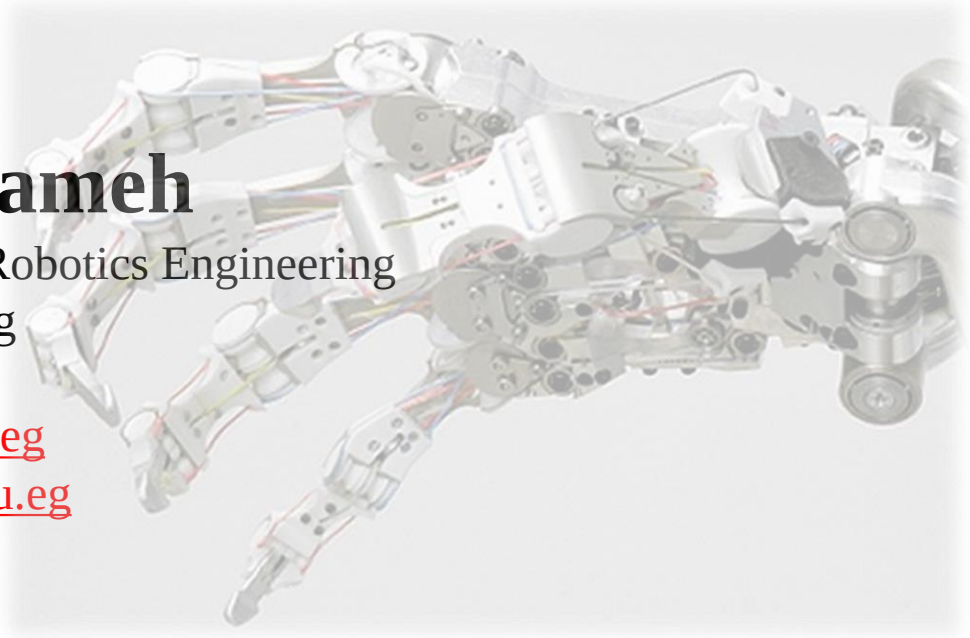
Introduction To Mechatronics



Lecturer

Dr.Eng. Ahmed Sameh

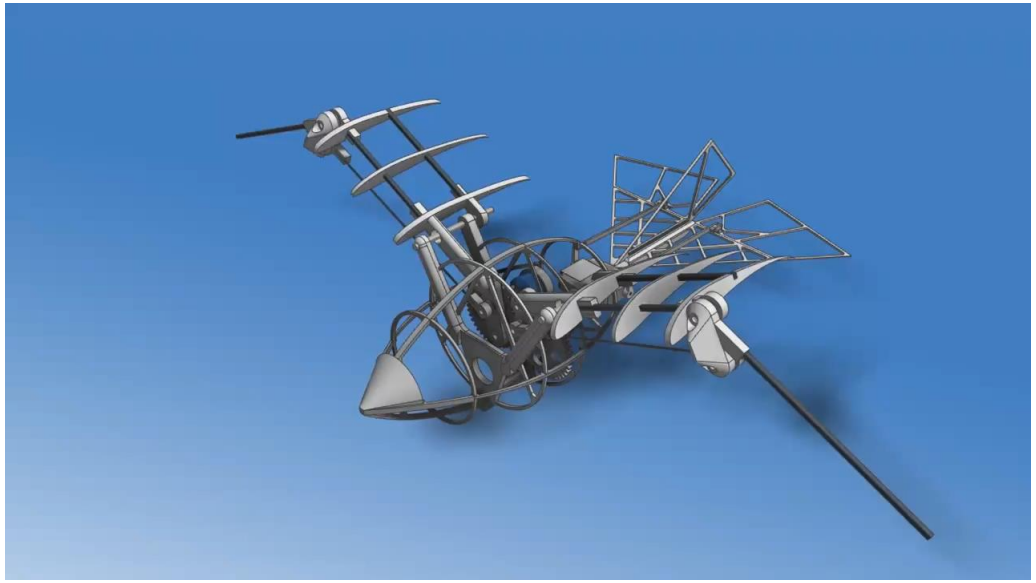
Assistant Professor in Mechatronics and Robotics Engineering
Faculty of Engineering
Mansoura University
asameh192@mans.edu.eg
ahmed.ismaeil@ejust.edu.eg

2022

About Lecturer

Dr.Eng. Ahmed Sameh

Assistant Professor in Mechatronics and Robotics Engineering
Faculty of Engineering
Mansoura University

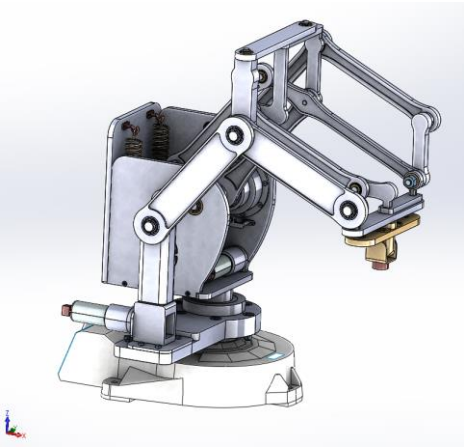


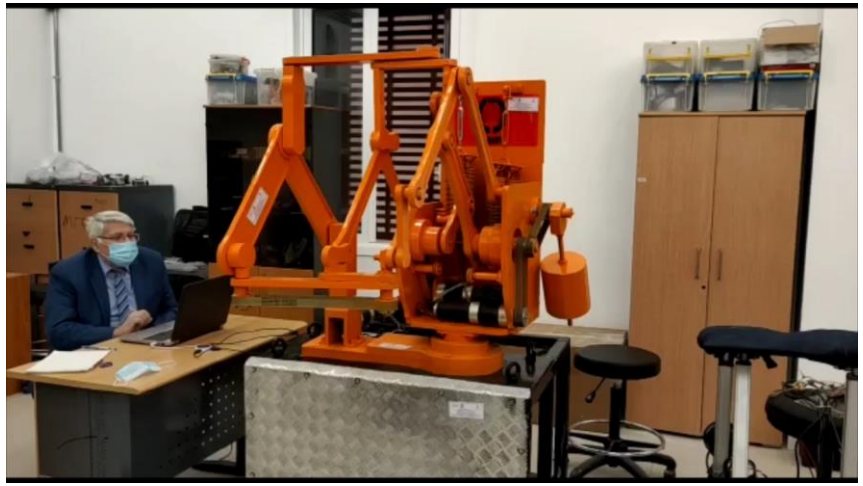
Bachelor's Degree in Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University.

Master's Degree in Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University.
Specialization field: Mechanical Design Engineering.
Thesis Title: Biologically Inspired Design and Control of Small Flapping Wing Air Vehicles.

Ph.D. graduated student & Researcher in Mechatronics and Robotics Engineering Department, School of Innovative Design, Faculty of Engineering, Egypt-Japan University of Science and Technology, Alexandria, Egypt.
Specialization field: Mechatronics and Robotics Engineering.
Thesis Title: Design and Implementation of a new 3D Interconnected Translational Manipulators.

A registered patent, More than 10 published international papers, More than 50 certificates in Mechanical Design, Mechatronics and Robotics Engineering





Introduction to Mechatronics

Course Contents:

Chapter 1: Overview of Mechatronics

1.1 What is Mechatronics?

1.2 Mechatronics Design Approach.

1.3 Measurements Systems.

1.4 Mechatronics Examples.

Chapter 2: Mechatronics System Modeling

2.1 Introduction

2.2 Mechanical System Modeling.

2.3 Basic Mechanical Model components

2.4 Developing Mathematical Model

Chapter 3: Mechatronics Sensors

3.1 Introduction

3.2 Position and speed measurement.

3.3 Stress and strain measurement.

3.4 Temperature measurement.

3.5 Vibration and acceleration measurement.

3.6 pressure and flow measurement.

Chapter 4: Mechatronics Actuators

4.1 Introduction

4.2 Moving-Iron transducers.

4.3 Solenoids.

4.4 Relays.

4.5 Electric motors.

4.6 Direct Current Motors

4.7 Servo motors.

4.8 The stepper motor

4.9 Motor selection.

Chapter 5: Robotic Systems

5.1 Introduction

5.2 History of Robotics

5.3 Current Research in Robotics around the world

5.4 CLASSIFICATION OF ROBOTICS

5.5 Popular Mechanisms in Mechatronics Systems

5.6 Robotic arm terminology

5.7 Robotic arm configuration

5.8 Basic robotic systems

5.9 End-of-arm tooling (EOAT)

5.10 Gripper mechanisms

5.11 Robotic manipulator kinematics

5.12 Robotic arm positioning concepts

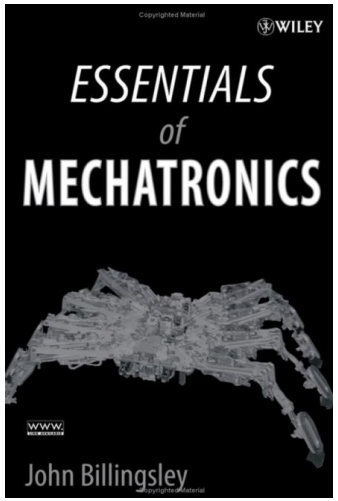
Tutorials

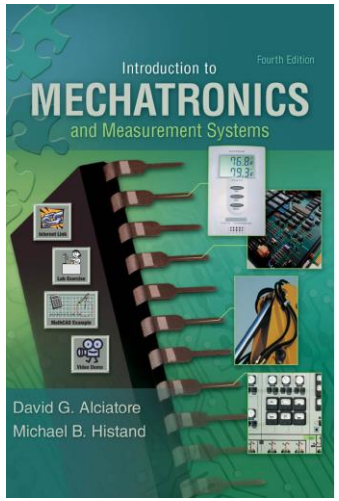
- Review of Lecture's Terminologies and definitions.
- Solve problems related to the topic of each lecture.
- Open discussion about lecture's applications.

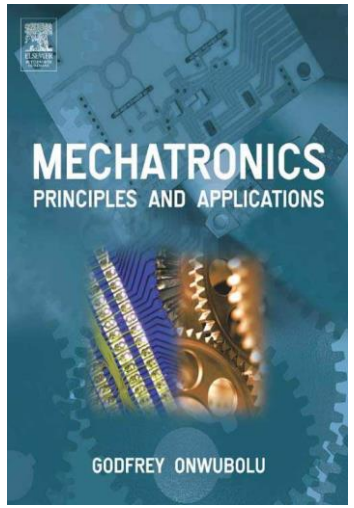
Lab sessions

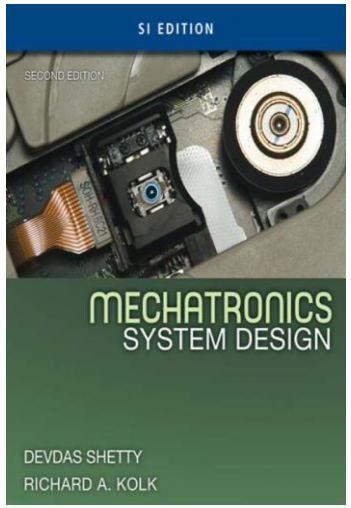
- Deal with real mechanical and electronic components.
- Testing mechatronics systems.
- Review different types of sensors and actuators.
- Build mini projects.
- Learn CAD Skills.
- Learn programming and coding skills to control mechanical structures.

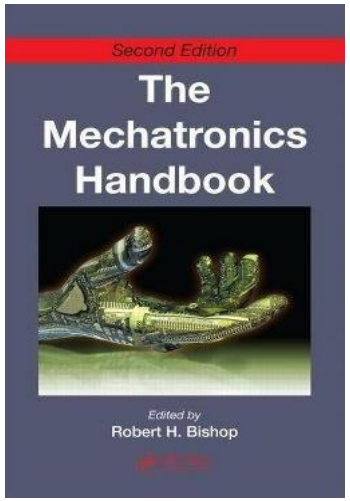
References







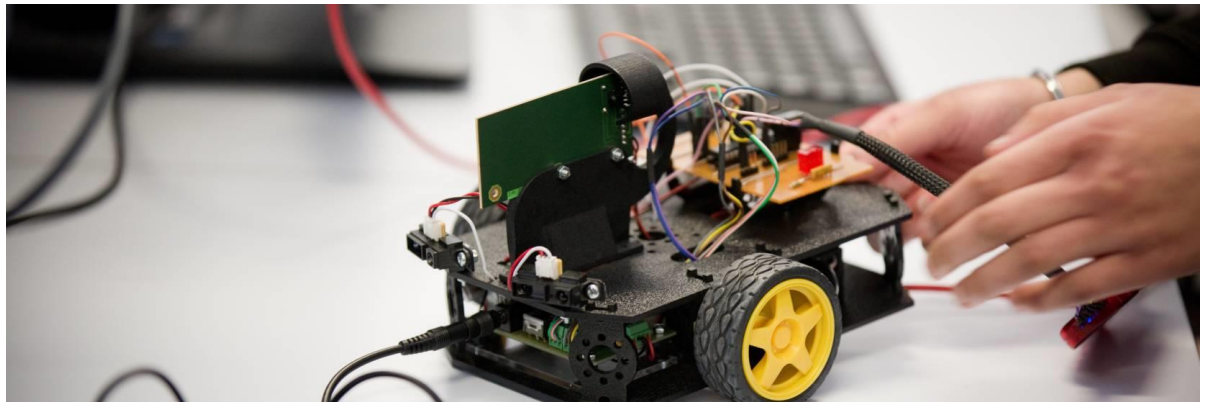


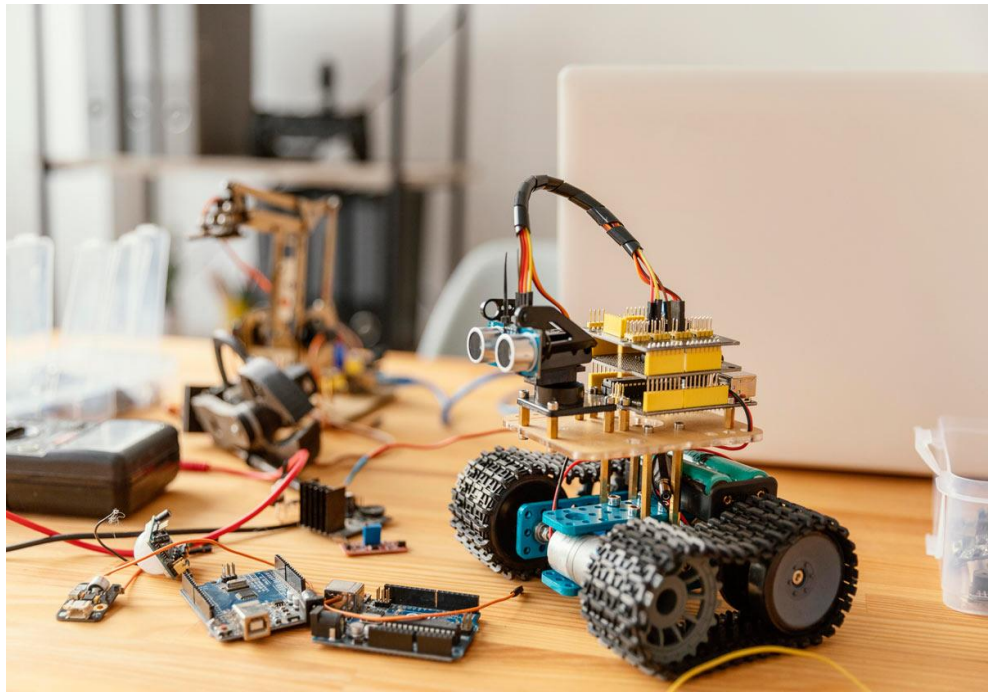


Course Outcomes

A student who successfully fulfills the course requirements will have demonstrated:

- ✓ An ability to identify, select, and integrate mechatronic components to meet product requirements.
- ✓ An ability to know the difference between different types of mechatronics parts and how to select the proper components to build your system.
- ✓ An ability to use commercial software tools for modeling and simulation of mechatronic systems such as Solidworks, Catia, Ansys and MATLAB.
- ✓ An ability to design, analyze, and optimize mechatronic products.
- ✓ An ability to write technical reports and present engineering design solutions efficiently.





Chapter 1

Overview of Mechatronics

What is Mechatronics?

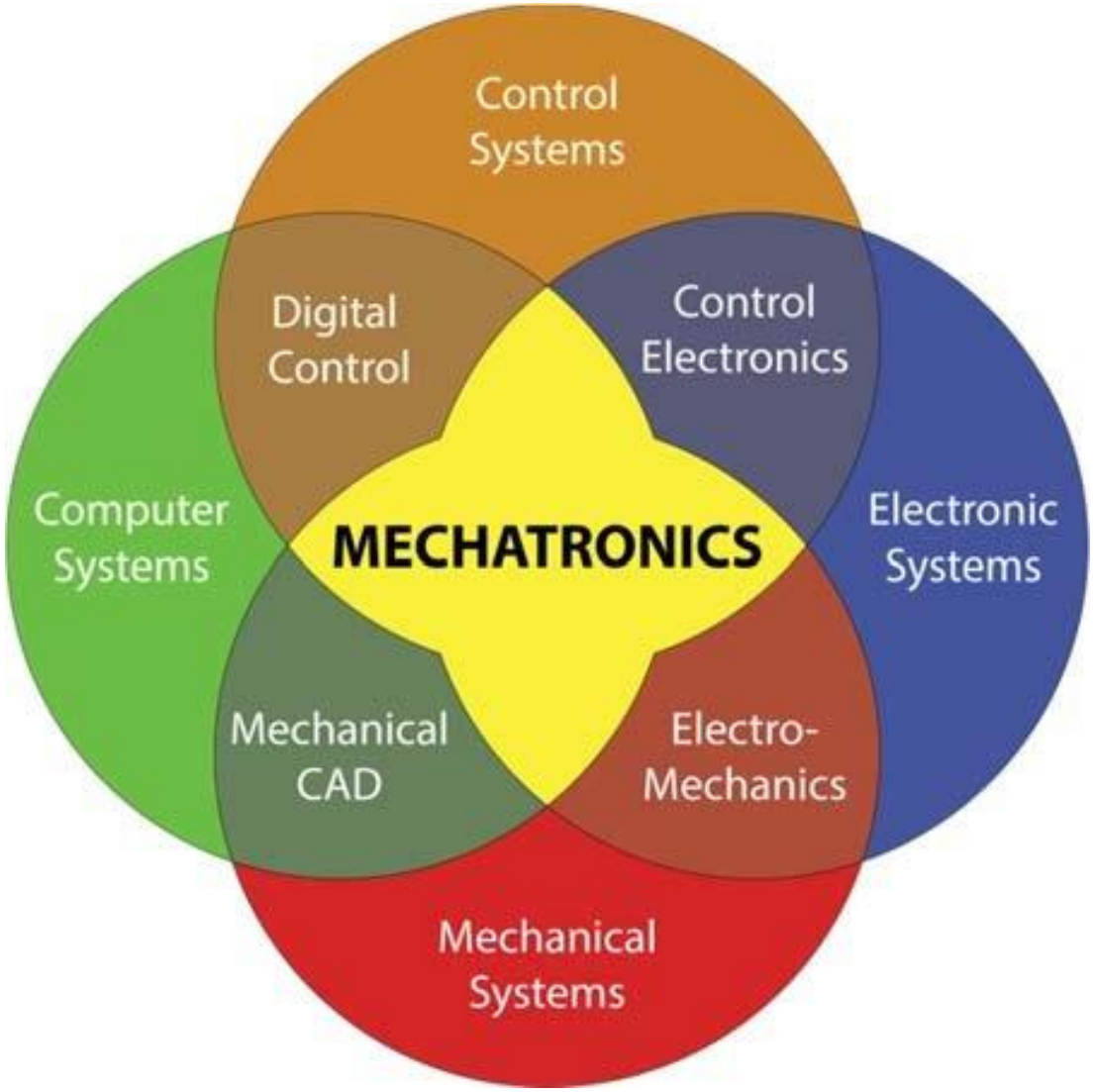
Yasakawa defined mechatronics in this way: ‘The word, mechatronics, is composed of “mecha” from mechanism and the “tronics” from electronics.’

