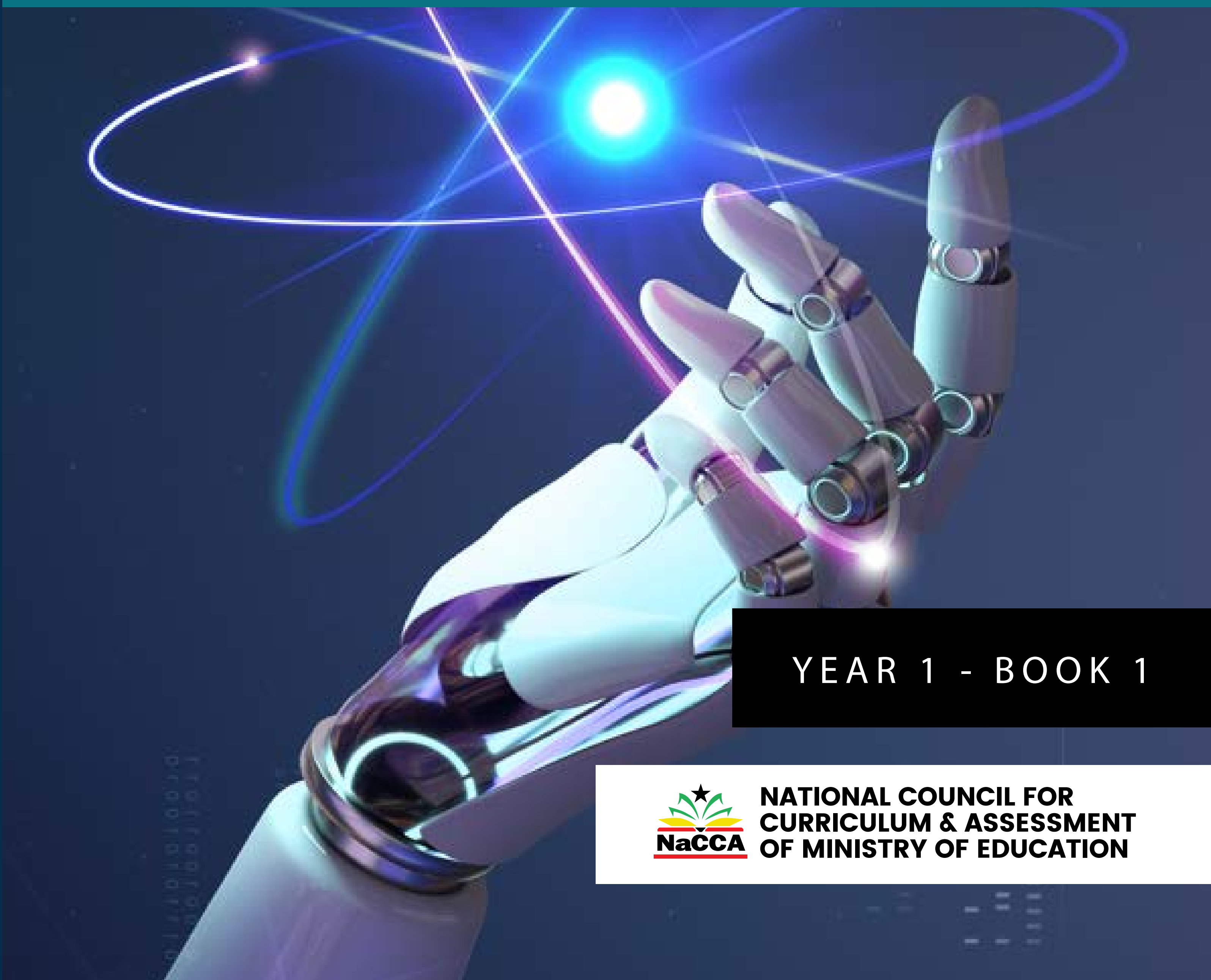
MINISTRY OF EDUCATION

# Robotics

TEACHER MANUAL



YEAR 1 - BOOK 1

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

# MINISTRY OF EDUCATION

REPUBLIC OF GHANA

# Robotics

## Teacher Manual

### Year One - Book One

NATIONAL COUNCIL FOR
CURRICULUM & ASSESSMENT
OF MINISTRY OF EDUCATION

**ROBOTICS TEACHER MANUAL**

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# INTRODUCTION

The National Council for Curriculum and Assessment (NaCCA) has developed a new Senior High School (SHS), Senior High Technical School (SHTS) and Science, Technology, Engineering and Mathematics (STEM) Curriculum. It aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, competencies, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, further their education and enter the world of work.

