

MEC 111 Unit 2 Slides

MEC 111 Unit 2 Study Guide: A Professional's Guide to the Fundamentals of Automation Technology

Section 1: The Symbiotic Worlds of Automation and Mechatronics

This section establishes the foundational principles of automation technology, framing it not merely as a set of tools but as a strategic response to the economic imperative for greater productivity and quality. It then introduces mechatronics as the synergistic engineering discipline that underpins the development of modern, intelligent automated systems.

1.1 Defining Automation Technology: Beyond the Buzzword

Automation technology is a comprehensive, interdisciplinary field that reduces human intervention in processes.¹ As defined in the course material, it is a crossover discipline that leverages knowledge and scientific methods from numerous technical sciences, including mechanical, electrical, production, and structural engineering.² In a broader industry context, automation is the application of technology—be it programs, robotics, or defined processes—to achieve outcomes with minimal human input.³ This encompasses a vast array of technologies, from robotics and expert systems to sensors, communications, and process control.⁴

It is crucial to understand that automation is not a monolithic concept but a spectrum of

complexity. This spectrum can be categorized into distinct levels:

- **Basic Automation:** This level involves the automation of simple, routine, and repetitive tasks. Examples include digitizing onboarding materials for new hires or automatically sending invoices, which helps to eliminate errors and free up human workers for more valuable activities.³
- **Process Automation:** This involves managing more complex, multi-step workflows that may involve multiple systems. Technologies like Robotic Process Automation (RPA) and Business Process Management (BPM) are used to bring uniformity, transparency, and efficiency to business and IT processes.³
- **Intelligent Automation:** This advanced form of automation integrates artificial intelligence (AI), machine learning, and other cognitive technologies to streamline and scale decision-making. Virtual agents that use natural language processing or AIOps platforms that proactively manage IT systems are prime examples of intelligent automation in practice.³

1.2 The Drive for Productivity in Modern Manufacturing

The primary catalyst for the widespread adoption of automation is the relentless demand for increased productivity. Productivity is defined as the rate at which goods are produced or work is completed.² In an environment of rapid technological change, consumers and industries demand the highest quality products and services, a standard that can only be met through a high level of productivity.²

This creates a direct causal chain: the market's demand for quality and efficiency necessitates higher productivity, and companies overwhelmingly choose to automate processes as the most effective strategy to achieve this goal.² The benefits that drive this adoption are tangible and transformative. Automation relieves human workers from tasks that are dangerous, physically exhausting, or mind-numbingly repetitive.⁵ Automated systems can operate continuously, 24/7, at a pace that far surpasses manual capabilities, leading to a significant increase in output. Furthermore, automation improves the consistency and quality of products while reducing operational costs, particularly those related to labor.⁵

1.3 Mechatronics: The Synergistic Integration of Disciplines

Mechatronics is the core engineering discipline that makes modern, intelligent automation

possible. The term itself, a portmanteau of "mechanics" and "electronics," signifies its origin as a field integrating mechanical and electronic systems.² However, the definition has evolved significantly over time. Today, mechatronics is understood as the synergistic integration of mechanical engineering, electronics, and computer science to design and create simpler, smarter, and more efficient systems.² A robot, which incorporates mechanisms, electronics, and computing to perform tasks, serves as a quintessential example of a mechatronic system.²

The evolution of the definition of mechatronics mirrors the technological progress of the last half-century. What began as a fusion of two fields in the late 1960s expanded to formally include computer science and software engineering.² In its contemporary form, mechatronics often integrates elements of artificial intelligence, robotics, cybersecurity, and the Internet of Things (IoT).⁶ This dynamic evolution positions mechatronics as a foundational discipline for the Fourth Industrial Revolution, or Industry 4.0. This new industrial era is characterized by "cyber-physical systems"—networks of interconnected machines and sensors that communicate, exchange data, and make intelligent, decentralized decisions—which are fundamentally mechatronic in nature.⁶

1.4 The Role of the Mechatronics Engineer: A Multidisciplinary Problem-Solver

A mechatronics engineer is a multidisciplinary problem-solver tasked with creating and improving automated processes.² Their work involves the research, design, implementation, and maintenance of intelligent systems by applying a holistic understanding of mechanical, electronic, computer, and software technologies.² A primary role is to design machinery and systems that can perform tasks automatically or with minimal human intervention.¹²