Harashima, Tomizuka, and **Fukoda** in 1996. In their words, mechatronics is defined as ‘the synergistic integration of mechanical engineering, with electronics and intelligent computer control in the design and manufacturing of industrial products and processes.

Another definition presented by Shetty and Kolk appeared in 1997: Mechatronics is a methodology used for the optimal design of electromechanical products.

More recently, we find the suggestion by W. Bolton: A mechatronic system is not just a marriage of electrical and mechanical systems and is more than just a control system; it is a complete integration of all of them.

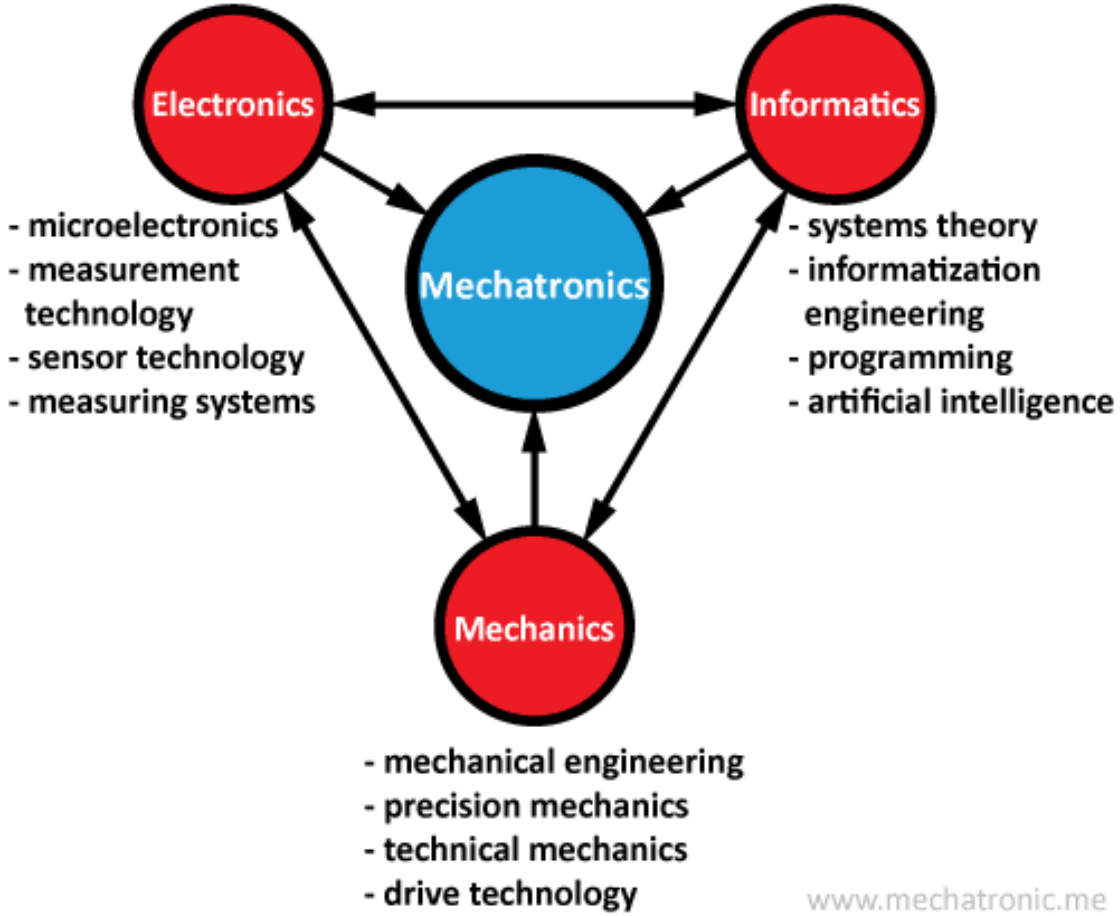
What is Mechatronics?



What is Mechatronics?

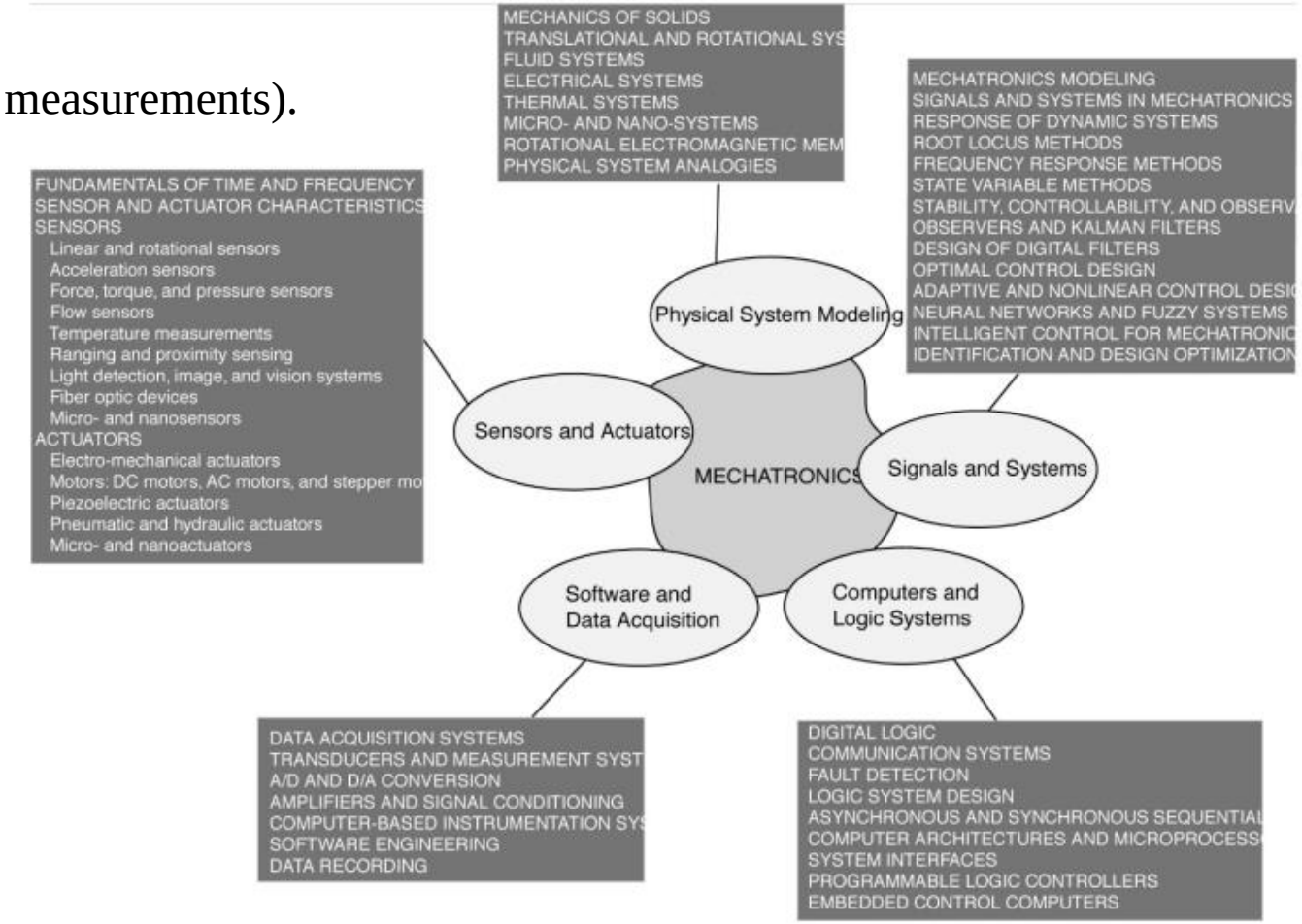
For many practicing engineers on the front line of engineering design, mechatronics is nothing new. Many engineering products of the last 25 years integrated mechanical, electrical, and computer systems, yet were designed by engineers that were never formally trained in mechatronics. It appears that modern concurrent engineering design practices, now formally viewed as part of the mechatronics specialty, are natural design processes.

The ongoing information technology revolution, advances in wireless communication, smart sensors design (enabled by MEMS technology), and embedded systems engineering ensures that the engineering design paradigm will continue to evolve in the early twenty-first century.



Key Elements of Mechatronics

1. Physical Systems Modeling.
2. Sensors and Actuators.
3. Signals and Systems.
4. Computers and Logic Systems.
5. Software and Data Acquisition (Digitizing real measurements).



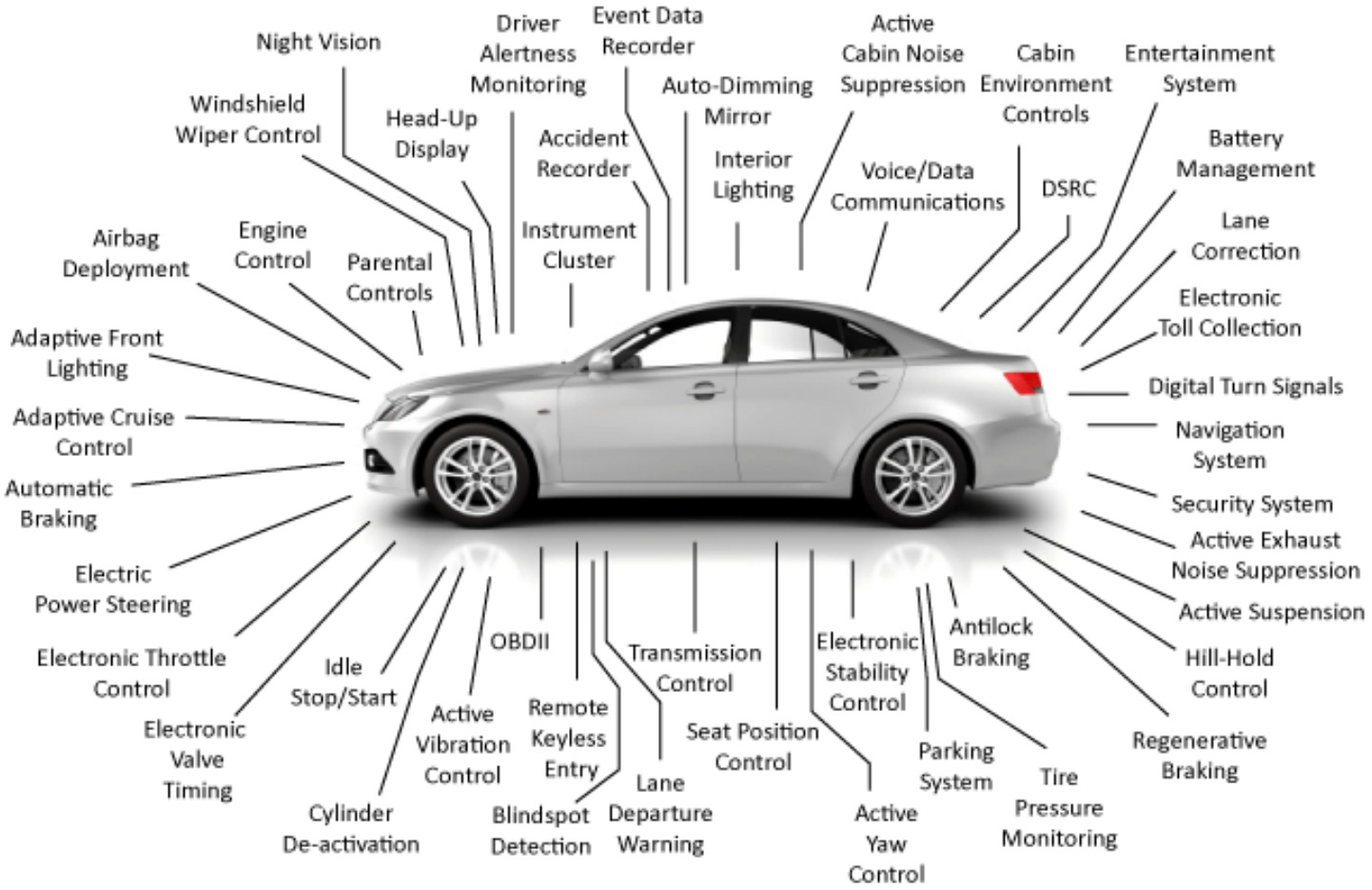
The Development of the Automobile as a Mechatronic System

Until the 1960s, the radio was the only significant electronics in an automobile. All other functions were entirely mechanical or electrical, such as the starter motor and the battery charging systems. There were no “intelligent safety systems,”

Seat belts, introduced in the early 1960s, were aimed at improving occupant safety and were completely mechanically actuated.

All engine systems were controlled by the driver and/or other mechanical control systems. For instance, before the introduction of sensors and microcontrollers, a mechanical distributor was used to select the specific spark plug to fire when the fuel–air mixture was compressed. The timing of the ignition was the control variable. The mechanically controlled combustion process was not optimal in terms of fuel efficiency.

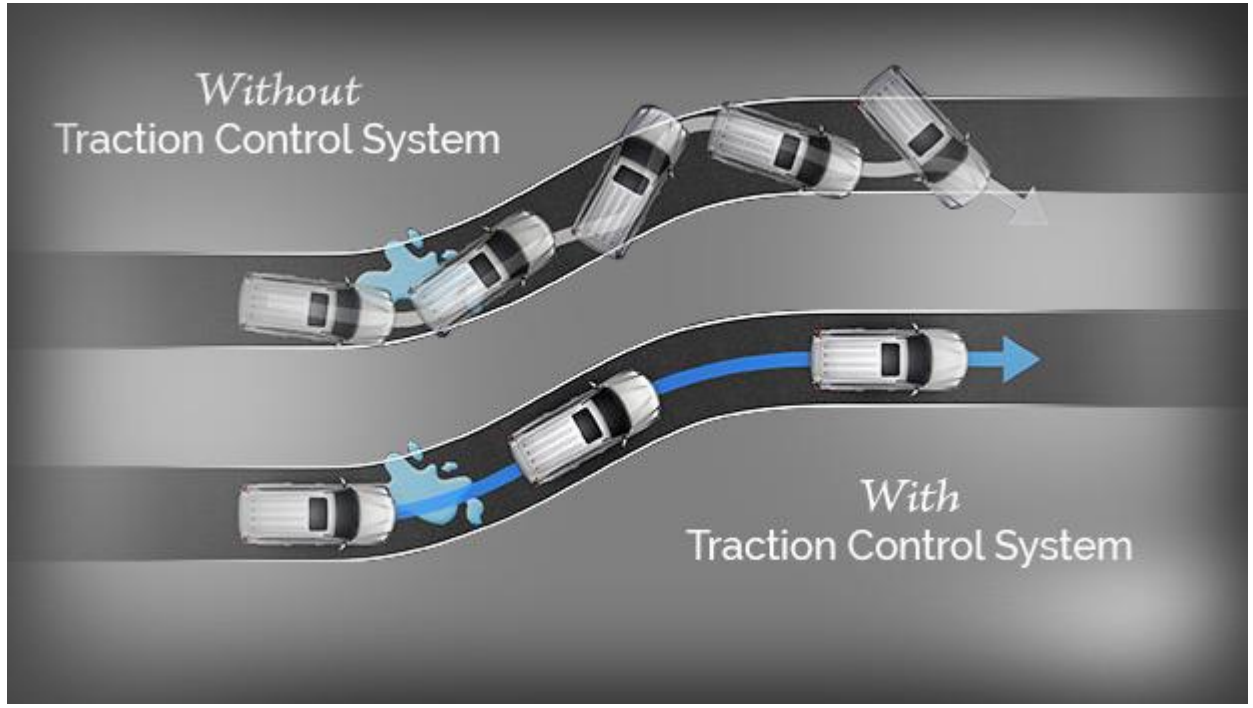
The electronic ignition system was one of the first mechatronic systems to be introduced in the automobile in the late 1970s.



The Antilock Brake System (ABS) was also introduced in the late 1970s in automobiles. The ABS works by sensing lockup of any of the wheels and then modulating the hydraulic pressure as needed to minimize or eliminate sliding.

Traction control is an electronic system that uses the same sensors as the anti-lock braking system (ABS) to reduce or prevent wheelspin.

The Traction Control System (TCS) was introduced in automobiles in the mid-1990s. The TCS works by sensing slippage during acceleration and then modulating the power to the slipping wheel. This process ensures that the vehicle is accelerating at the maximum possible rate under given road and vehicle conditions.