This is the first time that Ghana has developed an SHS Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

This Teacher Manual for Robotic covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively teach Year One of the new curriculum. It contains this information for the first 12 weeks of Year One, with the remaining 12 weeks contained within Book Two. Teachers are therefore to use this Teacher Manual to develop their weekly Learning Plans as required by Ghana Education Service.

Some of the key features of the new curriculum are set out below.

### Learner-Centred Curriculum

The SHS, SHTS, and STEM curriculum places the learner at the center of teaching and learning by building on their existing life experiences, knowledge and understanding. Learners are actively involved in the knowledge-creation process, with the teacher acting as a facilitator. This involves using interactive and practical teaching and learning methods, as well as the learner's environment to make learning exciting and relatable. As an example, the new curriculum focuses on Ghanaian culture, Ghanaian history, and Ghanaian geography so that learners first understand their home and surroundings before extending their knowledge globally.

### Promoting Ghanaian Values

Shared Ghanaian values have been integrated into the curriculum to ensure that all young people understand what it means to be a responsible Ghanaian citizen. These values include truth, integrity, diversity, equity, self-directed learning, self-confidence, adaptability and resourcefulness, leadership and responsible citizenship.

### Integrating 21st Century Skills and Competencies

The SHS, SHTS, and STEM curriculum integrates 21st Century skills and competencies. These are:

- **Foundational Knowledge:** Literacy, Numeracy, Scientific Literacy, Information Communication and Digital Literacy, Financial Literacy and Entrepreneurship, Cultural Identity, Civic Literacy and Global Citizenship
- **Competencies:** Critical Thinking and Problem Solving, Innovation and Creativity, Collaboration and Communication
- **Character Qualities:** Discipline and Integrity, Self-Directed Learning, Self-Confidence, Adaptability and Resourcefulness, Leadership and Responsible Citizenship

### Balanced Approach to Assessment - not just Final External Examinations

The SHS, SHTS, and STEM curriculum promotes a balanced approach to assessment. It encourages varied and differentiated assessments such as project work, practical demonstration, performance assessment, skills-based assessment, class exercises, portfolios as well as end-of-term examinations and final external assessment examinations. Two levels of assessment are used. These are:

- o Internal Assessment (30%) – Comprises formative (portfolios, performance and project work) and summative (end-of-term examinations) which will be recorded in a school-based transcript.
- o External Assessment (70%) – Comprehensive summative assessment will be conducted by the West African Examinations Council (WAEC) through the WASSCE. The questions posed by WAEC will test critical thinking, communication and problem solving as well as knowledge, understanding and factual recall.

The split of external and internal assessment will remain at 70/30 as is currently the case. However, there will be far greater transparency and quality assurance of the 30% of marks which are school-based. This will be achieved through the introduction of a school-based transcript, setting out all marks which learners achieve from SHS 1 to SHS 3. This transcript will be presented to universities alongside the WASSCE certificate for tertiary admissions.

## An Inclusive and Responsive Curriculum

The SHS, SHTS, and STEM curriculum ensures no learner is left behind, and this is achieved through the following:

- Addressing the needs of all learners, including those requiring additional support or with special needs. The SHS, SHTS, and STEM curriculum includes learners with disabilities by adapting teaching and learning materials into accessible formats through technology and other measures to meet the needs of learners with disabilities.
- Incorporating strategies and measures, such as differentiation and adaptative pedagogies ensuring equitable access to resources and opportunities for all learners.
- Challenging traditional gender, cultural, or social stereotypes and encouraging all learners to achieve their true potential.
- Making provision for the needs of gifted and talented learners in schools.

## Social and Emotional Learning

Social and emotional learning skills have also been integrated into the curriculum to help learners to develop and acquire skills, attitudes, and knowledge essential for understanding and managing their emotions, building healthy relationships and making responsible decisions.

## Philosophy and vision for each subject

Each subject now has its own philosophy and vision, which sets out why the subject is being taught and how it will contribute to national development. The Philosophy and Vision for Robotics is:

**Philosophy**: The next generation of creators and technology developers can be empowered through observation, curiosity and exposure to related robotic concepts and opportunities that leverage practical activities in a learner-centered environment leading to global and local ("glocal") relevance.

**Vision:** A skilled learner armed with 21st century skills and competencies in critical thinking, designing, and development of robot-based solutions for increasingly complex societal problems.