The unique value of a mechatronics engineer lies in their ability to function as a "systems thinker." They possess foundational knowledge in both mechanical and electrical engineering, allowing them to "speak both languages" and effectively bridge the communication and design gap between different engineering teams.⁸ This holistic perspective is critical for integrating disparate components—such as motors, sensors, and software—into a single, cohesive, and functional system.⁸ Beyond technical proficiency, the field also emphasizes the importance of interpersonal and teamwork skills to facilitate cooperation and constructive feedback within these multidisciplinary project environments.²

Section 2: The Anatomy of an Automated System

Every modern automated system, regardless of its specific application, is built upon a functional triad of core components. This section deconstructs the system into these three essential elements, moving from a high-level conceptual model to a practical examination of the hardware that enables a machine to sense its environment, decide on a course of action, and physically act upon that decision.

2.1 The Core Triad: Sensors, Actuators, and Controllers

As outlined in the course material, all modern automatic processes are realized through three fundamental components ²:

1. **Sensors** to detect the system's state and its environment.
2. **Actuators** to execute physical actions and output control commands.
3. **Controllers** to process information, manage program flow, and make decisions.

A useful analogy is to compare this triad to the human body. Sensors function as the system's "senses" (eyes, ears, touch), gathering information from the world. The controller acts as the "brain," processing this sensory input and deciding what to do. Finally, actuators serve as the "muscles," carrying out the brain's commands to interact with the world. This simple model illustrates how these components work in concert to create intelligent, responsive behavior.

The interaction between these three components forms the basis of a closed-loop feedback system, a fundamental principle of modern control theory. The process begins with a sensor measuring a physical property of the system (e.g., temperature, position). This measurement, known as the process variable, is sent to the controller. The controller compares this value to a desired value, or setpoint, and calculates the difference or error.¹⁴ Based on this error, the controller sends a command to an actuator, which then performs an action to reduce the error and bring the system closer to the setpoint. The sensor continuously measures the result of the actuator's action, "feeding back" the new state to the controller. This cycle of measure, compare, and correct allows the system to be adaptive, precise, and self-regulating.¹⁴

2.2 Sensors: A System's Senses

Sensors are the devices that bridge the gap between the physical world and the digital controller. Their primary function is to detect, analyze, measure, and process physical phenomena—such as changes in position, temperature, or light—and convert them into electrical signals that the controller can interpret.¹⁵ The selection of sensors is a critical design decision, as it dictates what information the system has about itself and its environment.

Common types of sensors used in industrial automation include:

- **Temperature Sensors:** These devices measure heat and are essential for process control in manufacturing, HVAC systems, and environmental monitoring.¹⁵
- **Pressure Sensors:** These instruments measure force per unit area in liquids or gases. They are vital in hydraulic and pneumatic systems, and can also be used to infer other variables like fluid flow, speed, and altitude.¹⁵
- **Proximity Sensors:** These sensors detect the presence of an object without physical contact. Common types include infrared (IR) sensors, which detect heat, and ultrasonic sensors, which use sound waves.¹⁷
- **Optical/Vision Sensors:** These sensors, ranging from simple photo-detectors to complex cameras, use light to gather information. They are used for object recognition, barcode scanning, quality inspection, and robot navigation.¹⁷
- **Force/Torque Sensors:** Crucial in robotics and delicate assembly tasks, these sensors measure forces and torques, allowing a robot to, for example, grip an object like a glass without breaking it.¹⁸
- **Accelerometers and Gyroscopes (MEMS):** Micro-Electro-Mechanical Systems (MEMS) are tiny devices that measure acceleration and rotational motion. They are essential for monitoring orientation, detecting vibration, and enabling navigation in mobile robots and vehicles.¹⁵

2.3 Actuators: A System's Muscles

Actuators are the components that perform the physical work in an automated system. They are responsible for converting a source of energy—typically electrical, pneumatic (compressed air), or hydraulic (pressurized fluid)—into controlled physical motion, which can be either linear (in a straight line) or rotary (circular).¹⁹ The choice of actuator technology is a primary design challenge for a mechatronics engineer, as it directly determines the system's capabilities, limitations, and overall cost. A task requiring immense force, like an industrial press, will necessitate a hydraulic actuator, which in turn dictates the need for a hydraulic power unit and specialized maintenance. In contrast, a task requiring high precision and speed, like a pick-and-place robot, will rely on electric servo motors. This selection process involves a cascade of design trade-offs between performance, cost, and complexity.

