoculture. The monoculture of vegetable crops results in steadily decreasing yield averages year after year, even with species rotation. The main reason for this is the damaging effects of pests, pathogens and weeds that accumulate in the soil, which are avoided by soilless growing systems in greenhouses (9). Such systems must replace the abiotic functions of the soil to ensure that the roots of the plants receive adequate water, oxygen and nutrients (macro-, meso- and micro-nutrients). In previous production systems, there was a conflict between the supply of these needs, with an excess or deficiency of one causing an imbalance of the other or both.

In soilless cultivation, the nutrients needed for plant growth are applied in the form of nutrient solution, which is analogous to the nutrient supply capacity of soil, since the mineral nutrients are present in the aqueous phase of the soil as dissolved ions. Since the solid supporting medium (substrate) of plant roots usually contains little or only minimal amounts of nutrients, nutrient solution is mandatory for plant development.

A number of soilless cultivation systems have been developed, the most important of which are not exhaustive:

- Drip irrigation (Drip irrigation)
- Nutrient film technique (NFT)
- Deep flow technique (DFT)
- Tápköd culture (Aeroponics)
- Low tide system (Ebb/Flow)

Systems that apply nutrient solution directly to the roots of plants are called hydroponics (hydroponics), while systems that apply nutrient solution to the root medium are called agroponics (10).

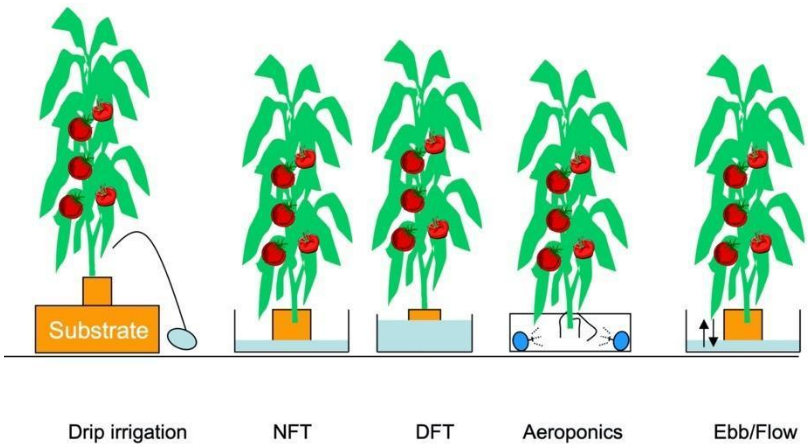
So-called agrosponge systems using a substrate are not really suitable for growing high density crops (e.g. leafy vegetables), so they are used more for growing vegetables grown for their yield (tomatoes, peppers, cucumbers). For growing leafy vegetables without soil, mainly NFT and DFT hydroponic systems are used, but aeroponics is also used. In totally enclosed growing systems using only artificial lighting, as in the case of vertical farms, hydroponic systems are generally used (11).

The Nutrient Film Technique (NFT) system is based on a 1-2% sloping channel with a thin layer of nutrient film continuously flowing at the bottom. This is where the roots of the plants take up the water and nutrients they need. The advantage of this system is that much less nutrient solution is present, which is an advantage in vertical growers because of the lower weight. The oxygen supply to the roots is also more favourable, which increases the flow rate by increasing the slope angle, thus improving the oxygen level in the nutrient solution (12). The disadvantage is that the temperature of the smaller amount of nutrient solution is more variable, but this is not a problem in growing systems with strict air temperature control (13).

Deep Flow Technique (DFT) was historically the first hydroponic soil-less cultivation system. Created in the 1920s, the tank culture was based on a 15 cm layer of nutrient solution in concrete basins. The plants were planted in a so-called seedbed on a metal mesh, which also served as a light barrier for the nutrient solution. The disadvantage was that it was not aerated, but it became the starting point for many solutions using a shallower layer of nutrient solution.

Aeroponics is a soil-less cultivation method requiring high investment and operating costs and a very precise technical background. It was developed in the 1970s and is also suitable for factory-scale cultivation. The basic principle is that the roots of the plants are suspended in a completely enclosed space, where the nutrient solution is injected in very fine atomization, in doses of a few seconds every 2-3 minutes. From the nutrient mist that forms around the roots, the roots, suspended in the air, are able to take up the nutrients continuously, with an excellent oxygen supply. The disadvantage is that even a short power failure is enough to dry out the roots and kill the crop (14).