# ACKNOWLEDGEMENTS

Special thanks to Professor Edward Appiah, Director-General of the National Council for Curriculum and Assessment (NaCCA) and all who contributed to the successful writing of the Teacher Manuals for the new Senior High School (SHS), Senior High Technical School (SHTS) and Science Technology, Engineering and Mathematics (STEM) curriculum.

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# SCOPE AND SEQUENCE

**Robotics Summary**

| S/N | STRAND | SUB-STRAND | YEAR 1 | | | YEAR 2 | | | YEAR 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CS | LO | LI | CS | LO | LI | CS | LO | LI |
| 1 | Principles of Robotic Systems | Robots and Society | 2 | 2 | 3 | 2 | 2 | 4 | 2 | 2 | 4 |
| | | Robot Control Principles | 2 | 2 | 4 | 2 | 2 | 4 | 3 | 3 | 5 |
| | | Sensors and Actuators | 2 | 2 | 4 | 2 | 2 | 4 | 1 | 1 | 2 |
| 2 | Robot Design Methodologies | Digital and Analogue System Design | 2 | 2 | 4 | 2 | 2 | 3 | 1 | 1 | 2 |
| | | Tools and Apps for Robot Design | 1 | 1 | 2 | 1 | 1 | 1 | - | - | - |
| 3 | Robot Construction and Programming | Higher Order Design Thinking | 1 | 1 | 2 | 1 | 1 | 1 | - | - | - |
| | | Robot Construction | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 1 | 1 |
| | | Programming Robot | - | - | - | 2 | 2 | 4 | - | - | - |
| **Total** | | | **12** | **12** | **22** | **14** | **14** | **23** | **8** | **8** | **14** |

**Overall Totals (SHS 1 – 3)**

| | |
|---|---|
| **Content Standards** | **34** |
| **Learning Outcomes** | **34** |
| **Learning Indicators** | **59** |

# SECTION 1: ROBOT CONTROL PRINCIPLES 1

Strand: **Principles of Robotic Systems**

**Sub-Strand:** Robot Control Principles

**Learning Outcomes**

1. *Appraise the peculiar characteristics of the various industrial revolutions and analyse the performance impact on human-robot coexistence in a working environment*
2. *Outline the essential economic and social benefits of using robots in 21st-century environments*

**Content Standards:**

1. Demonstrate understanding of the role of robots as socio-technical systems.
2. Identify the uses of robots and automated systems in different workplaces guided by roboethics.

## INTRODUCTION AND SECTION SUMMARY

This section focuses on the interaction between Robots and Society. It explores the dynamic relationship between humans and robots within the context of various industrial revolutions. It will help learners analyse how these revolutions have shaped human-robot coexistence in working environments. Furthermore, learners will delve into the economic and social benefits of integrating robots into 21st-century environments while considering critical ethical implications - Roboethics. They will apply this knowledge to critically assess real-world scenarios, enabling informed decision-making in the field of robotics and automation.

The weeks covered by the section are

**Week 1:**

1. The Industrial Revolution: Unveiling the Evolution of Modern Industry
2. Interdependence of Humans and Robots: Impact on Organisational Performance Indicators

**Week 2:**

1. Economic and Social Benefits of Robots in 21st Century Environments: Balancing Standards and Ethics

## SUMMARY OF PEDAGOGICAL EXEMPLARS

This section integrates a range of pedagogical approaches to engage learners in understanding the intricate dynamics between robots and society. Through experiential learning, learners will observe industrial revolutions by watching videos and conducting individual research. They will share their personal reflections and engage in class discussions to deepen comprehension. Collaborative and problem-based learning approaches using mixed-ability groups will also be employed to help learners clearly indicate the characteristics of each industrial revolution, construct timelines, and identify impacts of robot integration in various 21st-century environments. Facilitators of this section are encouraged to employ effective methods of differentiation by proactively recognising and capitalising on the shared characteristics among students while also addressing their individual differences that lie in interests, readiness levels, and learning styles. In addition, facilitators are also advised to provide access to diverse resources to cater to the varying preferences of learners.

## ASSESSMENT SUMMARY

Following each thematic area in this section, assessments gauge student learning. These come in two forms: learning tasks and key assessments. Learning tasks, primarily formative, focus on solidifying understanding and acquiring new knowledge or skills. Facilitators guide these activities to enhance the learning process. In contrast, key assessments, typically summative, evaluate student mastery after instruction. These are often given as homework, mid-semester exams or end-of-semester exams, usually done outside the class. Instructors have the flexibility to choose the assessment types that best suit their learners and learning objectives. However, it is advisable that instructors at least guide learners to do one of the learning tasks.