The table below provides a comparative analysis of the three primary actuator types.

Feature	Electric Actuators	Pneumatic Actuators	Hydraulic Actuators
Power Source	Electrical energy (motors, solenoids)	Compressed air or gas	Pressurized fluid (typically oil)
Force Output	Low to Medium	Low to Medium	Very High
Precision	High	Low to Medium	Low
Speed	Medium to High	Very High	Low to Medium
Key Advantages	High precision and repeatability, clean operation, easy to control and integrate.	Cost-effective, simple, fast, inherently safe (no ignition source).	Extremely high force and power density, robust, holds force at zero speed.
Key Disadvantages	Lower force than hydraulics, potential for overheating under heavy load.	Low precision, requires continuously running compressor, air is compressible.	Complex, requires pumps and reservoirs, potential for fluid leaks, requires skilled maintenance.
Typical Applications	Robotics, CNC machines, automated	Material handling, clamping,	Heavy machinery (construction,

	assembly, medical devices.	"pick and place" operations, door openers.	presses), aircraft flight controls, automotive brakes.	
(Data synthesized from ¹⁹⁾				

2.4 Controllers: A System's Brain

The controller is the central processing unit of the automated system. Its function is to manage, command, direct, and regulate the behavior of all other components based on a pre-written program.¹⁴ As noted in the slides, most modern controllers are

program controllers, meaning their logic and decision-making processes are defined by software.² The controller executes this program by continuously reading inputs from sensors, performing logical operations and calculations, and sending output commands to the actuators.²³

In industrial automation, the most common type of controller is the Programmable Logic Controller (PLC). PLCs are ruggedized industrial computers designed to withstand harsh factory environments and execute control logic with high reliability.²³ More advanced systems may use Programmable Automation Controllers (PACs), which combine the functionality of a PLC with the capabilities of a personal computer, offering more advanced data processing and networking features.²⁴ Regardless of the specific hardware, the controller's role remains the same: to be the intelligent core that orchestrates the entire automated process.

Section 3: Engineering Mindsets: The Black Box Approach

To effectively design and manage complex mechatronic systems, engineers rely on powerful conceptual tools. One of the most fundamental of these is abstraction, which is practically applied through an approach known as "black box thinking." This section explores how

engineers manage overwhelming complexity by focusing on the interfaces between components—their inputs and outputs—rather than becoming lost in the details of their internal workings.

3.1 Thinking Like an Engineer: A Problem-Solving Perspective

The fundamental role of an engineer is to create technical solutions to satisfy human needs.² This role fosters a pragmatic, problem-solving mindset that constantly seeks the most effective and efficient path to a solution. This approach has given rise to powerful mental models, such as black box thinking, which allow for the systematic deconstruction and resolution of complex technical challenges.²

3.2 Deconstructing "Black Box Thinking": A Focus on Inputs and Outputs

Black box thinking is an approach where a system or component is viewed solely in terms of its inputs and outputs, without any knowledge of its internal workings.²⁵ The implementation is considered "opaque," like a sealed black box. The only thing an engineer needs to know is that a specific, defined input will reliably produce a specific, predictable output.² This concept, which has its roots in early 20th-century electronic circuit theory and was later formalized in the field of cybernetics, is based on the "explanatory principle"—the assumption of a stable, causal relationship between what goes into the box and what comes out of it.²⁵

This approach is not a form of ignorance but a deliberate and essential strategy for managing complexity. Mechatronic systems are, by definition, the integration of numerous complex subsystems from different engineering domains. It is practically impossible for a single engineer to be an expert in the semiconductor physics of a microcontroller, the metallurgy of a gearbox, and the compiler design of a software library simultaneously. Black box thinking allows an engineer to effectively integrate these components by treating each one as a functional block with well-defined interfaces and guaranteed behaviors, making large-scale systems integration possible.²⁶