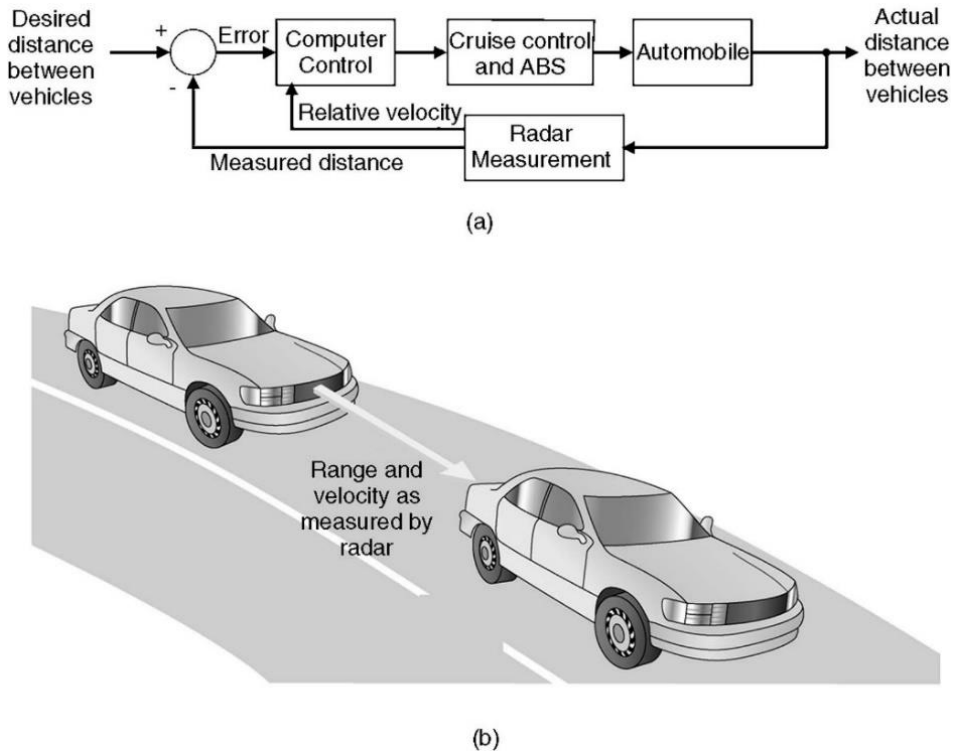


Millimeter wave radar technology has recently found applications in automobiles. The millimeter wave radar detects the location of objects (other vehicles) in the scenery and the distance to the obstacle and the velocity in real-time.

This technology provides the capability to control the distance between the vehicle and an obstacle (or another vehicle) by integrating the sensor with the cruise control and ABS systems. The driver is able to set the speed and the desired distance between the cars ahead of him. The ABS system and the cruise control system are coupled together to safely achieve this remarkable capability.

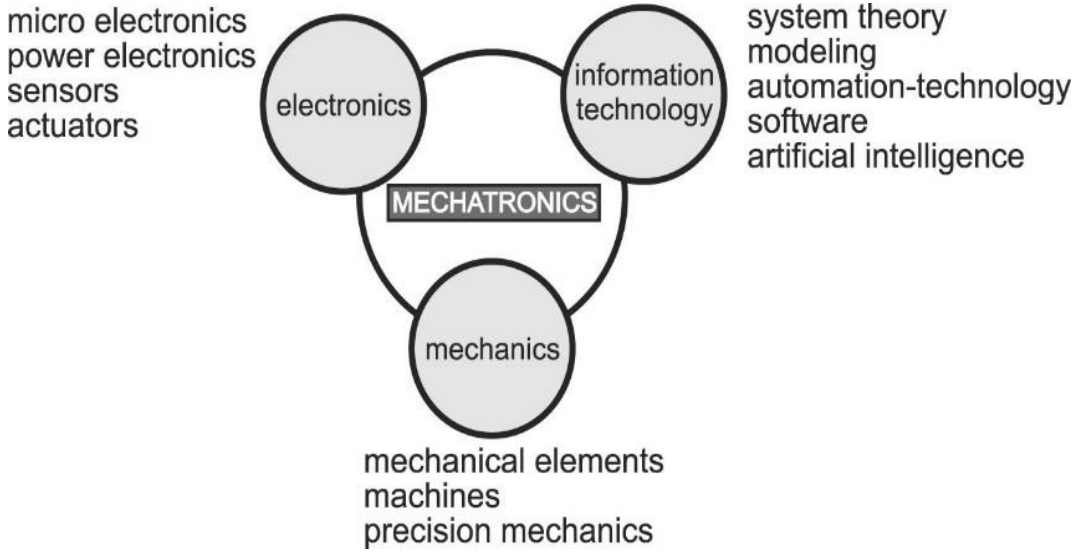
In automobiles today, typically, 8, 16, or 32-bit CPUs are used for implementation of the various control systems.

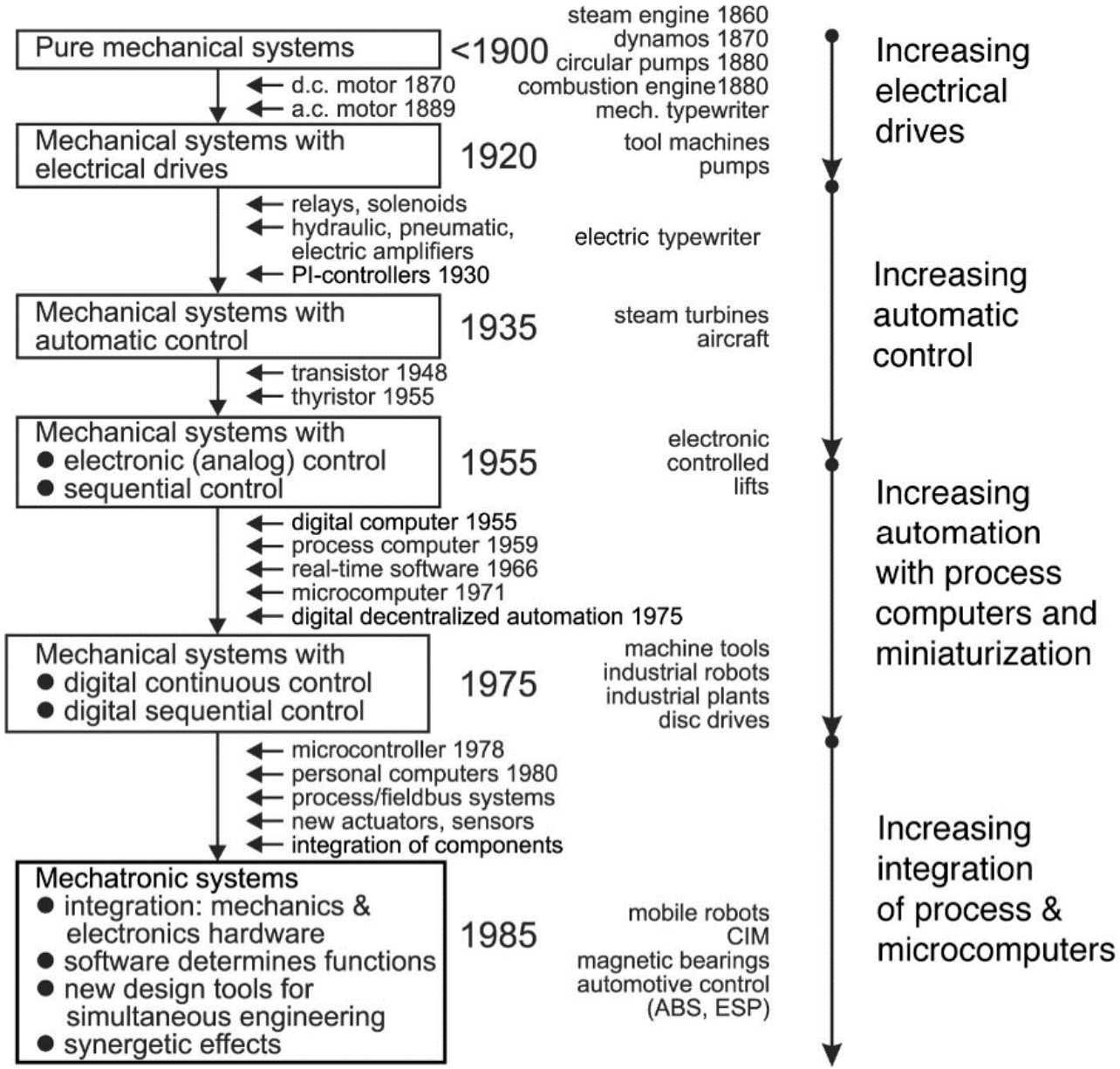
The 32-bit processor is used for engine management, transmission control, and airbags; the 16-bit processor is used for the ABS, TCS, instrument cluster, and air conditioning systems; the 8-bit processor is used for seat, mirror control, and window lift systems. Today, there are about 30–60 microcontrollers in a car.



Using a radar to measure distance and velocity to autonomously maintain desired distance between vehicles.

So, the definition of Mechatronics can be as : "**Mechatronics is the synergetic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes**".





Design Steps

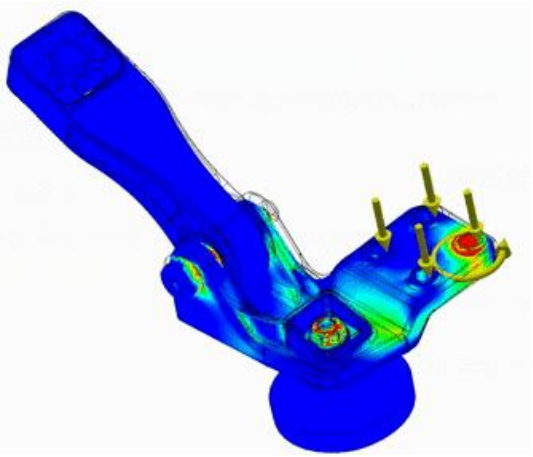
The computer aided development of mechatronic systems comprises:

1. constructive specification in the engineering development stage using CAD and CAE tools,

2. model building for obtaining static and dynamic process models,

3. transformation into computer codes for system simulation, and

4. programming and implementation of the final mechatronic software.



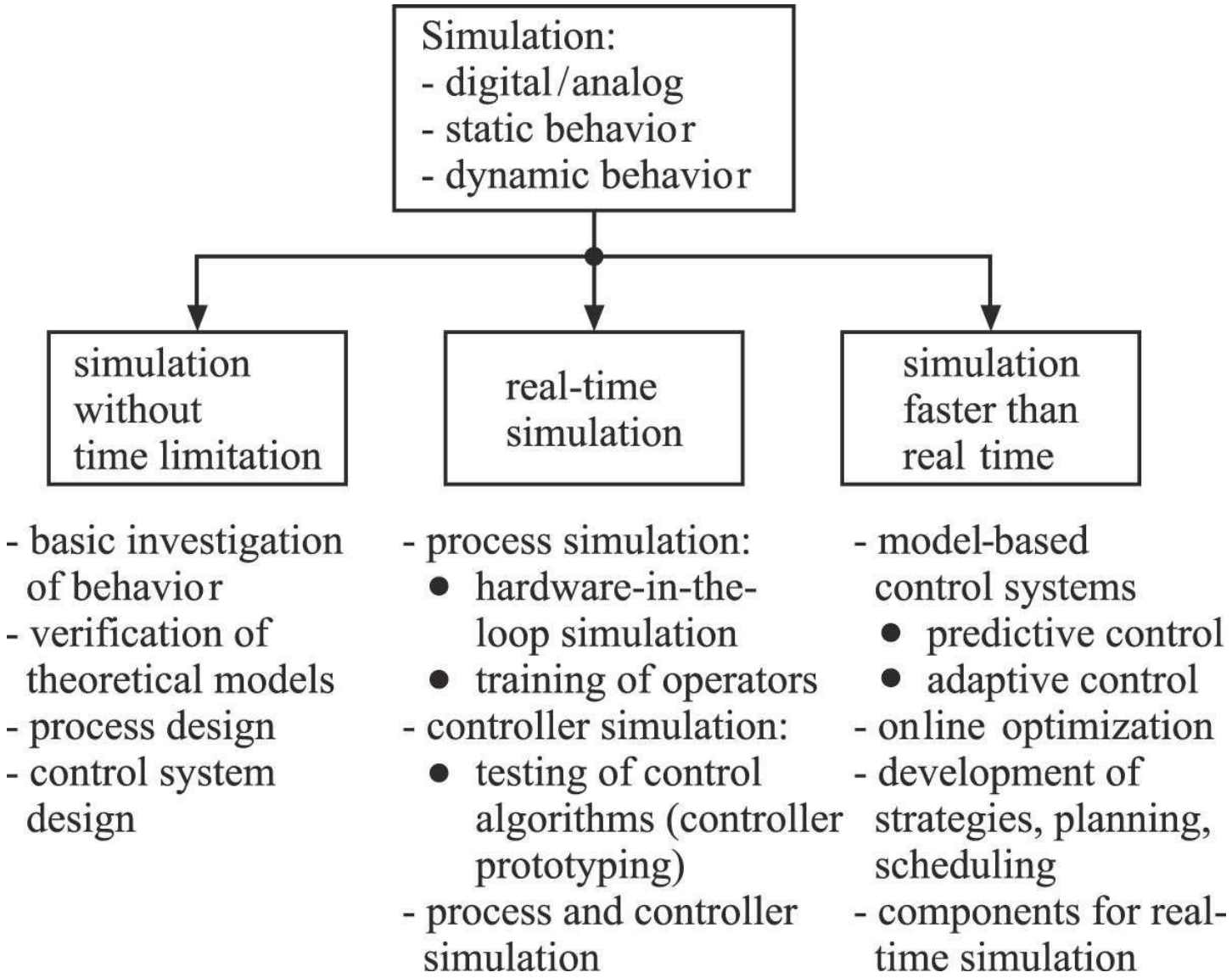
A broad range of CAD/CAE tools is available for 2D- and 3D-mechanical design, such as Catia, Solidworks, fusion 360, NX, Solidedge, Inventor and autocad. Simulation Tools such as MSC ADAMS. Programming tools such as Labview, MATLAB, Maple and Mathcad.

Softwares used in design and simulation of control circuits such as Firtzing, Tinycad, proteus and Eagle.

Simulation of Mechatronic system

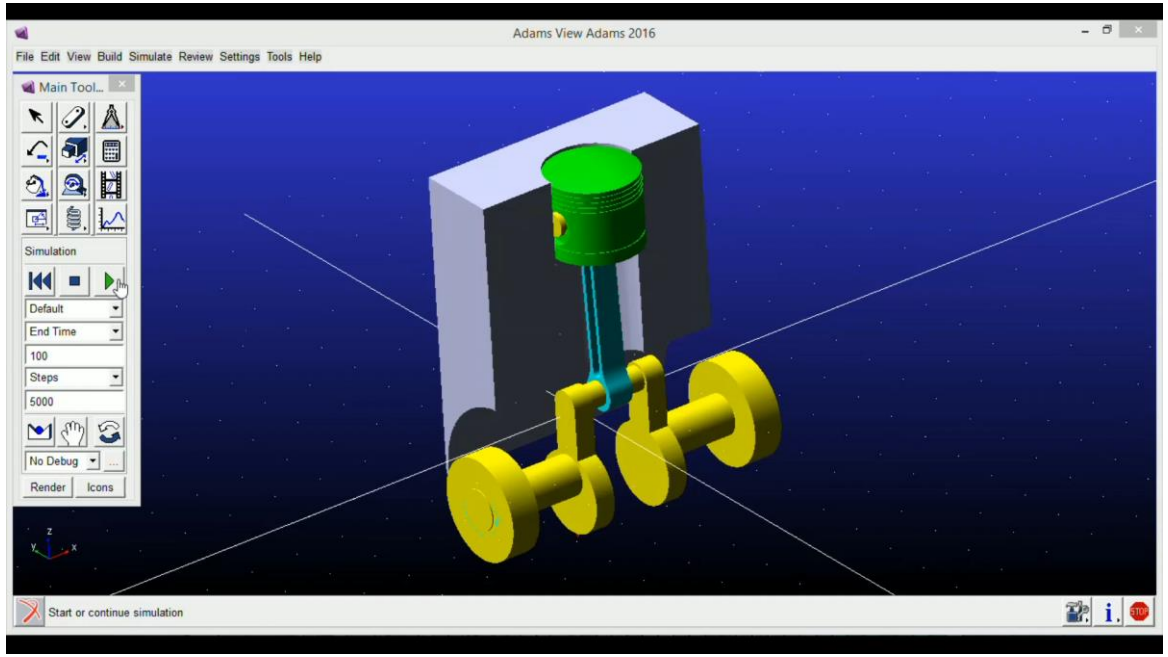
Increasingly, real-time simulation is applied to the design of mechatronic systems. This is especially true if the process, the hardware, and the software are developed simultaneously in order to minimize iterative development cycles and to meet short time-to-market schedules. With regard to the required speed of computation simulation methods, it can be subdivided into:

1. simulation without (hard) time limitation,
2. real-time simulation, and
3. simulation faster than real-time.