# WEEK 1

**Learning Indicator(s):**

1. *Describe the distinct features and advancements that characterise the transition from each of the industrial revolutions.*
2. *Analyse how the four organisational performance indicators (price, quality, flexibility, and innovation) have been impacted by the interdependence of humans and robots in working environments.*

## Theme or Focal Area: The Industrial Revolution — Unveiling the Evolution of Modern Industry

## Introduction

Robots have become an integral part of our modern world, revolutionising industries and addressing societal challenges. To understand their impact, it is crucial to explore the distinct features and advancements characterising the transition from each of the industrial revolutions. Studying the industrial revolutions provides a historical context for understanding the evolution of technology and automation, laying the foundation for appreciating the development and significance of robotics in modern industries.

## Industrial Revolutions

The Industrial Revolutions, spanning from the late 18th century to date, have marked significant shifts in manufacturing, technology, and societal structure. These periods have introduced innovations such as mechanisation, steam power, and mass production, transforming economies and lifestyles worldwide. However, there are variations in research regarding each revolution's precise start and end dates, reflecting differing interpretations of historical events and their impacts on society's evolution. Despite these differences, the Industrial Revolutions collectively reshaped human civilisation, laying the foundation for modern industrialised societies and the field of robotics.

1. **First Industrial Revolution (1760-1830):**

   The First Industrial Revolution, also known as Industry 1.0, marked a shift from manual labour to machine-based manufacturing. It led to the rise of factory systems, mass production, and the use of coal and iron as key resources, transforming agrarian-based (agric-based) economies into industrialised urban centres. During this period, the concept of robots was not yet born; however, key ideas, especially regarding actuation (mechanical motion), were initiated, and this later became a significant feature of robots. Some of the key advancements that characterise this revolution include the following:

   a. **Early automation**: Automated looms and textile machinery were introduced to mechanise the process of weaving cloth. This introduction reduced reliance on human labour and boosted productivity.

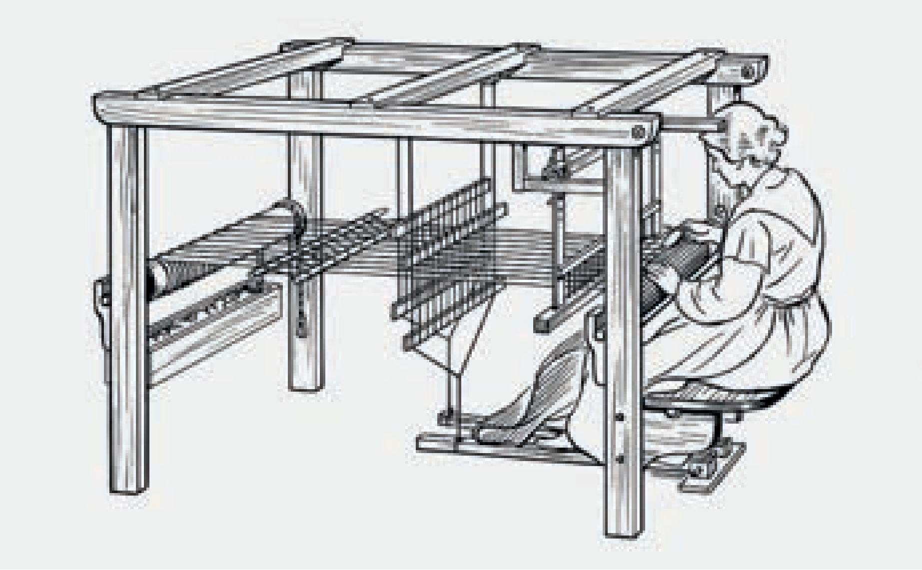

**Fig. 1.1:** *A Loom used in the textile industry*

b. **Mechanisation in mining**: Steam-powered machines, such as Thomas Savery's steam pump, steam trains and drills, were developed to extract and transport coal and minerals. This enhanced efficiency and safety in mining operations.

**Fig. 1.2:** *A Steam Train*

2. **Second Industrial Revolution (1870-1914)**

The Second Industrial Revolution, also known as Industry 2.0, was marked by the widespread adoption of steel production, the development of electrical power and lighting, the invention of the telephone, the expansion of the railroad network and the introduction of mass production techniques. These advancements led to greater efficiency in industrial production. Even though these were not directly robotic systems, the Second Industrial Revolution set the stage for advancements in technologies, which played critical roles in providing electrical power, and other technologies, including communication technologies, which later became an integral part of robots. Some of the notable advancements in the Second Industrial Revolution include the following:

a. **Electrical power systems**: The development of electrical power systems facilitated the automation of various process-powering machines and enabled the growth of industries like steel production and transportation.