In Ebb/Flow systems, the growing area is flooded with nutrient solution for a period of time to allow the plants and growing medium to absorb sufficient nutrient solution, and then the remaining nutrient solution is drained off. It is also used by home gardeners, mainly for seedlings, potted herbs and ornamentals on growing tables.



The main soilless systems used in greenhouses

4.6 SOILLESS CULTIVATION WATER AND NUTRIENT SUPPLY (CLOSED SYSTEM)

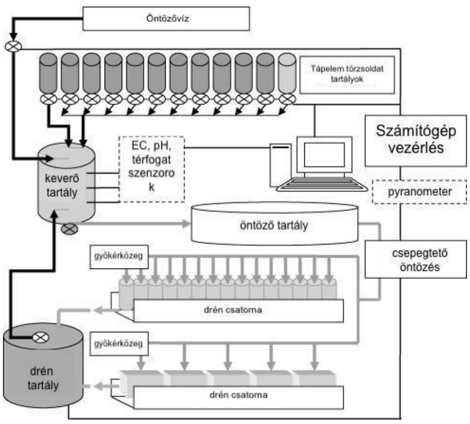
In soil-less cultivation, closed systems can also be used to minimize environmental pollution from run-off nutrient solution (drainage) (15). In addition to significant savings in irrigation water and nutrients, high yields and improved water use efficiency allow for more cost-effective cultivation overall (16). However, the accumulation of ions that are rarely taken up by plants can cause partial runoff to control salinity in root zones, thereby reducing the effectiveness of closed-cycle systems to prevent groundwater contamination. Intelligent automation systems based on mass balance models can be used to minimise the need for recycled effluent discharge, thereby reducing groundwater contamination (17).

The biggest risk factor in soil-less cultivation is undoubtedly the disinfection of drainage water, without which even a single diseased plant can infect the whole stand. It is the cost of disinfection that is most expensive in closed systems. There are a number of different methods of disinfection available, including pasteurisation, UV irradiation, chemical treatment, sand filtration and sterilisation filtration by reverse osmosis equipment (13).

Water detection sensors

Proper EC and pH levels are key factors for healthy culture growth. The Priva control computer and dual EC and pH sensors, you can automatically monitor and control EC and pH levels. By including a water flow sensor, the correct EC and pH levels can be determined - a pre-calculation that only Priva can provide. The control computer then corrects for deviations from the desired values based on the readings from the dual EC and pH sensors. And pressure sensors facilitate optimal water management in the reservoir and nutrient solution storage tanks.

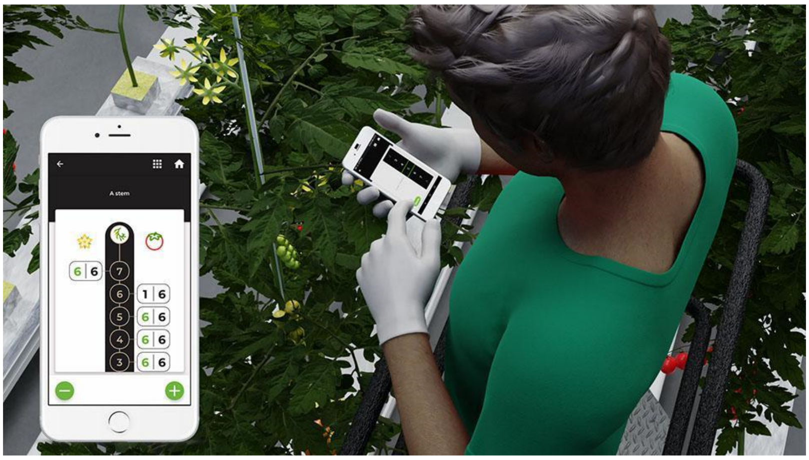
When growing on substrate, you can accurately measure the amount and EC value of drainage water with the drainage sensor. Using the Priva Growscale scale, you can automatically adjust the water dosage according to the growing conditions and the condition of the plant and the substrate, based on the needs of the plant.