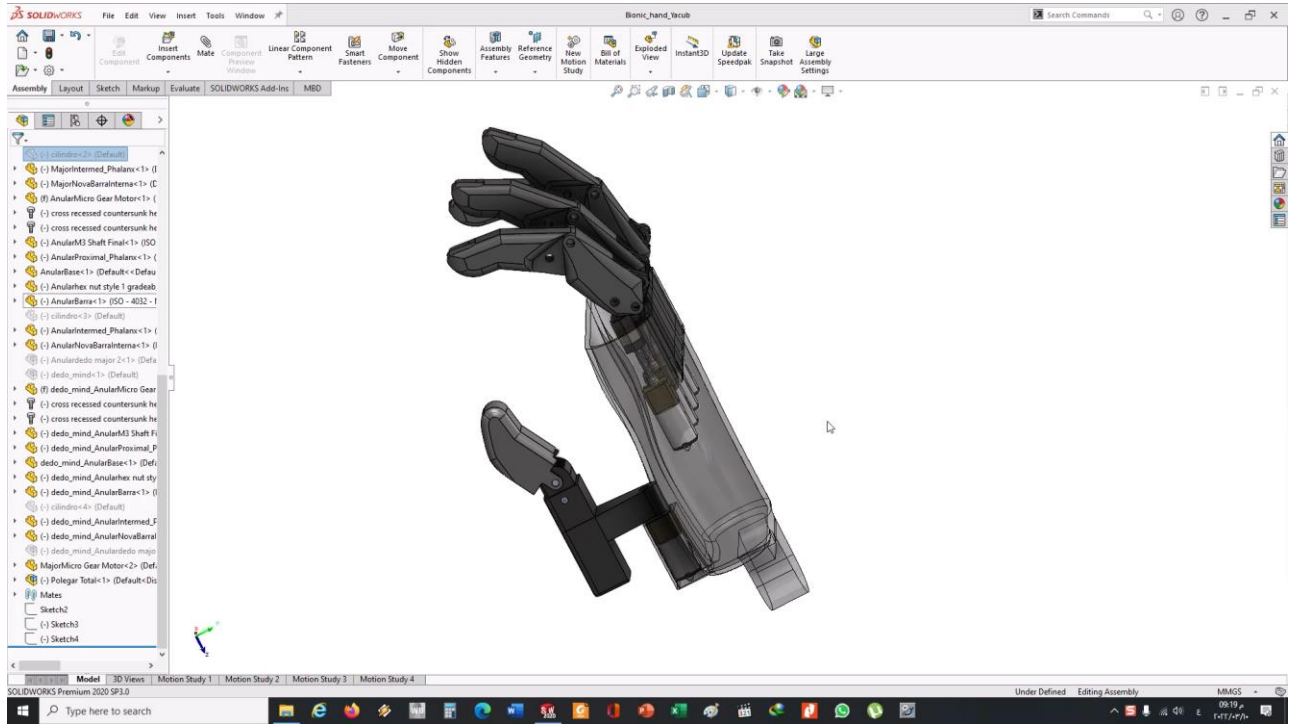


Simulation of Mechatronic system

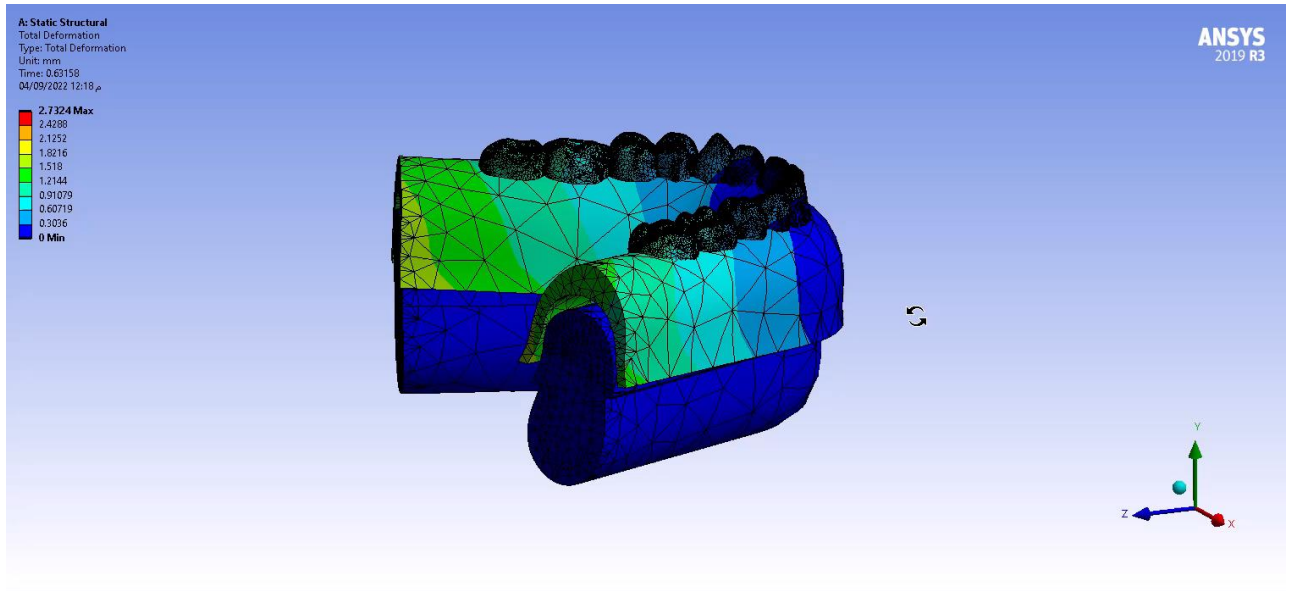
Herewith, real-time simulation means that the simulation of a component is performed such that the input and output signals show the same time-dependent values as the real, dynamically operating component. This becomes a computational problem for processes which have fast dynamics compared to the required algorithms and calculation speed.

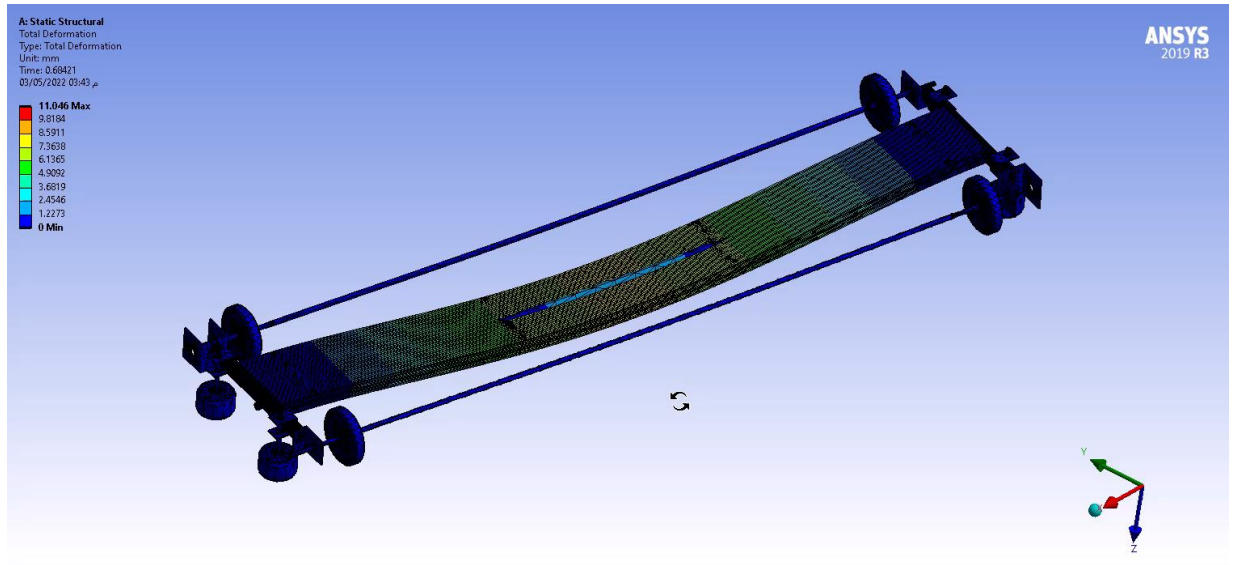


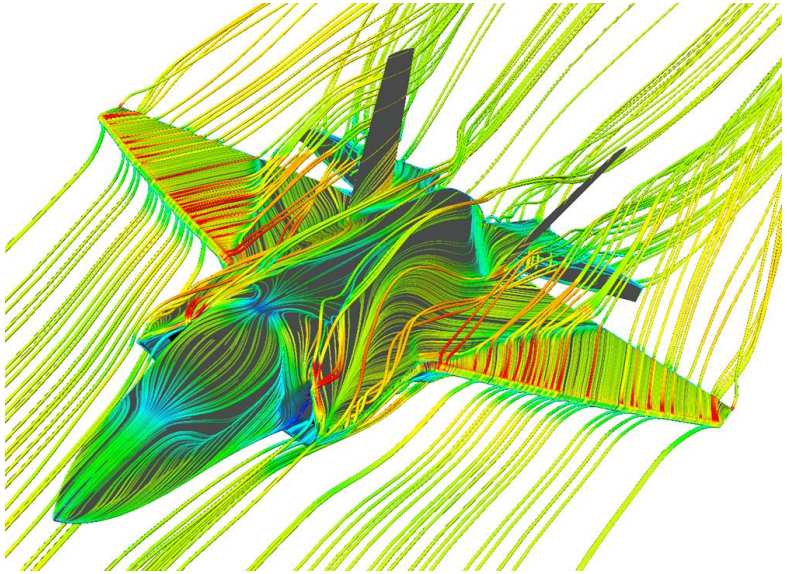
Multi-body dynamic simulation

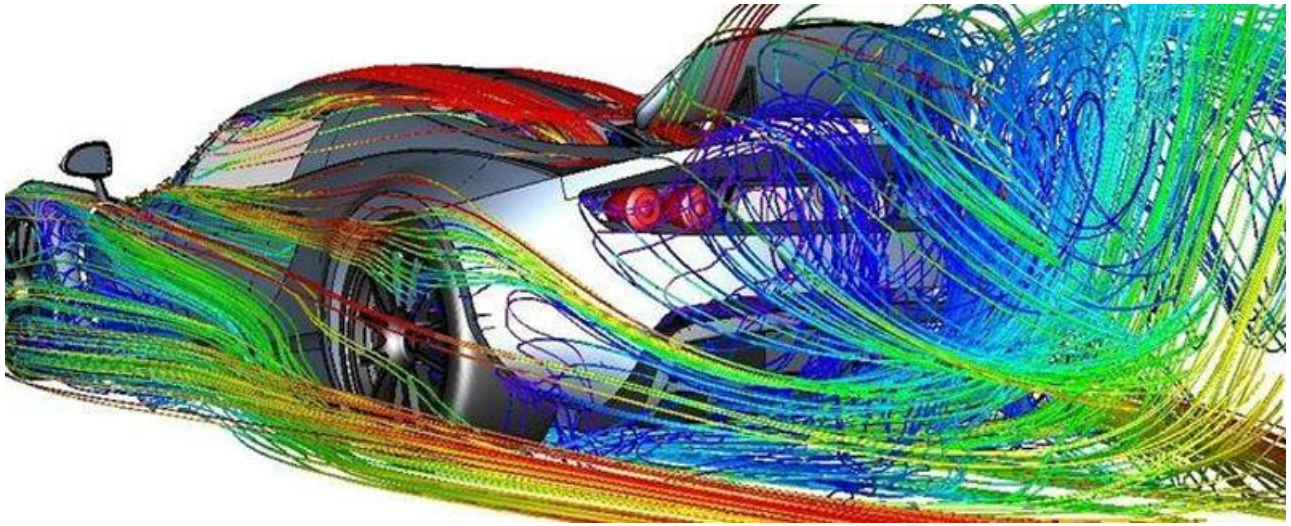


Solidworks Animation









Finite element analysis simulation

Control Prototyping

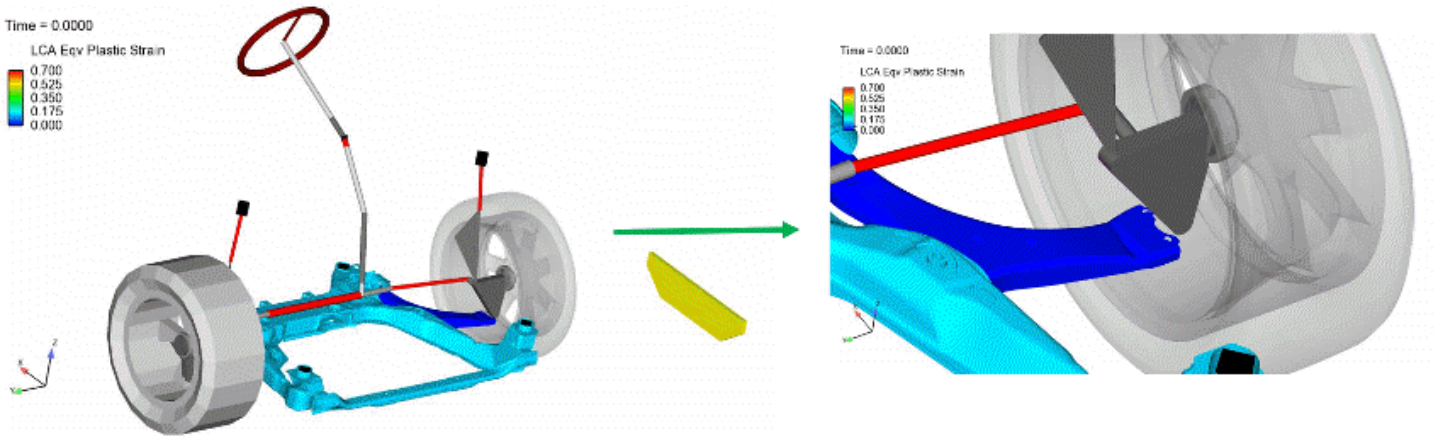
For the design and testing of complex control systems and their algorithms under real-time constraints, a real-time controller simulation with hardware, other than the final series production hardware may be performed. The process, the actuators, and sensors can then be real. This is called control prototyping.

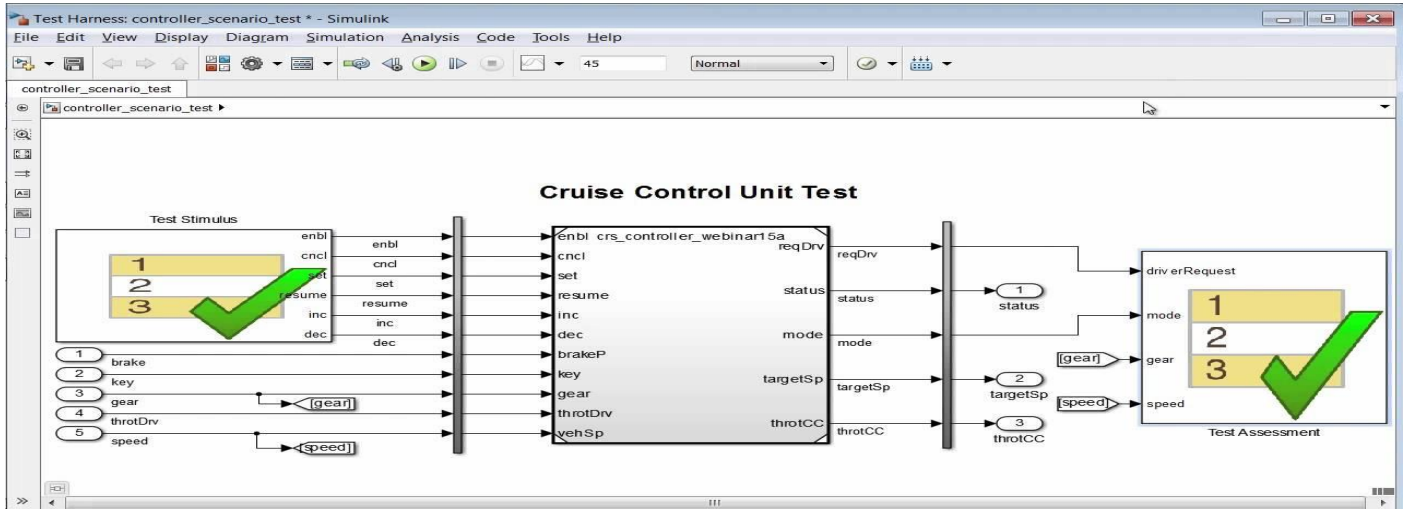
Advantages of using control simulation

- Testing of signal processing and control systems, together with other design of actuators, process parts, and sensor technology, in order to create synergetic effects.

- Reduction of models and algorithms to meet the requirements of cheaper mass production hardware; and

- Defining the specifications for final hardware and software.

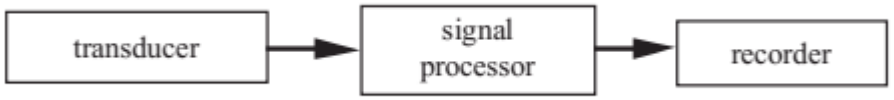


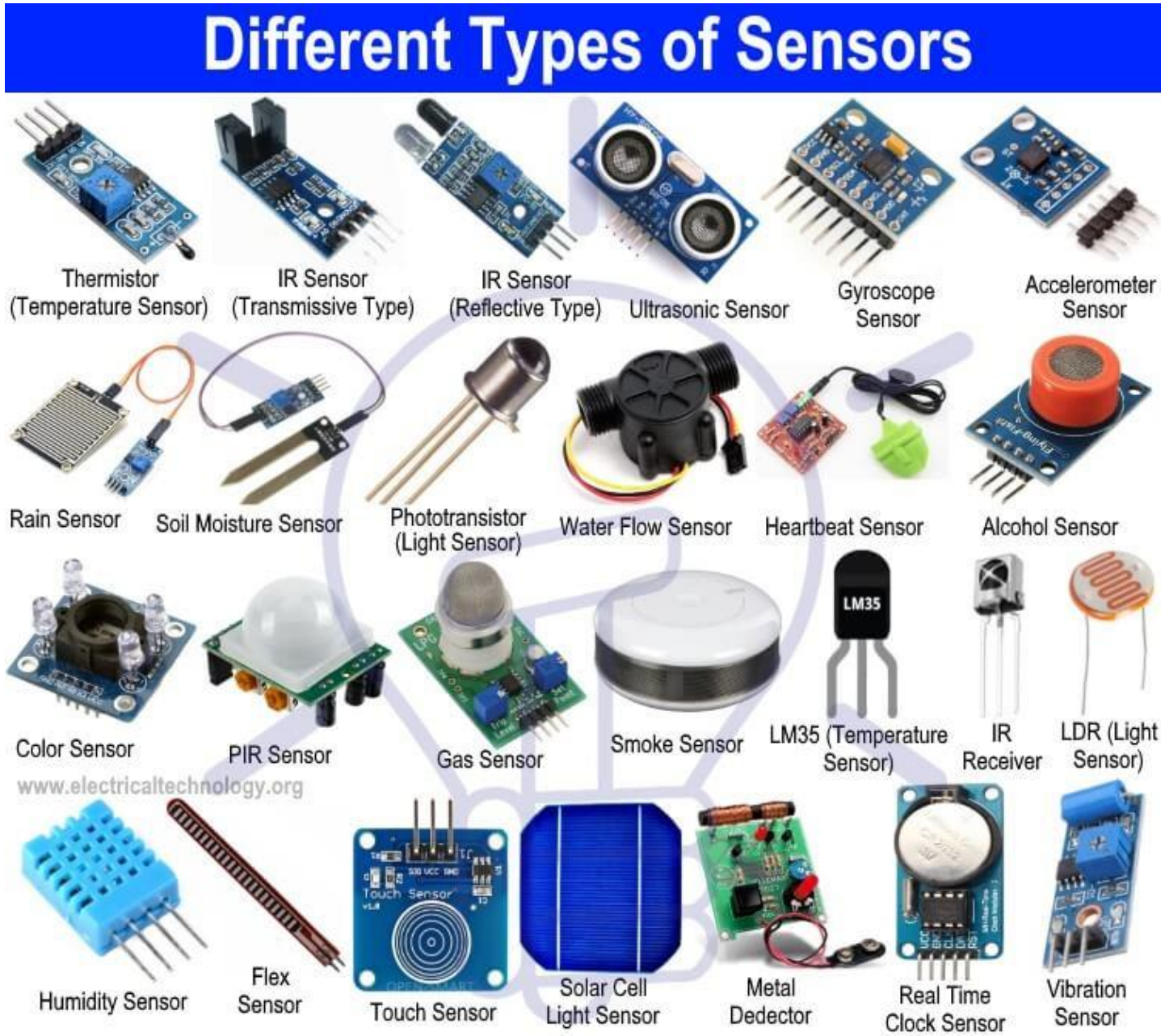


Measurement Systems

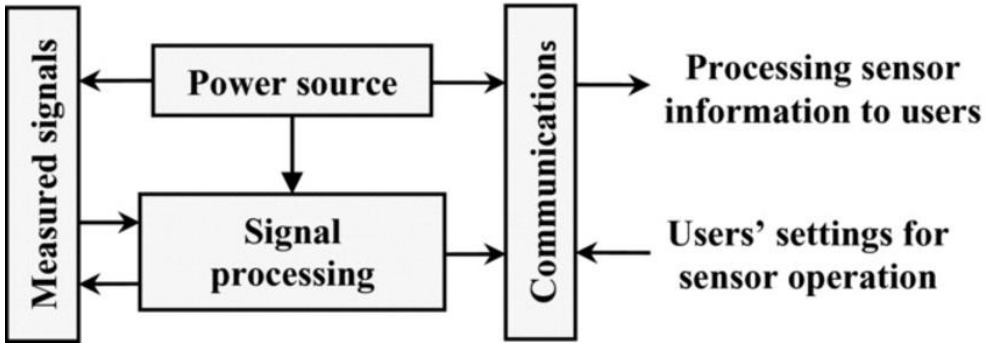
A fundamental part of many mechatronic systems is a measurement system composed of the three basic. The transducer is a sensing device that converts a physical input into an output, usually a voltage. The signal processor performs filtering, amplification, or other signal conditioning on the transducer output.