3.3 Case Study in Practice: The Electric Motor as a Black Box

The slides provide an excellent practical example of this concept: an engineer designing an automated machine that uses an electric motor.² The machine designer treats the motor as a black box. The relevant

inputs are the electrical specifications (e.g., voltage, current) and control signals. The critical *outputs* are the motor's performance characteristics (e.g., torque, speed, power) and its physical properties (e.g., dimensions, shaft diameter). The designer selects the appropriate motor by matching these input/output characteristics to the machine's requirements, without needing to understand the complex physics of electromagnetic induction, winding configurations, or magnetic flux within the motor itself.²

It is important to distinguish this conceptual "black box" from the physical device often called a "black box" in vehicles and aircraft. An automotive black box, more formally known as an Event Data Recorder (EDR), is a device that *records* a vehicle's inputs (steering, braking, speed) and system states for the purpose of post-accident analysis.²⁷ While it shares the name, its function is one of data logging, not abstraction for design purposes.

3.4 Beyond the Black Box: When Internal Workings Are Critical

The black box approach is a tool, not a universal rule. The slides correctly contrast the machine designer with the engineer who is tasked with *designing the electric motor itself*.² For this engineer, the internal workings are not opaque; they are the entire focus of the design problem. This engineer requires an in-depth, expert knowledge of the motor's mode of operation and the physical fundamentals of its components.²

This introduces the concept of "white box" (or "glass box") analysis, where the internal mechanisms are known, visible, and critical to the task at hand.²⁹ The skill of an experienced systems engineer lies in knowing where to draw the boundary of the black box. For initial system integration, treating a motor as a black box is efficient. However, if the machine later exhibits unexpected vibrations, the engineer may need to "open the box" to investigate the motor's internal characteristics, such as bearing tolerances or rotor balance. The boundary of abstraction is not fixed; it is a dynamic choice that an engineer must make based on the specific problem they are trying to solve. Applying the appropriate level of abstraction is a hallmark of engineering expertise.

Section 4: The Language of Engineering: Technical

Communication and Diagrams

Engineering is a collaborative discipline that relies on precise, unambiguous communication. To achieve this, engineers have developed a set of standardized graphical languages to represent technical solutions. These diagrams and documents are not mere illustrations; they are legally and technically binding specifications essential for design, manufacturing, and maintenance in a globalized environment.

4.1 The Imperative of Standardization in Technical Plans

Engineers use standardized and internationally understood description tools, the majority of which are graphical, to convey complex technical information.² Standardization is non-negotiable because it ensures that a design can be interpreted consistently by different people in different places. A technical drawing created by an engineer in the United States following the ANSI standard must be correctly understood by a manufacturer in Europe who typically uses the ISO standard, and vice versa. This shared understanding eliminates ambiguity, prevents costly manufacturing errors, and facilitates global collaboration.³⁰

4.2 Technical Drawings: From Concept to Component

Technical drawings describe the physical form and structure of a product or system. They are the primary documents used for manufacturing and assembly.

4.2.1 Dimensional Drawings

A dimensional drawing is the definitive blueprint for manufacturing a single component. It provides all the necessary information for production, including precise dimensions, tolerances (the acceptable range of variation for a dimension), required surface finish, and the type of material to be used.² These drawings typically use a method called orthographic projection, where the object is shown in a series of 2D views, each one rotated by 90 degrees,

to represent its complete 3D geometry.²

4.2.2 Assembly Drawings and Parts Lists

An assembly drawing shows how multiple individual components fit together to create a final product or sub-assembly. These drawings contain few dimensions, focusing instead on illustrating the spatial relationship between parts. Each component in the assembly drawing is labeled with an item number, which corresponds to an entry in a separate document called a Parts List or Bill of Materials (BOM).² The Parts List provides the detailed information for each item, including its part number, description, and the quantity required for one complete assembly. This includes standard, off-the-shelf parts like screws, nuts, and bearings.²

4.2.3 A Note on Global Standards: ISO vs. ANSI

A critical real-world consideration is the existence of different international standards for technical drawings. The two most prominent are ISO (International Organization for Standardization), widely used in Europe and Asia, and ANSI/ASME (American National Standards Institute / American Society of Mechanical Engineers), used in the United States. While largely similar, they have key differences that engineers must be aware of to avoid misinterpretation.