Construction of an irrigation system for soil-less cultivation

4.7 FITO MONITORING

For continuous monitoring of plant health, non-destructive sensors are already available that can be used to monitor real-time parameters of characteristics that are visible to the naked eye (stem diameter, leaf number, quail number) or not visible to the naked eye (leaf surface temperature, photosynthetic activity). Gremon Systems' in-house developed solution is the Crop Monitor, which works in conjunction with the Trutina system mentioned above. It records plant vitality based on stem diameter, main shoot growth and flowering cluster spacing (internode length). It determines the leaf area index (LAI), based on the length, width and number of leaves, and the vegetative/generative balance of the plants, based on the number of clusters, flowers and tied berries, as well as vegetative parameters.



Graphical user interface of the Gremon Systems Fitomonitoring system

4.8 PHYTOTECHNICAL WORKS AND HARVESTING

Not only in vegetable production, but also in almost all sectors of horticulture, the demand for manual labour is high, which nowadays presents practising horticulturists with an almost insurmountable challenge.

Phytotechnology, i.e. direct intervention on plants, may include, in the case of continuous-growing vegetable species: plant clipping, shoot positioning, removal of axillary shoots, leaves, flowers and fruit stems. A number of manufacturers offer tools for these operations. Self-operating robots have been developed for removing the lower leaves of tomatoes, which can also work efficiently at night.

The Priva Deleafing (mailing) robot

In the case of continuous-growing vegetable crops, the most important tool for implementing phytotechnology is the cultivator trolley, which is used to move between the rows. It is a height-adjustable, stationary structure powered by a battery-operated electric motor. Phytotechnicians can control its progress and change the height of the stand on which they can carry out their work while standing.

Self-propelled, lift truck, electric picker

Although it does not fall under the heading of phytotechnical work, harvesting cannot be done without touching the plants, which is one of the biggest jobs, especially for continuous-growing vegetable crops. For vegetable species (leafy vegetables, root vegetables, brassica, asparagus) that can be harvested in a single pass, usually for their vegetative part, a number of automatic, even driverless, solutions are already available.

Harvesting, in the case of crops grown for their generative part, is carried out several times, even several times a week, and therefore care should be taken to minimise damage to the crop. Examples of such vegetable species are tomatoes, peppers and cucumbers, where manual harvesting can account for up to 30% of the total production cost, for example, in the case of long-cropped, high-hectare tomato crops, the harvesting period is usually from early March to the end of December, for about 10 months. The development of robots with artificial intelligence (Metomotion, Panasonic tomato harvesting robot), which can be applied to harvesting operations, offers a solution to this problem. The success of precision vegetable production depends on the extent to which it can be properly adapted to manage and harvest the continuous needs of plants in space and time.

MetoMotion's self-powered tomato harvesting robot

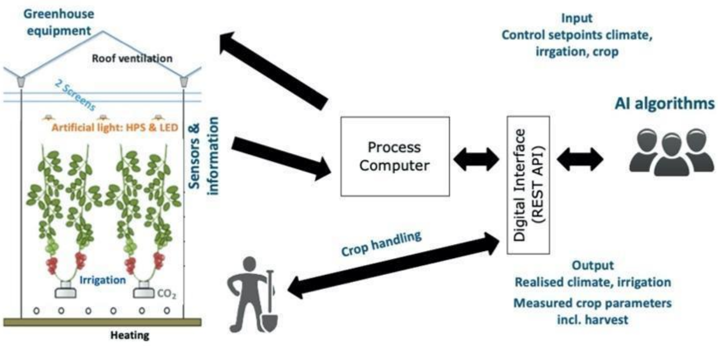
4.9 FITNESS TECHNOLOGY ADMINISTRATION (GREMON SYSTEMS INSIGHT MANAGER)

However, the highly costly and labour-intensive phytotechnical and harvesting work needs to be monitored precisely, on a worker-by-worker basis, so that performance-related pay can be implemented. Gremon Systems' Insight Manager software, which identifies workers with a unique magnetic card, is a solution developed for this purpose. Card readers in the plant house track individual performance, which can then be transmitted to payroll.