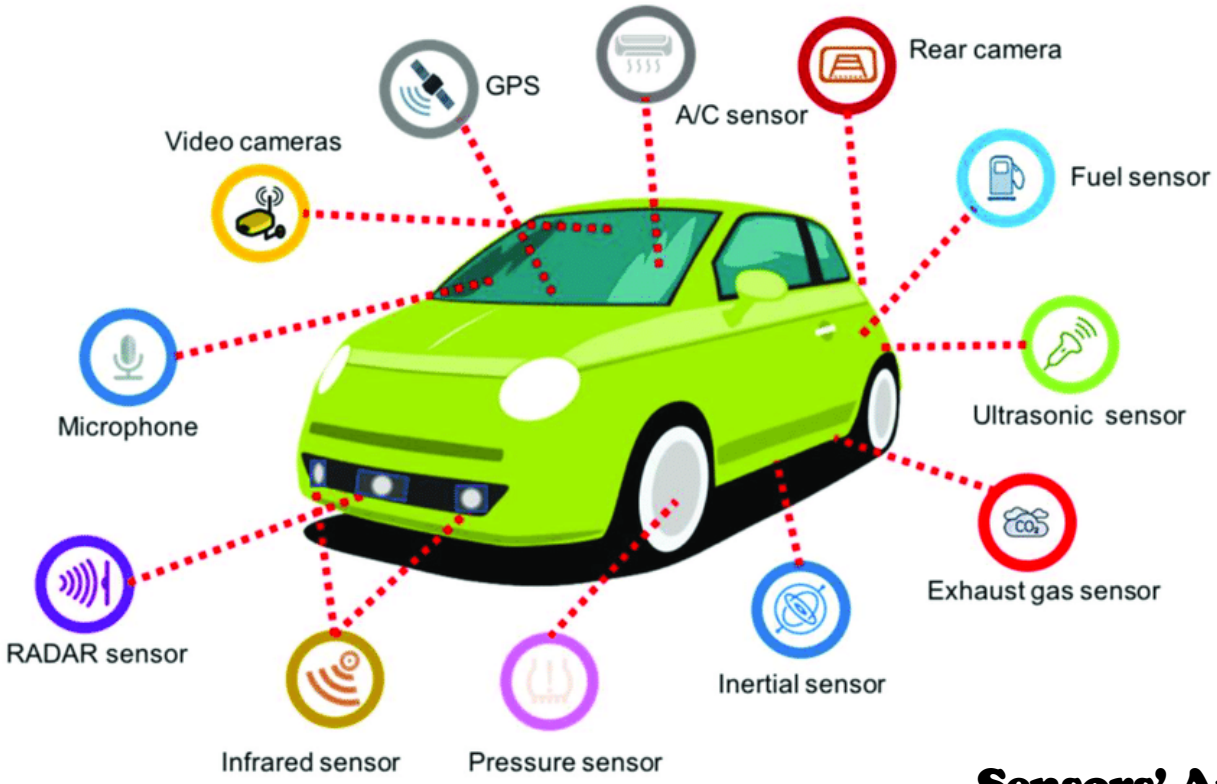
The term sensor is often used to refer to the transducer or to the combination of transducer and signal processor. Finally, the recorder is an instrument, a computer, a hard-copy device, or simply a display that maintains the sensor data for online monitoring or subsequent processing

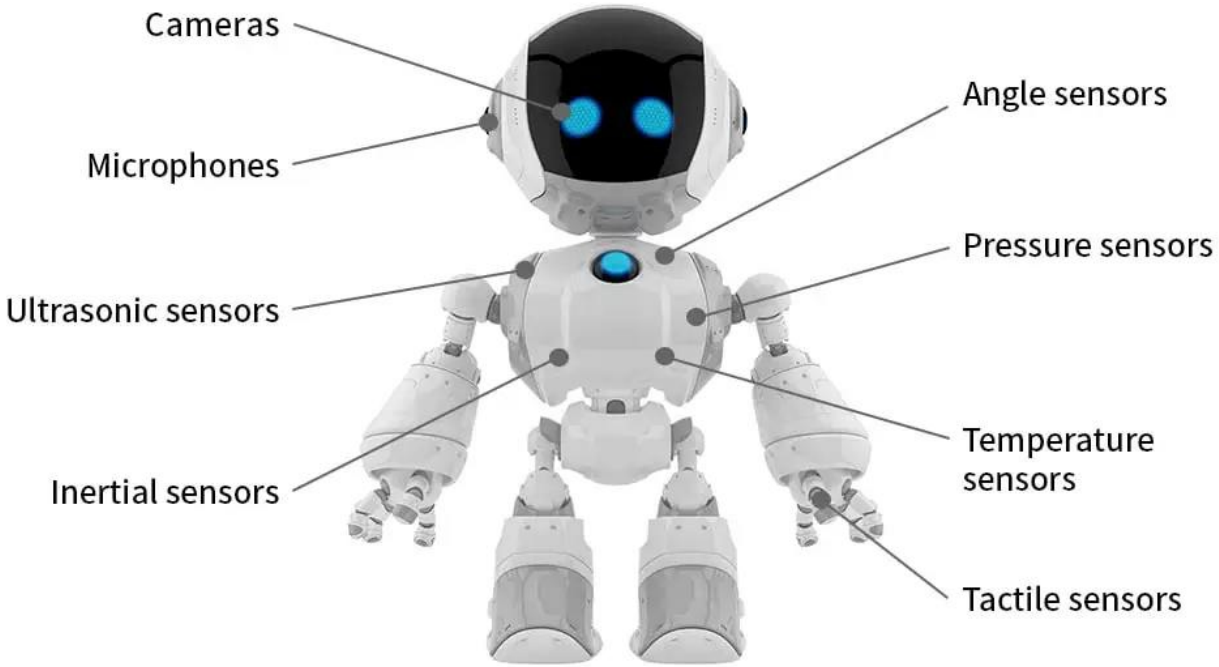




Sensor parts



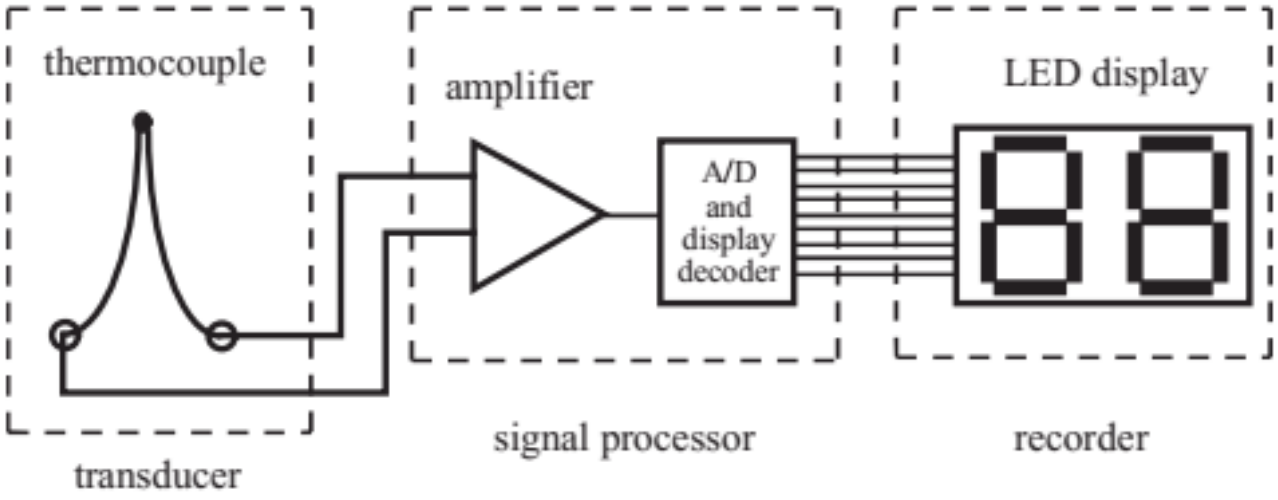




Sensors' Applications

Measurement System—Digital Thermometer

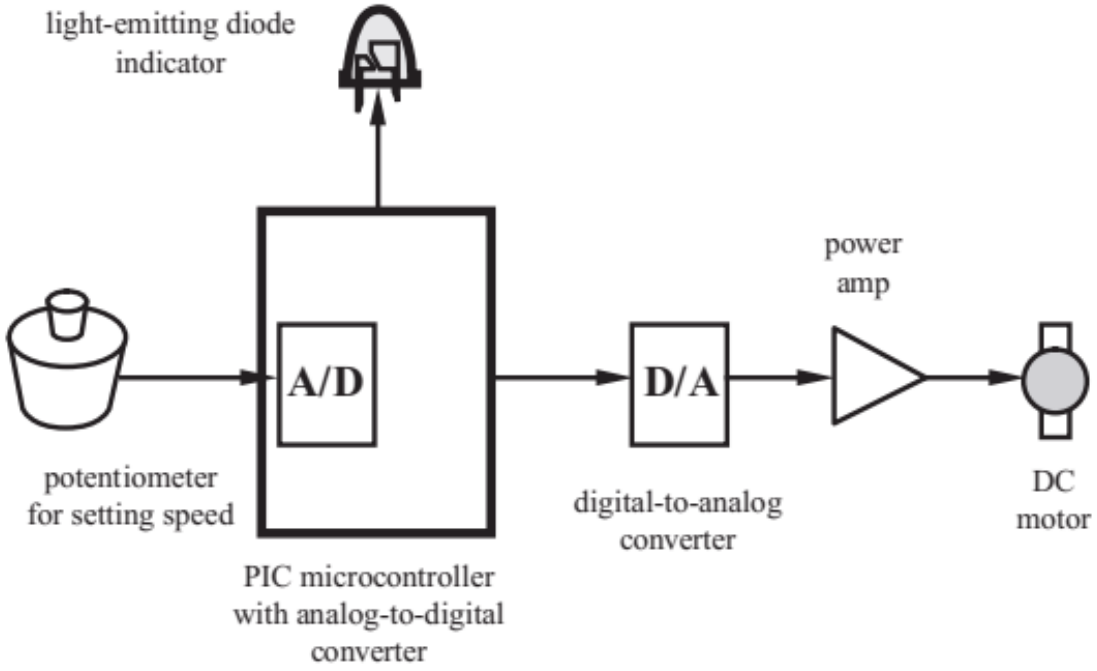
The following figure shows an example of a measurement system. The thermocouple is a transducer that converts temperature to a small voltage; the amplifier increases the magnitude of the voltage; the A/D (analog-to-digital) converter is a device that changes the analog signal to a coded digital signal; and the LEDs (light emitting diodes) display the value of the temperature.



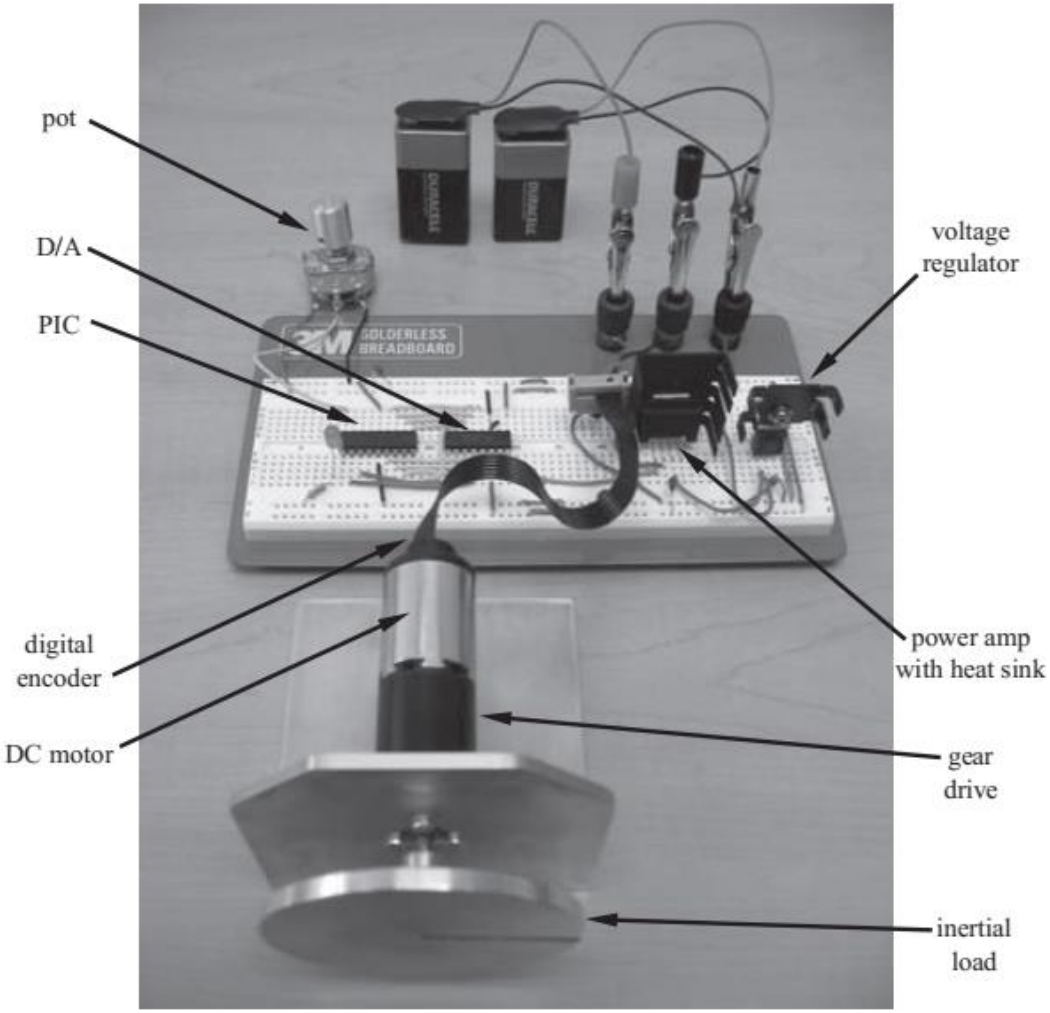
Mechatronics Examples

Example 1: DC motor power-op-amp speed controller

This design example deals with controlling the rotational speed of a direct current (DC) permanent magnet motor. Figure below illustrates the major components and interconnections in the system. The light-emitting diode (LED) provides a visual cue to the user that the microcontroller is running properly. The speed input device is a potentiometer (or pot), which is a variable resistor. The resistance changes as the user turns the knob on top of the pot.

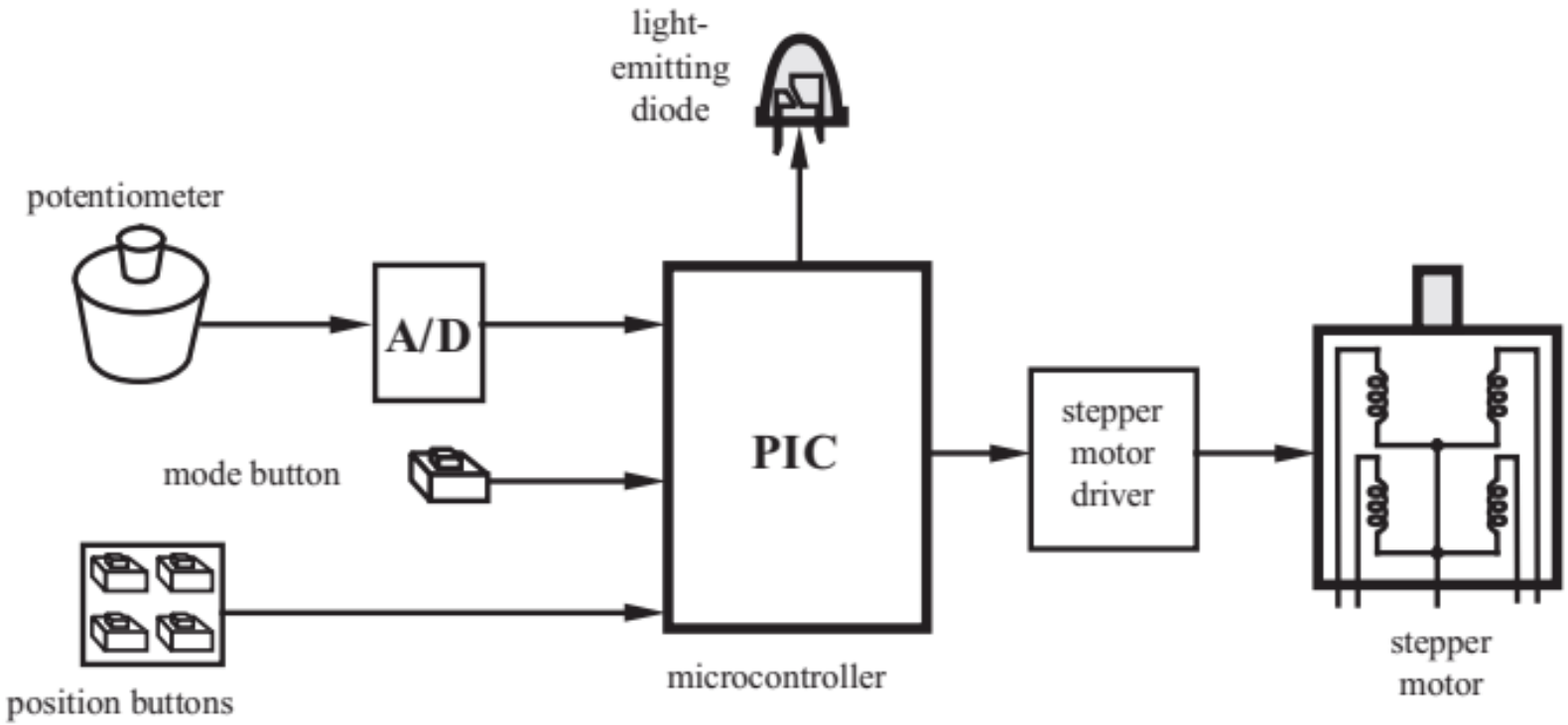


The voltage signal is applied to a microcontroller (basically a small computer on a single integrated circuit) to control a DC motor to rotate at a speed proportional to the voltage. Voltage signals are “analog”, but microcontrollers are “digital,” so we need analog-to-digital (A/D) and digital-to-analog (D/A) converters in the system to allow us to communicate between the analog and digital components. Finally, because a motor can require significant current, we need a power amplifier to boost the voltage and source the necessary current.