Feature	ISO Standard	ANSI/ASME Standard
Projection Method	First-Angle Projection	Third-Angle Projection
Dimension Placement	Above and parallel to the dimension line	Centered and read horizontally
Unit of Measurement	Millimeters (mm)	Inches (in)

Diameter Symbol	\varnothing	DIAM or \emptyset	
(Data synthesized from ³⁰)			

4.3 Circuit Diagrams: Mapping Functional Relationships

While technical drawings describe physical form, circuit diagrams describe functional interconnection. These diagrams, also known as schematics, show how electric, pneumatic, or hydraulic components in a system are connected to one another.² Circuit diagrams are highly abstract because they use standardized symbols that represent the

function of a component, not its physical appearance or size.² For example, the symbol for a resistor is the same regardless of whether the physical resistor is large or small. This abstraction allows engineers to focus solely on the functional logic of the circuit. Like technical drawings, circuit diagrams adhere to international standards, such as those from the IEC (International Electrotechnical Commission) and IEEE (Institute of Electrical and Electronics Engineers), to ensure universal understanding.³¹

4.4 Flow Charts: Visualizing Logic Before Code

Flow charts are used to describe the logical behavior of a system over time. In automation, a flow chart is a graphical representation of an algorithm that is developed *before* any programming code is written.² It visualizes the sequence of operations, the decisions to be made, and the different paths the program can take. This serves as a crucial blueprint for the software that will run on the system's controller.

A complete understanding of a mechatronic system requires literacy in all these graphical languages. For example, to understand a pneumatic cylinder in a system, an engineer must consult the dimensional drawing for its physical size, the circuit diagram to see how it is connected to a control valve, and the flowchart to understand the logical conditions under which it is commanded to extend or retract. Each document provides a different, essential layer of abstraction for describing the same system.

4.4.1 Key Symbols and Programming Conventions

Flow charts use a small set of standardized symbols to represent different types of programming actions. Mastering these symbols is the first step to creating and interpreting control logic.

Symbol Shape	Name	Function in Programming Logic
Oval / Pill	Terminator	Represents the start or end point of a program or subroutine.
Rectangle	Process	Represents a specific action or operation (e.g., "Advance Cylinder," "Turn on Motor").
Diamond	Decision	Represents a conditional statement (e.g., an "If" statement) where the path branches based on a true/false or yes/no answer.
Parallelogram	Input / Output	Represents data entering the system (e.g., "Read Sensor Value") or leaving the system (e.g., "Display Warning").
Arrow	Flow Line	Indicates the direction of logical

		flow and connects the symbols in sequence.	
(Data synthesized from ³³)			

4.4.2 Applied Logic: Deconstructing the Presentation Examples

The slides provide two examples that illustrate how a flowchart translates directly into program logic.²

1. **Tank Filling Process:** This flowchart shows a sequence of actions ("Open inlet valve") and decisions ("Is tank full?"). The "Is tank full?" diamond represents an If statement. If the condition is true (yes), the program follows one path; if it is false (no), it follows another, likely looping back to wait until the tank is full.
2. **Cylinder Advancement:** This flowchart shows a decision diamond with the condition $(T1=1) \& (T2=1)$. This directly translates to the programming statement: IF (PushButton1 is ON) AND (PushButton2 is ON) THEN.... If the condition is true (y), the process box "action" is executed, which corresponds to the command ...advance cylinder. If the condition is false (n), the flow line loops back, repeating the check until both buttons are pressed. This visual representation makes the control logic clear before a single line of code is written.

Finally, it is vital to recognize that this technical documentation is more than just a set of design tools; it constitutes a collection of legal and financial instruments. An inaccurate dimension on a drawing can lead to a rejected batch of parts, resulting in significant financial loss. An ambiguous circuit diagram can lead to incorrect wiring and system failure. In the event of an accident or failure, these documents become key evidence in contract disputes and liability investigations. Therefore, the rigorous creation of and adherence to standardized documentation is a core professional and ethical responsibility for every engineer.

Section 5: Synthesis and Self-Assessment

This final section consolidates the concepts from the previous sections through an integrated application scenario and a series of questions designed to test both foundational knowledge

and deeper conceptual understanding.