Card reader and graphical user interface for Gremon Systems, Insight Manager administration system

4.10 AUTONOMOUS (SELF-OPERATING) GREENHOUSE

Artificial intelligence (artificial intelligence (AI) has made significant breakthroughs in many fields, but not yet in horticulture. The creation of the Autonomous Greenhouse aims to combine horticultural science and artificial intelligence to achieve breakthroughs in the production of fresh food with more efficient use of resources. A team of scientists, technicians and students with different horticultural and artificial intelligence expertise will develop solutions to grow vegetables under remote (sensor) control. The growing equipment must of course be computer-controllable, in terms of heating, ventilation, shading, lighting, humidification, CO_2 supply, water and nutrient supply. The control of the greenhouse can also be operated remotely by an industrial computer if the various sensors continuously collect data via a digital interface. By comparing the results obtained in AI-controlled greenhouses with those of a manually operated reference greenhouse, it can be concluded that in terms of detailed results (yield, resource utilization efficiency, net profit) in terms of yield, resource utilization and net profit achieved, AI generally performed well in greenhouse control and was able to outperform conventional technology (18).



Autonomous greenhouse operation (18)

4.11 VERTICAL FARM (PLANT FACTORY)

To solve the triple problem of food, resources and the environment, transdisciplinary methodologies based on new concepts need to be developed to significantly improve the yield and quality of food crops with less resource use and less environmental degradation than current crop production systems (31). Plant Factory with Artificial Light (PFAL) is expected to be one such crop production system to achieve this mission (32). In European countries, the term "Vertical Farm" is the preferred term, while in Asia the term "Plant Factory" is accepted when referring to intensive plant production systems with vertically stacked or vertically tilted shelves (Den Besten, 2019). The popularity of the term "Vertical Farm" (VF) is related to the fact that European consumers prefer the term "farm" rather than "factory" for fresh produce.

The advantages of VF include improved resource use efficiency (RUE), high productivity and the production of better quality crops without the use of pesticides (33). The use of LED light sources in horticulture is a more environmentally friendly and economically viable solution than HPS lighting (Paucek et al, 2020).

Interest in fresh, functional foods is growing, driven by consumers' increasing demand for diets that support health and longevity. Microgreens have enormous potential for micro-adaptation of leafy vegetable production and for improving the quality of human diets (34).

When properly designed and used, VF has the following potential advantages over conventional farming:

a. It can be built anywhere because it needs neither sunlight nor soil;

b. Growing conditions are not affected by the external climate and soil fertility;

c. Production is continuous throughout the year and productivity exceeds that of open field technologies;

d. The quality of production, for example the concentration of phytonutrients, can be improved by manipulating environmental parameters

a The light quality can be better than in the open air;

e. The product is pesticide-free and does not need to be washed off before meals;

f. The product has a longer shelf-life, as the bacterial load is usually less than 300 colony forming units (CFU)/1, which is 1/100-1/1000th of the production of field crops;

g. Transport costs can be reduced by deploying VFs near urban areas;

h. High resource use efficiency (water, CO_2, fertiliser, etc.) is achieved by minimising the release of pollutants into the external environment.

Even in soilless cultivation of VF, the nutrients that are essential for plant growth are supplied in the form of nutrient solution, as the media used to support the plants contain no or minimal amounts of nutrients. According to researchers, the nutrient requirements for nutrient solutions used in VF systems can be summarised as follows requirements for the use of VFs (35):

It contains all the essential nutrients (except carbon) in ionic form, including the so-called macro-nutrients (oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur) and the micro-nutrients (iron, boron, manganese, copper, zinc, molybdenum, chlorine, nickel, cobalt),

The concentration of ions should be at an optimal level and uniform for plant growth,

It must not contain substances harmful to plants or pathogenic micro-organisms,

pH should be uniform between 5.5 and 6.5,

Contain sufficient dissolved oxygen for the respiratory activity of the roots.

Greensense Farm's indoor plant production and Plant Factory book cover

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5. Digitisation of the microclimate in greenhouses

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5.1 CLIMATE CONTROL OF PRODUCTION EQUIPMENT

The use of cultivation equipment has two main purposes. Firstly, to protect the crops from external environmental factors (extreme temperatures, wind, hail, heavy rainfall, etc.) and secondly, to create a microclimate that creates the optimal environmental conditions necessary to achieve the desired growing objective. The production objective is most often to maximise the yield of a raw crop that can be harvested for fresh consumption.

To achieve the former, we aim to control the climate of the growing equipment, optimise light (irradiation), temperature, humidity and CO_2 concentration.

(Lighting is discussed in Theme 6.)