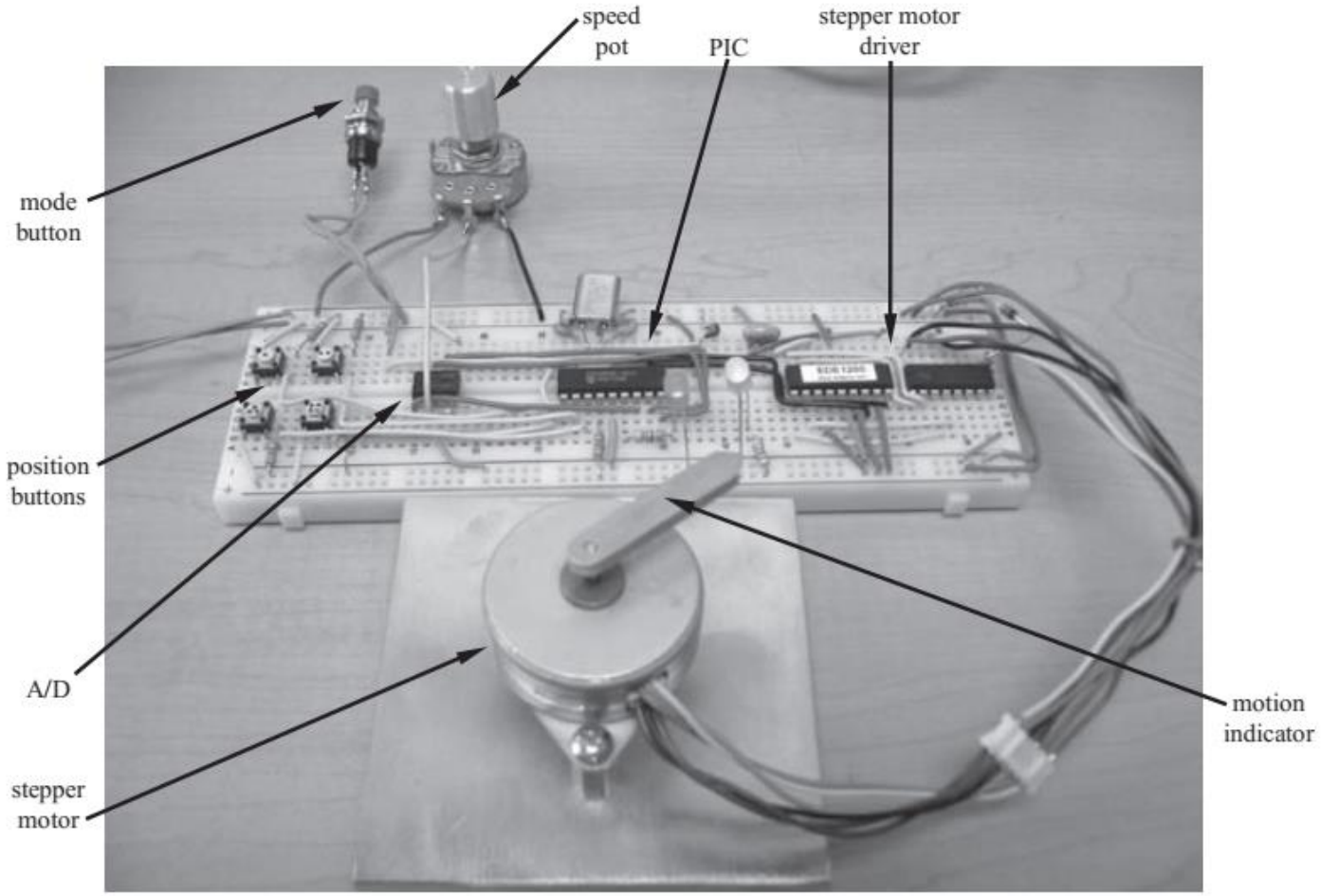
Example 2: Stepper motor position and speed controller

This design example deals with controlling the position and speed of a stepper motor, which can be commanded to move in discrete angular increments. Stepper motors are useful in position indexing applications, where you might need to move parts or tools to and from various fixed positions (e.g., in an automated assembly or manufacturing line). Stepper motors are also useful in accurate speed control applications (e.g., controlling the spindle speed of a computer hard-drive or DVD player), where the motor speed is directly proportional to the step rate

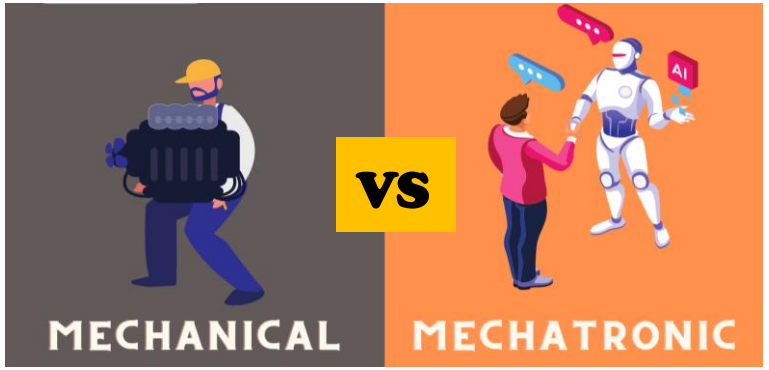


The input devices include a pot to control the speed manually, four buttons to select predefined positions, and a mode button to toggle between speed and position control. In position control mode, each of the four position buttons indexes the motor to specific angular positions relative to the starting point (0 , 45 , 90 , 180). In speed control mode, turning the pot clockwise (counterclockwise) increases (decreases) the speed.

The LED provides a visual cue to the user to indicate that the PIC is cycling properly. A microcontroller uses that value to generate signals for a stepper motor driver circuit to make the motor rotate.



Mechanical Engineering



Mechatronics Engineering

Mechanical engineering deals with the laws of motion, force, and energy, it basically works around mechanics, kinematics and dynamics & will give you a foundation of the things and nature around you and teach you how it works.
Mechanical engineering provides invention and technology that showcase alternatives for human beings to increase their productivity and work efficiently.

Mechanical engineering teaches you about materials, solid and fluid mechanics, thermodynamics, heat transfer, control, instrumentation, design, and manufacturing to understand mechanical systems.

Mechatronics engineering not only combines the technology of mechanical engineering & Electronics engineering but also Electrical and robotics etc.

every mechanical system or machine is converted into a more user-friendly system using different microcontroller, programming, sensor, feedback & control system.

These systems can be programmed to work manually through user commands or work 24/7 without any miscalculation and eliminates human error.

Mechatronics teaches you how to integrate & control mechanical components using electronic sensors, electrical actuators and programmable devices such as microcontrollers & microprocessors all into one single project.

MECHATRONICS TECHNOLOGY APPLICATIONS

Real Life Application

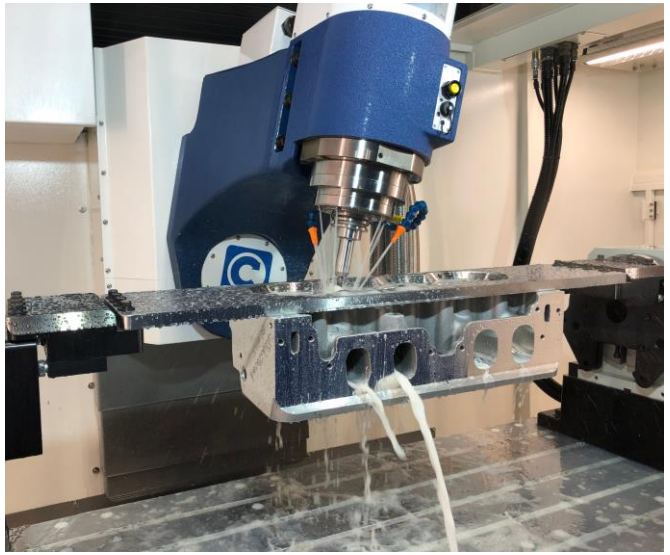
Mechatronics is widely used in your day-to-day life. It is used in appliances like washing machines and dishwashers. It's also used in measuring devices like testing of sensors, and calibration devices. Moreover, its uses in automatic air conditioning systems, automatic door systems, and security systems improve the quality of life as well as the security of secure facilities. Furthermore, it's used in unmanned aerial vehicles as well as automatic guided vehicles for mines detection.

Around the House

Refrigerators that can order milk when you are running low. Washers that text you when the load is ready for the dryer. Vacuums that carry cats around the house while they clean your hardwood floors. All of these devices are available due to mechatronics. And, of course, who is ever without their smart phone? A cell phone's camera, for example, uses mechatronics to take cute pictures and videos of your cat riding that robotic vacuum.

CNC Machines

CNC stands for **computer numerical control** and these machines play an important role in the manufacturing industry. These complex machines are controlled by a computer and provide a level of efficiency, accuracy and consistency that would be impossible to achieve through a manual process



Grinding CNC Machine

Lathe CNC Machine

Plasma Cutting CNC Machine

engineeringlearn.com

CNC Electric Discharge

5 Axis CNC Machine

Laser Cutting CNC Machine

Manufacturing Applications

The micro-factory concept turns the manufacturing philosophy upside down. Multiple small yet highly efficient manufacturing units are strategically placed close to the markets. These distributed manufacturing units can produce small batches and a high product mix. The manufacturer can change product design quickly, at minimum cost, allowing production in small batches with different specifications – as opposed to large batches and long runs of highly standardized products in the traditional approach. In the micro-factory concept, products are manufactured on customer order – i.e., upon receiving confirmed orders from the customer, without carrying an inventory of finished products.

Micro-Factory for watch making industry

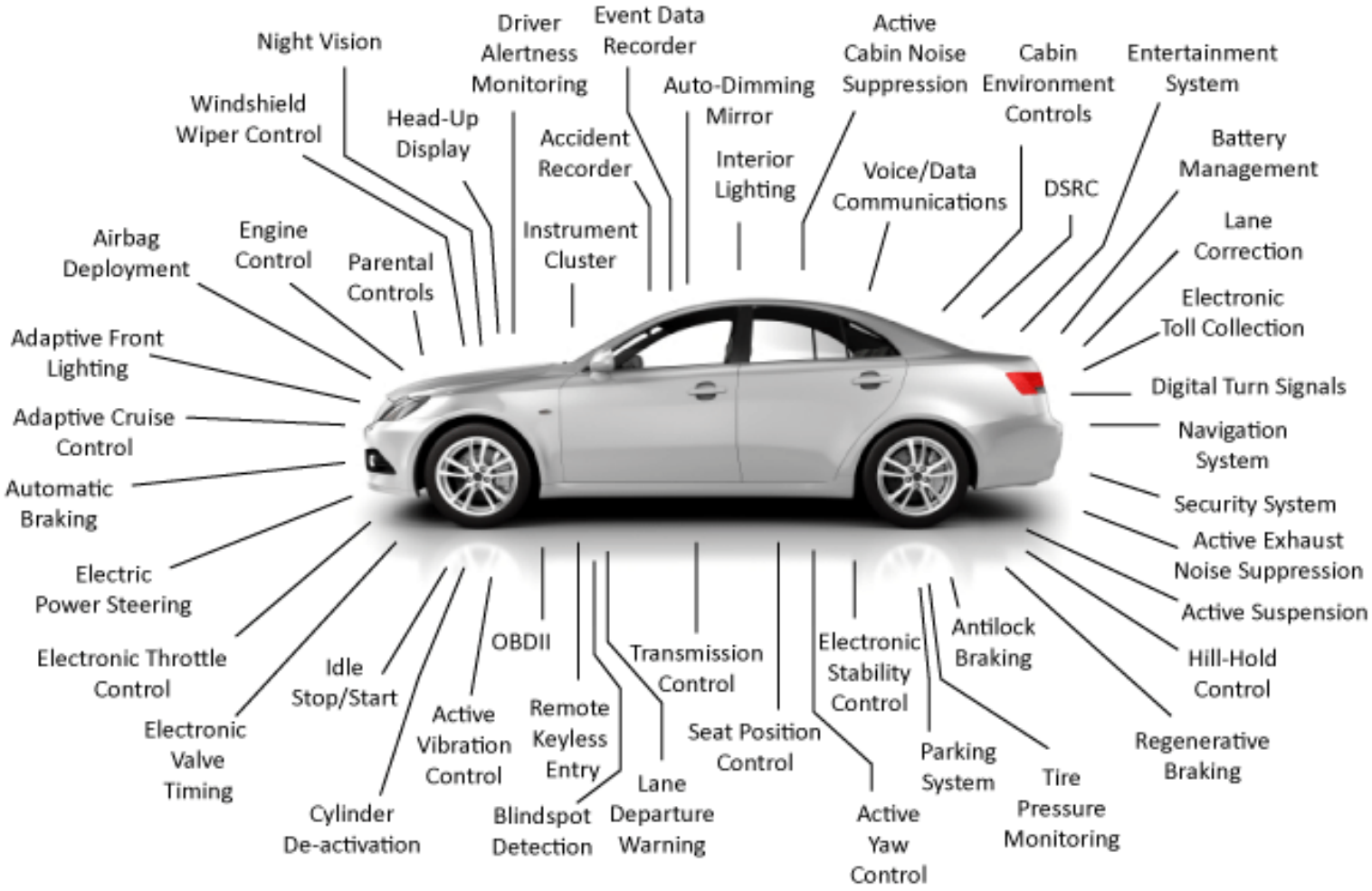
Micro-Factory device used for small boards

Car systems

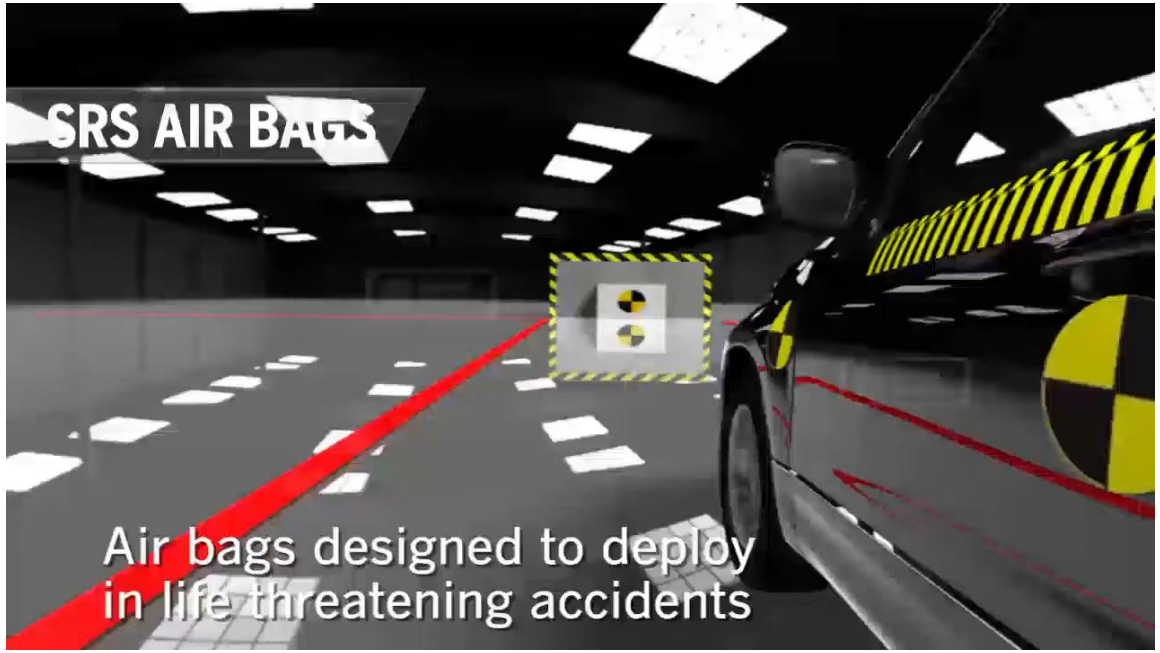
Mechatronics engineering has saved thousands of lives through the advent of anti-lock brakes and stabilization, air bag inflation, and fully autonomous vehicles.

Examples of common sensors used in cars:

- **Car engine management**
- **Electronic stability control**
- **Yaw control sensor**
- **Wheel speed sensors**
- **Steering angle sensors**
- **Rotational speed sensors**
- **Airbag Inflation**
- **Cruise control acceleration and deceleration**
- **Power door locks**
- **Anti-Lock braking system**
- **Traction control system**



ABS system

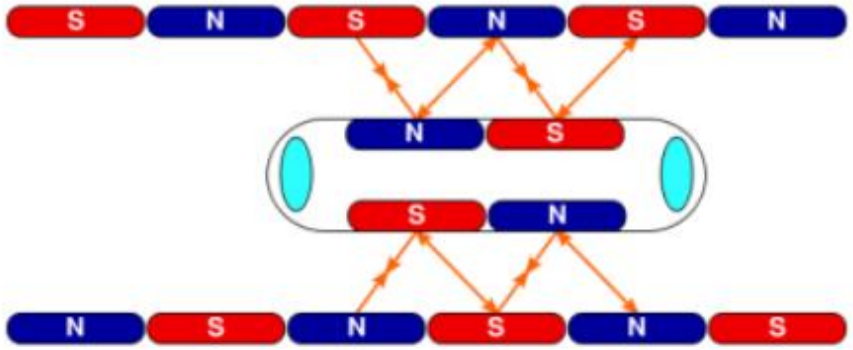


Airbag system

High Speed Trains

- Train Position and Velocity constantly monitored from main command center.
- Error margin in scheduling no more than 30 seconds
- Fastest trains use magnetic levitation

Magnetic Levitation



Robotics Systems

Robotics is the engineering science and technology of robots, and their design, manufacture, and application. Robotics is related to electronics, mechanics, and software other words, mechatronics.