5.1 Connecting the Concepts: A Holistic View of a Mechatronic System

To see how all these concepts work together, consider a hypothetical automated bottling and capping line, a common mechatronic system in manufacturing.³⁵

- **Primary Goal:** The system's purpose is to increase **productivity** (bottles per hour) and **quality** (consistent fill levels, proper cap torque).
- **Sensors:** A variety of sensors would be needed to monitor the process:
 - An **optical sensor** at the start of the line to detect the presence of a bottle.
 - A **level sensor** (e.g., ultrasonic or capacitive) at the filling station to ensure the correct fill height.
 - A **torque sensor** on the capping mechanism to verify that the cap is tightened correctly but not stripped.
 - A **vision sensor** (camera) for final quality inspection to check for label placement and cap alignment.
- **Actuators:** Different actuators would perform the physical tasks:
 - An **electric motor** with a variable frequency drive (VFD) to run the conveyor belt at a controlled speed.
 - A **pneumatic actuator** to lower and raise the filling nozzle quickly and cleanly.
 - An **electric servo motor** on the capping head to apply precise, controlled torque.
- **Controller:** A central **PLC** would act as the system's brain. It would run a program that sequences all operations based on sensor inputs: wait for a bottle, stop the conveyor, lower the nozzle, fill to the correct level, raise the nozzle, move the bottle to the capper, apply the cap, and so on.
- **Black Box Thinking:** The system integrator would treat many components as **black boxes**. For example, the vision inspection camera would be treated as a device that takes an input (a trigger signal) and produces an output (a pass/fail signal), without the integrator needing to understand the complex image processing algorithms running inside it. Similarly, the VFD for the conveyor motor is a black box that accepts a speed command and outputs the correct electrical frequency.
- **Technical Documentation:** A complete documentation package would be required to build, operate, and maintain this line:
 - **Assembly drawings** for the mechanical frame and conveyor structure.
 - **Dimensional drawings** for any custom-machined parts like brackets or mounts.
 - **Circuit diagrams** for the main electrical control panel, showing how the PLC, motor drives, sensors, and safety relays are all interconnected.
 - **Flowcharts** detailing the PLC's control logic for every step of the bottling and

capping sequence.

5.2 Knowledge Check: Key Questions and Conceptual Problems

This self-assessment is divided into two parts. The first part covers the foundational questions from the presentation slides, while the second part presents more advanced conceptual challenges based on the deeper analysis in this guide.

Review Questions

2

1. **What is automation technology?**
 - o It is a crossover discipline that uses knowledge and scientific methods from numerous technical sciences (e.g., mechanical, electrical, production engineering) to create systems that operate with minimal human intervention.
2. **What are mechatronic systems?**
 - o They are automated processes, essential for efficient manufacturing, that synergistically incorporate computing, electronics, and mechanisms to perform tasks.
3. **What is the purpose of a circuit diagram?**
 - o To show how electrical, pneumatic, or hydraulic components are functionally interconnected, using standardized symbols that represent function rather than physical appearance.
4. **What is the difference between a dimensional drawing and an assembly drawing?**
 - o Dimensional drawings provide the detailed information (dimensions, tolerances, materials) required to manufacture a single component. Assembly drawings show how multiple components fit together to form a finished product.
5. **What is the purpose of a flow chart?**
 - o A flow chart is a graphical representation of an algorithm or process, used to define and visualize the control logic before programming begins. It shows the steps as boxes and the sequence of operations with arrows.

Conceptual Challenges

1. A company wants to automate the process of lifting heavy engine blocks (up to 500 kg) onto an assembly line. Based on the principles in Section 2.3, would you recommend a pneumatic, hydraulic, or electric actuator? Justify your choice by discussing at least two advantages and one disadvantage of your selected technology for this specific application.
2. You are integrating a third-party laser scanner into a quality control system. Explain how you would apply "black box thinking" to this task. What specific input and output information would you need from the scanner's documentation without needing to know its internal optics or firmware?
3. Explain why a single assembly drawing is insufficient to manufacture and program a robotic work cell. Describe what other two types of diagrams are necessary and what specific information each one provides that the others do not.

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