Temperature

The temperature available in the plant essentially determines whether or not a particular crop can be grown at a particular time. One of the most important characteristics of the growing equipment is the so-called ΔT value, which expresses the difference between the internal and external temperature that can be achieved by using the equipment. In principle, equipment intended for continuous operation over long growing seasons should be designed for a ΔT of 30-35°C, so that the +10°C threshold temperature for the development of heat-sensitive crops can be achieved even in the event of frosts of -20°C or below in winter.

The temperature can be further increased by using heating, the main types of which are ground heating, hot air injection, air space heating and vegetation heating. The latter two are mainly used in large airspace installations. Vegetation heating is the most efficient, with pipes usually placed on the floor near the root zone and the warm air flowing upwards through the leaves of the plants. The tubes can be made of plastic (polypropylene), usually black in colour, 3-4 cm in diameter, with a ribbed surface for more efficient heat transfer, and are placed near the root zone of the plants. The metal (usually iron) tubes are placed on a scaffolding a few centimetres high, the width of which corresponds to the gauge of the metal wheeled trolleys used for harvesting and phytotechnical work. They have a smooth surface and are originally painted white, but this wears off with constant use. Water (20-25°C) flows in the pipes, often using thermal water for heating, but also natural gas and renewable energy sources (wood, wood chips, etc.) are used as heating fuel. The technical solution for air space heating is very similar, with a smooth surface and usually white, but here the pipes are placed at the height of the plant stand and are therefore less efficient as the root zone is not heated. For heat-demanding plants, the temperature of the root zone is also important.



Energy screens are used to reduce the energy loss at night due to lack of sunlight, acting as a reflective surface to reduce long-wave thermal radiation, and can produce heat losses of up to 15°C. They are usually made of woven polyethylene with aluminium fibres. They are also suitable for shading, but unfortunately they cannot reduce the high temperatures of summer days.

Temperature reduction plays an important role in the summer climate control of production facilities, and there are a number of methods that can be used. The cheapest is ventilation, which can be used to control not only temperature but also humidity and CO_2 . Therefore, the proportion and positioning of the ventilation surface is an important consideration when designing growing systems. Large air-space growers usually use roof vents, the proportion of which is influenced by the size and proportions of the unit (length, width, height), the prevailing wind direction and the natural or built-in wind shade. Generally speaking, increasing the surface area of ventilating windows increases the ventilation efficiency but also the likelihood of ingress of harmful organisms. In addition to ventilation, the use of shading screens, shading paints, cooling walls, heat pumps and fogging to reduce temperature is also known. A combination of the above solutions is usually used to prevent excessive heating of the plant in summer, e.g. ventilation, shade painting, humidification irrigation.

Humidity

Plants continuously evaporate water (transpiration) through their gas channels (stomata), increasing the relative humidity (RP%) of the air. This process is based on diffusion, so the 100% RH air in the space inside the gas channels is exchanged with lower RH air in the environment. The greater the difference between the outside and inside of the gas loop, the faster this process is, which also promotes water uptake through the roots. Therefore, for practical purposes, the relative humidity is replaced by the water vapour pressure deficit (VPD%), which is the difference in relative humidity between the inside and outside of the gas loop. Low humidity increases the closure of the gas stomata, thereby also reducing assimilation and transspiration camel activity. High humidity can increase the likelihood of fungal and bacterial infections and reduce the efficiency of evaporation, thus reducing assimilation. A not insignificant aspect for crops that require pollination and are grown for their yield (tomatoes, peppers, eggplants) is that low humidity can dry out the pollen pollen, resulting in a loss of fertilisation and yield. And if the humidity is too high, the pollen grains may stick together, also negatively affecting the efficiency of fertilisation.

Humidity control can also be achieved most cheaply by ventilation. Humidity can be increased by using a humidifier with special spray nozzles and reduced by using an active dehumidifier.

CO_2

Plants use large amounts of CO_2 for assimilation, and ventilation is also the cheapest way to replace it. The most modern cultivation equipment is already equipped with CO_2 fertilisation. Mainly due to human activity, concentrations in the outside air have been increased to an average of 400 ppm (0.04%) (6), 700-1000 (7), and in other cases up to 1200 ppm in the equipment, maximising assimilation (8). Commercially available tank CO_2 is usually used for this purpose. Using mixing fans is important to maintain homogeneous air quality in the greenhouse in order to ensure that adequate concentrations are uniformly available throughout the greenhouse.