The first digitally operated and programmable robot, the “Unimate”, was installed in 1961 to lift hot pieces of metal from a die-casting machine and stack them. Today, the commercial and industrial sectors are in widespread use of robots, performing jobs cheaper or more accurately and reliably than humans do. They are also employed for jobs, which are too dirty, dangerous, or dull to be suitable for humans. Robots are widely used in manufacturing assembly, and packing; transport; earth and space exploration; surgery; weaponry; laboratory research; safety; and mass production of consumer and industrial goods.

Serial Manipulators

- ✓ links connecting in a serial fashion using Active joints .
- ✓ Limited speed
- ✓ Less rigidity
- ✓ Large workspace
- ✓ High power consumption
- ✓ Less accuracy
- ✓ Large inertia

Parallel Manipulators

- ✓ Multiple kinematic chains connecting a fixed base to a movable platform.
- ✓ Actuators are fixed at/near the base.
- ✓ Light weight links
- ✓ Small inertia
- ✓ High rigidity
- ✓ High accuracy
- ✓ High velocity
- ✓ Limited workspace

Handling for metal casting

Palletizing

Handling for plastic moulding

Sealing

Welding

Painting

Laser welding

Pressing

Packaging

Handling for forging

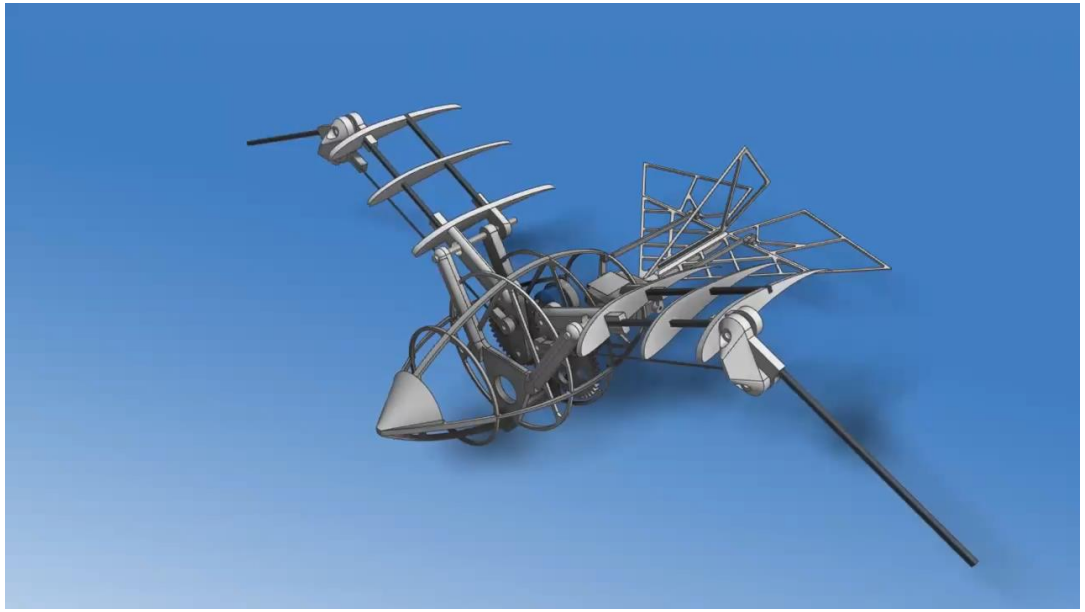
Picking and placing

Assembly

Flying robots

Essentially, a drone is a flying robot that can be remotely controlled or fly autonomously using software-controlled flight plans in its embedded systems, that work in conjunction with onboard sensors and a global positioning system (GPS). UAVs were most often associated with the military and in surveillance applications.

Drone/Quad-copter



Ornithopter/Flapping wing vehicle

Legged /Quadruped Robots

BigDog is a dynamically stable quadruped military robot that was created in 2005 by Boston Dynamics.

BigDog's walking pattern is controlled through four legs, each equipped with four low-friction hydraulic cylinder actuators that power the joints.
It can stand up, sit down, walk with a crawling gait that lifts one leg at a time, walk with a trotting gait lifting diagonal legs, or trot with a running gait. The travel speed of BigDog varies from a 0.45 mph (0.2 m/s) crawl to a 3.6 mph (1.6 m/s) trot

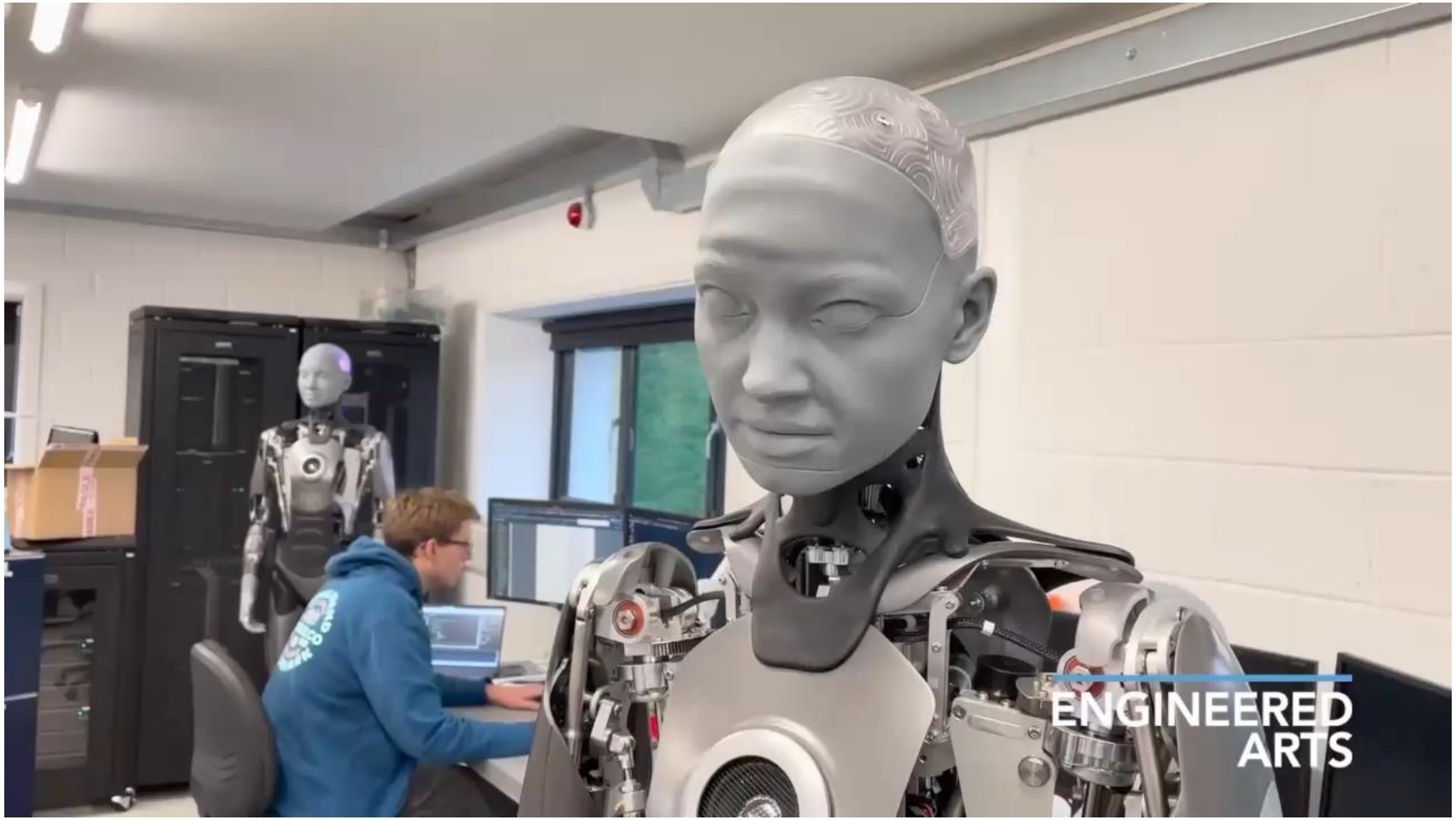
Approximately 50 sensors are located on BigDog. These measure the attitude and acceleration of the body, motion, and force of joint actuators as well as engine speed, temperature and hydraulic pressure inside the robot's internal engine. Low-level control, such as position and force of the joints, and high-level control such as velocity and altitude during locomotion, are both controlled through the onboard computer.

Legged /Quadruped Robots

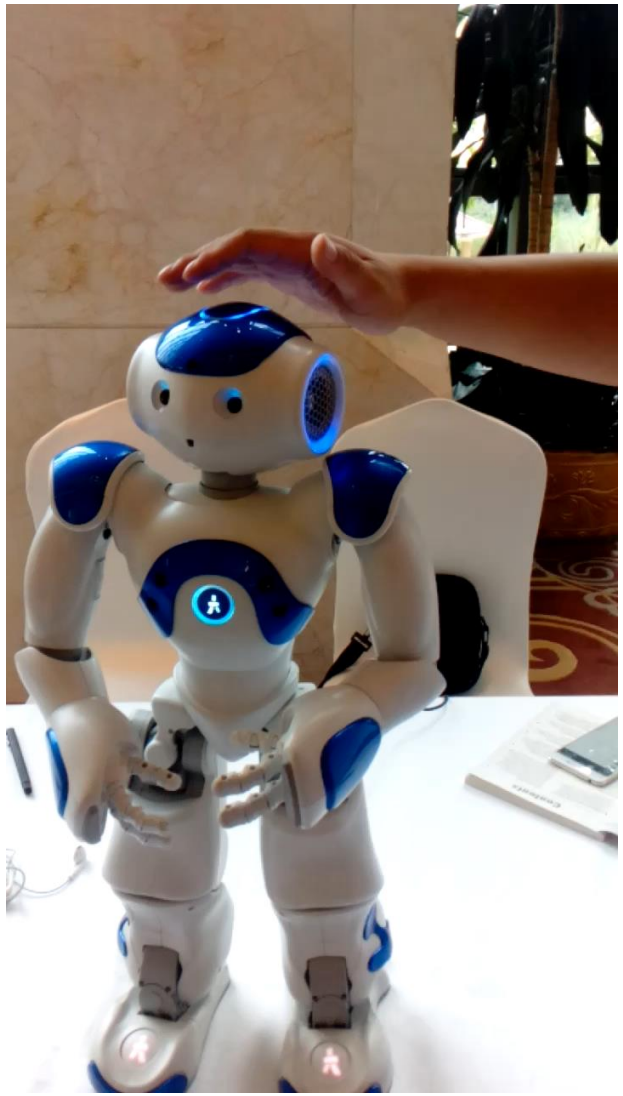
Smart Robotic legged Toys

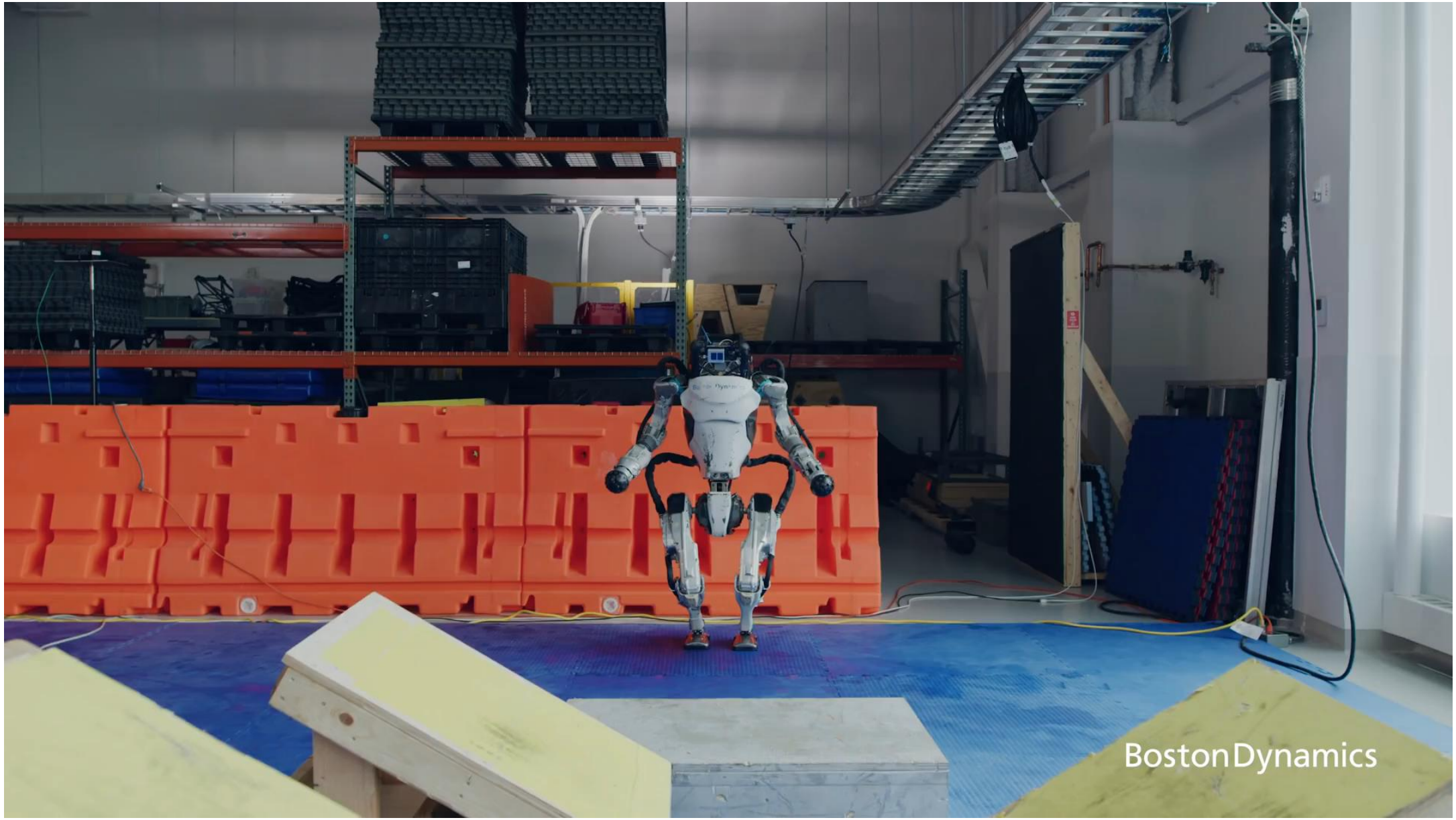
Humanoid robots

A humanoid robot is a robot resembling the human body in shape. The design may be for functional purposes, such as interacting with human tools and environments, for experimental purposes, such as the study of bipedal locomotion, or for other purposes. In general, humanoid robots have a torso, a head, two arms, and two legs, though some humanoid robots may replicate only part of the body, for example, from the waist up. Some humanoid robots also have heads designed to replicate human facial features such as eyes and mouths. Androids are humanoid robots built to aesthetically resemble humans.



Humanoid robots




BostonDynamics

Mobile robots

Mobile robots have the capability to move around in their environment and are not fixed to one physical location. Mobile robots can be "autonomous" (AMR - autonomous mobile robot) which means they can navigate an uncontrolled environment without the need for physical or electro-mechanical guidance devices.

The components of a mobile robot are a controller, sensors, actuators and power system.

The controller is generally a microprocessor, embedded microcontroller or a personal computer (PC). The sensors used are dependent upon the requirements of the robot. The requirements could be dead reckoning, tactile and proximity sensing, triangulation ranging, collision avoidance, position location and other specific applications. Actuators usually refer to the motors that move the robot can be wheeled or legged. To power a mobile robot usually we use DC power supply (which is battery) instead of AC.

A robotic vacuum cleaner

Delivery mobile robot

Mobile robots' examples

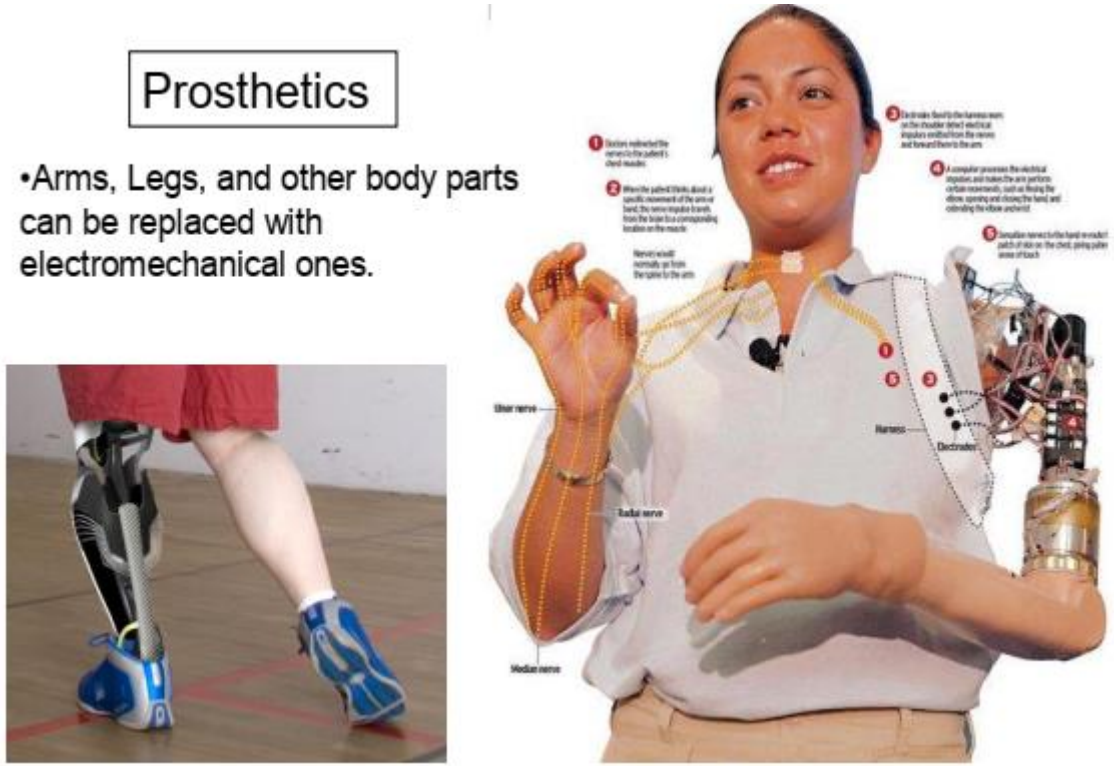
KUKA
KUKA
KUKA

Boston Dynamics

FESTO

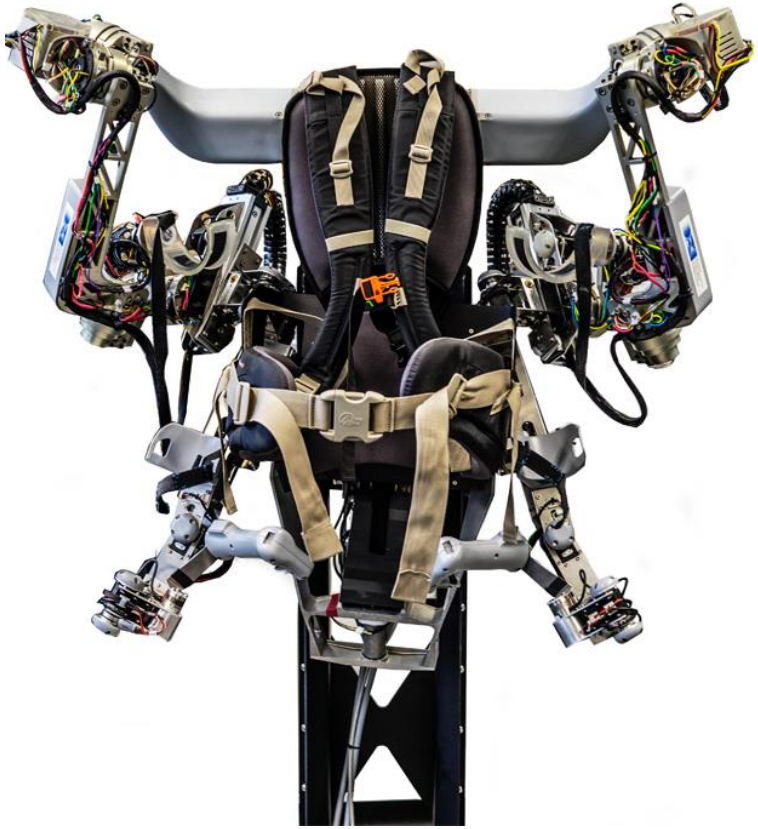
Medical applications

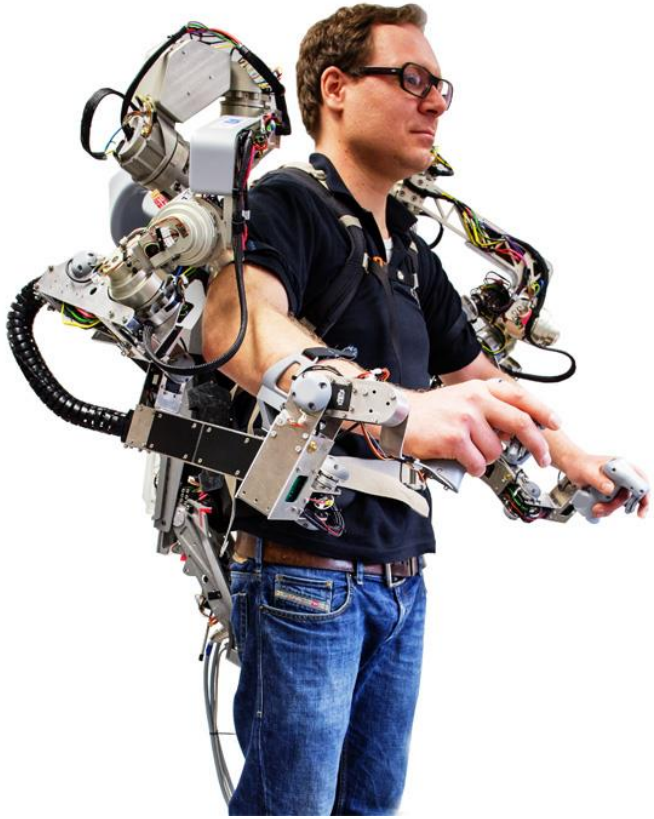
application of mechatronics have become primary to ensure that more lives are sustained and saved through state-of-the-art medical innovation and invention. These improvements come in the form of measures to facilitate prosthetics in the form of replacements of damaged body parts by electrochemical ones or in other cases, systems that improve health responses are implanted into the body. Cases also abound where preventive medicine has equally been enhanced by the modern sanitation systems. The ease of carrying out surgical operations in medicine has greatly improved overtime as well because of fine-tuning effects of medical mechatronics applications.



Medical applications

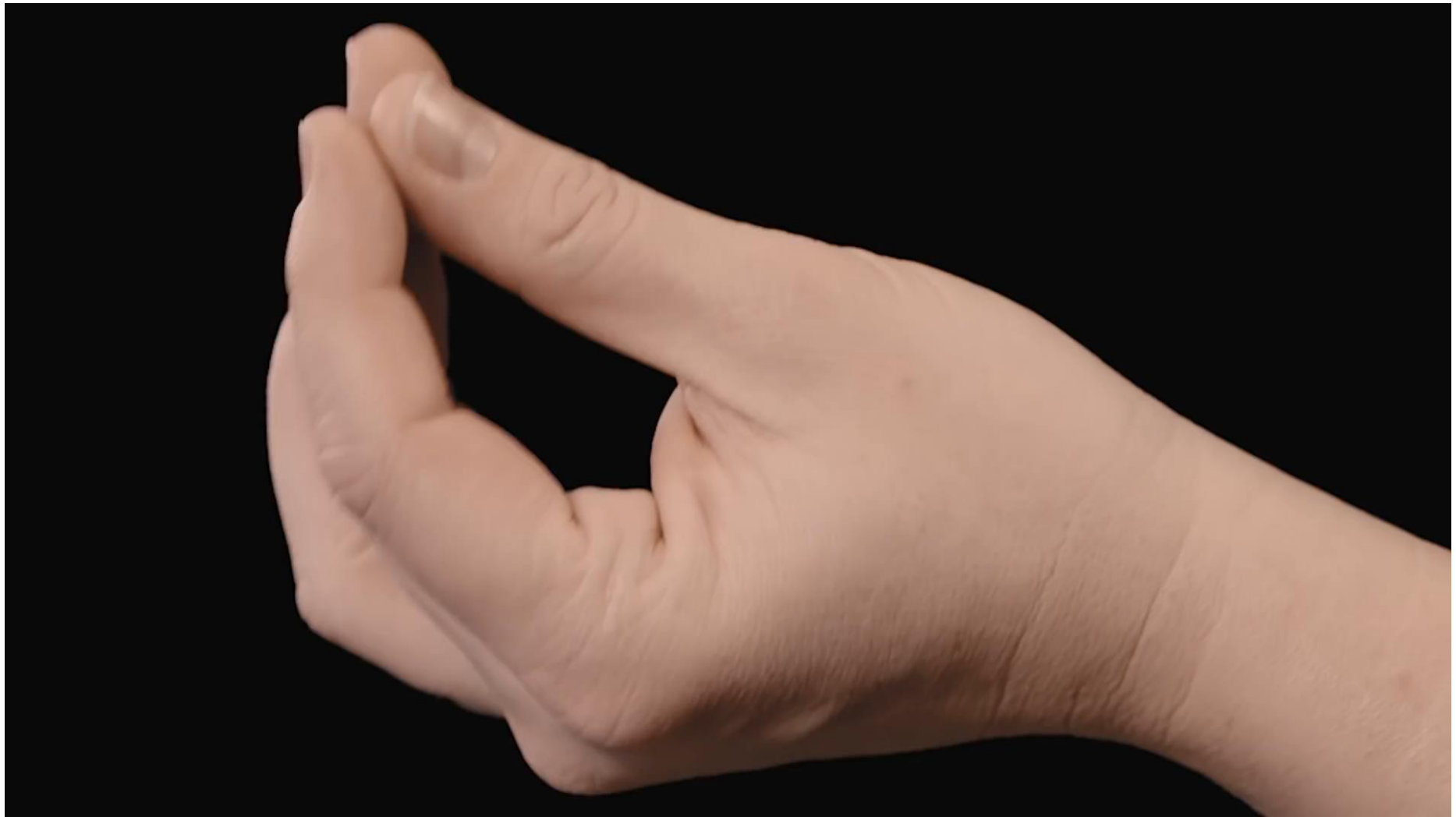
An exoskeleton, as the name suggests, is an external frame that can be worn to support the body, either to help a person overcome an injury or to enhance their biological capacities. Powered by a system of electric motors, the frame gives limbs extra movement, strength and endurance.





Surgical robotic applications

Bionic hand robotic applications



Sanitation applications

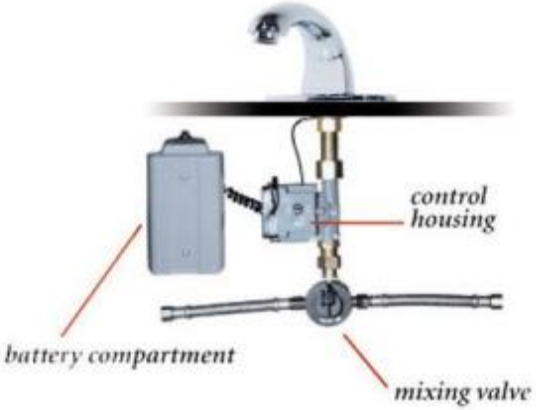
Systems Uses
- Motion sensors
- Control circuitry
- Electromechanical actuators
- Independent power source

Soap Dispenser

Paper Towel Dispenser

Advantages
- **Reduces spread of germs** by making device hands free
- **Reduces wasted materials** by controlling how much is dispensed

System Uses
- Proximity sensors
- Control circuitry
- Electromechanical valves
- Independent power source



Advantages
- **Reduces spread of germs** by making device hands free
- **Reduces wasted water** by automatically turning off when not in use

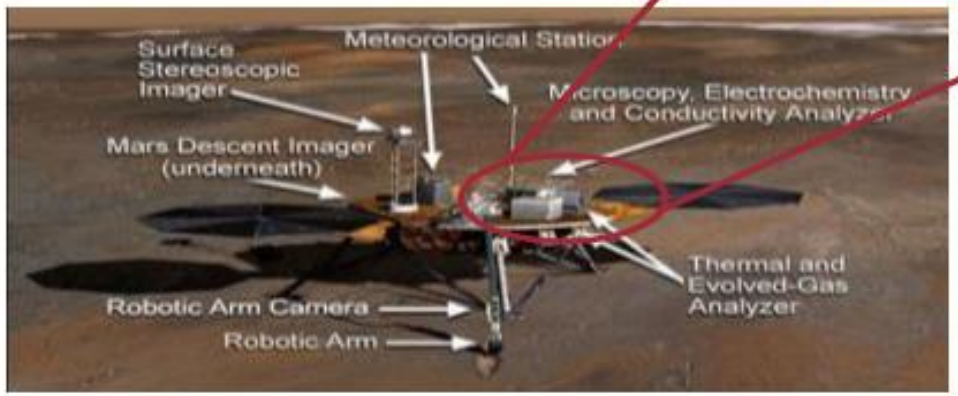
Space Exploration applications

Some proposed uses for mechatronics in space exploration include robotic arms on the International Space Station, development of life-sustaining systems on the moon or otherwise uninhabitable planets or flying robots to examine planets' surfaces.

Phoenix Mars Lander's

System Can

- Collect specimens
- Has automated onboard lab for testing specimens



Advantages

- Robot that can travel to other planets and **take measurements automatically**.

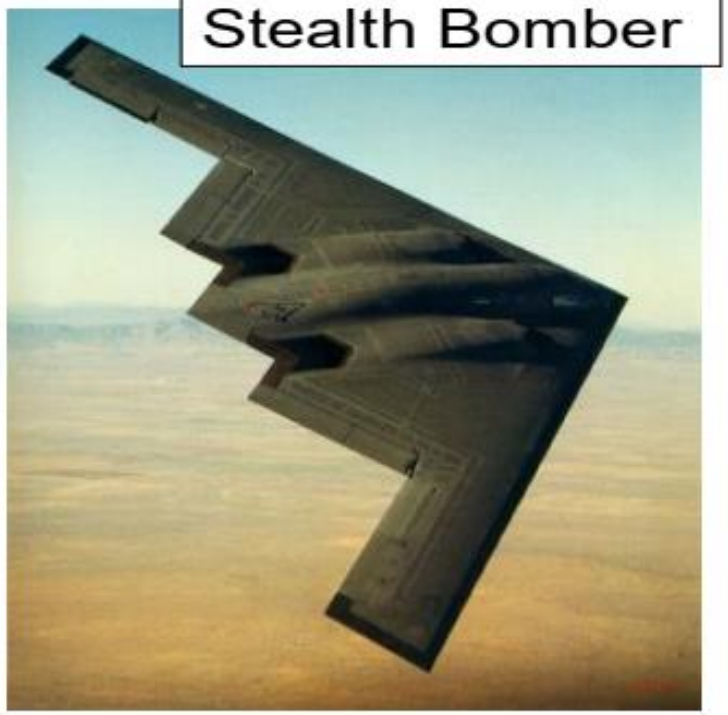
Military and Defense applications

UAVs are a component of an unmanned aircraft system (UAS), which includes adding a ground-based controller and a system of communications with the UAV. The flight of UAVs may operate under remote control by a human operator, as remotely-piloted aircraft (RPA), or with various degrees of autonomy, such as autopilot assistance, up to fully autonomous aircraft that have no provision for human intervention.

- Advanced technology is making our soldiers safer.
- Some planes can now be flown remotely.

Unmanned Aerial Vehicle

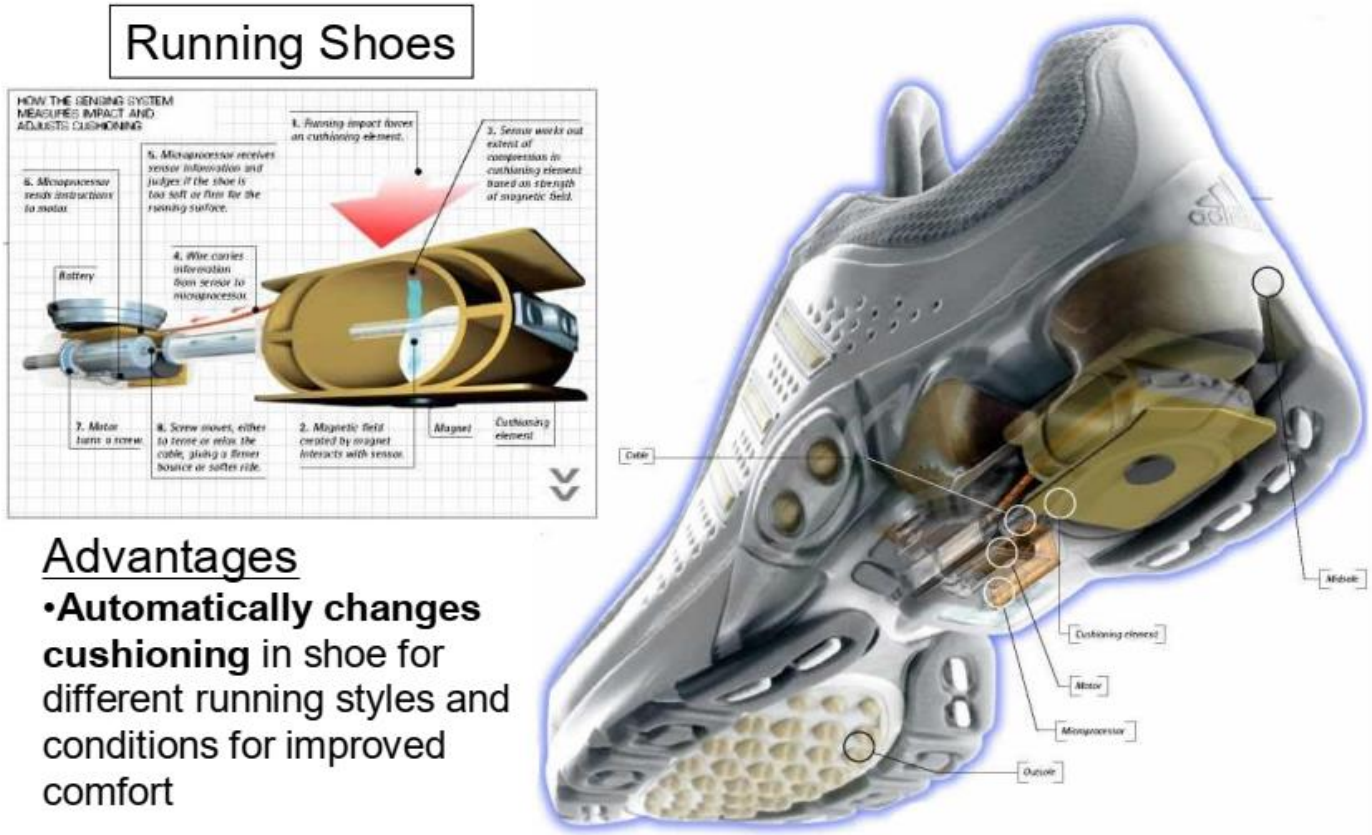
Stealth Bomber



Sports applications

The shoes have pressure sensors in the soles that sense when to put the foot inside and triggers an algorithm that allows an automatic lacing. With integrated LEDs, the shoes can alert a user of low battery or a tight fit. Moreover, these shoes do not need charging every day, and the charge can last up to two weeks.

Some types of smart shoes features a wide range of uses and is fit for everyone. These interactive smart shoes provide personalized feedback to analyze health, fatigue, posture, steps, and calories and create precise data for improving health and preventing injuries. It is easily connected to Bluetooth 4.0 device and provides personalized coaching in real time via a smartphone app. The lightweight next-gen shoe design boasts of auto-lacing and temperature regulation.



Sports applications

Mobile robot smart shoes

thank you!