HORTICULTURE 4.0

Vocational Education
for Digital Transformation in Horticulture

BACKGROUND

E-Agriculture is no more the future, it is the present. Farmers have always been aware of the fact that their success depends on several factors like the quality of soil, the weather, the amount of water, but they didn't have tools to influence, to measure and control these parameters to optimise the circumstances determining crop growth. In the age of digital transformation horticulture plays a crucial role as it provides fresh and nutritious food for the growing global population.

Using smart technologies in greenhouses decreases the uncertainty and increases the productivity, and therefore, automated greenhouses are becoming increasingly popular.

The need for automation and remote control of greenhouses is increasing in many countries worldwide, however, educated labour force is scarce. Vocational education can only respond to these challenges with several years of delay, while technological changes happen at an exponential rate.

Teaching material on the automation and remote control of greenhouses does not exist for VET and not even for universities. Due to the fact that the subject is quite new, the related technology and services have not yet been standardised, and farmers are therefore faced with the difficult task of selecting which system to use.

Co-funded by the European Union

The Consortium will develop a learning outcome oriented curriculum and further training program on "Smart Greenhouses" for European VET teachers in response to the growing needs of the agricultural sector's labour market.

OBJECTIVES

The objective of the project is to contribute to the digital and green transition of agriculture by delivering innovative, high quality learning materials for VET teachers on smart greenhouses, involving actors from the labour market.

THE PROJECT WILL

1. Identify the digital skills needs for smart greenhouses in collaboration of companies in order to tackle future skills mismatches in horticulture

2. Facilitate the development and scale-up of flexible, modular, and learner-centred micro-courses enabling VET schools of the agriculture sector to give quick and relevant response to the needs of the labour market

3. Foster technical and digital skills and effective, innovative training methods of teachers in agriculture, help them to learn and teach in virtual environments and provide them up-to-date knowledge on smart greenhouses

PLANNED RESULTS

1. Digital Competence Map of smart greenhouse workers
2. Smart Greenhouses Curriculum
3. Smart Greenhouses – practice-oriented learning content
4. E-learning platform for delivering online course for VET teachers
5. Smart Greenhouses e-book for VET teachers and Trainers

PARTNERSHIP

Project coordinator:

Alföldi Agrárszakképzési Centrum Galamb József Mezőgazdasági Technikum és Szakképző Iskola, (HU)

Partners:

iTStudy Hungary Számítástechnikai Oktató- és Kutatóközpont Kft. (HU)

Hungarian University of Agriculture and Life Sciences (HU)

Universitatea Sapientia din Municipiul Cluj-Napoca (RO)

Foundation "Pro Scientia Naturae", Senta (SR)

PROJECT BASICS

Acronym	Horticulture 4.0
Title	Vocational Education for Digital Transformation in Horticulture
Project number	2021-2-HU01-KA220-VET-000050665
Project type	Erasmus + KA220-VET - Cooperation partnerships in vocational education and training
Duration	36 months
Start date	01-03-2022
End date	28-02-2025
Target group	VET teachers and trainers in the agricultural sector
Beneficiaries	VET students learning for horticultural qualifications (IVET/CVET)
	VET providers and horticultural enterprises
Partner countries	Hungary, Romania, Serbia

SMART GREENHOUSE PRACTICE-ORIENTED LEARNING CONTENT

Module 1 – Advanced digital skills for smart green houses

ICT technologies used in climate control systems, LED lighting, irrigation systems, valves and pumps, sensor and control systems.

Module 2 Smart technologies in greenhouses

Topic 1: Mobile communication in greenhouses, data transmission
Topic 2: Micropropagation techniques in the laboratory
Topic 3: Greenhouse vegetable and ornamental crop production technologies
Topic 4: Digitalisation of the microclimate in greenhouses
Topic 5: Precision greenhouse irrigation systems
Topic 6: Digitalisation of artificial lighting in greenhouses
Topic 7: Other greenhouse automation, sensors, robotics
Topic 8: Plant protection for precision greenhouse production

Module 3 – Innovative Teaching Methods

Project coordinator: Alföldi ASZC Galamb József Mezőgazdasági Technikum és Szakképzőiskola
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