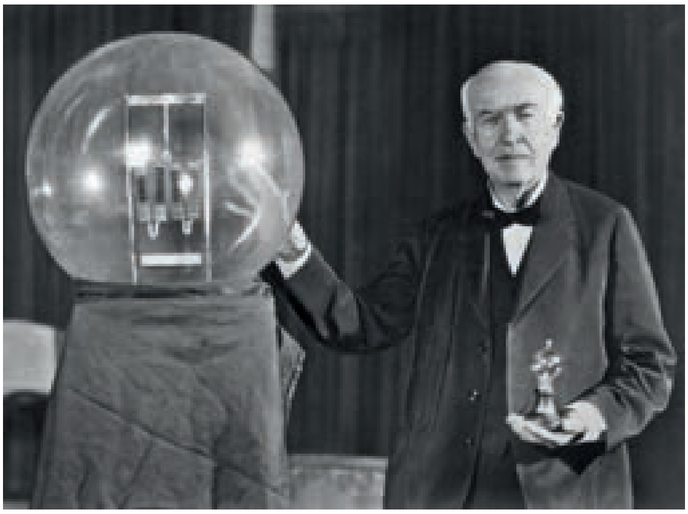

**Fig. 1.3:** *Thomas Edison at the Light Bulb's Golden Jubilee anniversary (Duranton; 2023)*

b. **Assembly line innovations**: The introduction of conveyor belts and mechanised assembly lines increased production rates and efficiency, as seen in Henry Ford's automobile factories.

**Fig. 1.4:** *Assembly Line in Henry Ford's Auto-mobile industry (Arnold, 2016)*

c. **Precision machinery**: Advanced machine tools, including lathes and milling machines, allowed for precise and standardised manufacturing, promoting interchangeable parts and mass production.

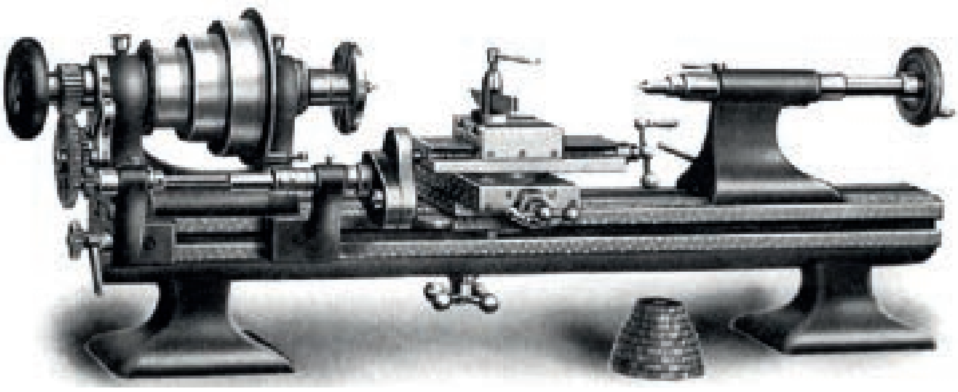

**Fig. 1.5:** *An early generation Lathe and Milling Machine (Murray, 2022)*

3. **Third Industrial Revolution (1950s-1990s)**

The Third Industrial Revolution, also known as the Digital Revolution or Industry 3.0, brought about the advent of computers and electronics. The first and second industrial revolutions made significant progress in designing machines that had mechanical parts that were either controlled by steam engines or electrical energy. This was close to mimicking human actuation in the real world but lacked a brain to mimic human thinking. By the third industrial revolution, some machines (Robots) began to resemble humans in their functionality by using computers or processors to receive data from sensors. They then processed this data and used the same computers or processors to control and coordinate the movement of mechanical subsystems. This forms the true definition of machines that fully qualify as robots.

Some key technologies of the 3rd Industrial Revolution include the following:

a. **Robotic automation**: Industrial robots started to emerge, performing tasks with greater precision, speed, and reliability. Early applications included automated assembling, welding, and material handling in manufacturing plants.

**Fig. 1.6:** *Robots being employed in an assembly line (Briefing, 2016)*

b. **Development of computer technology**: During the third industrial revolution, computer technology advanced rapidly, causing a move from mainframe computers to personal computers (PCs). This shift made computing power more accessible to individuals and businesses, radically changing data processing and automation. The development of microprocessors and software applications further accelerated the integration of computers into various industries, fostering innovation and driving economic growth.

**Fig. 1.7:** *An early Macintosh Apple PC (Everand, 2024)*

c. **Rise of the internet**: During the third industrial revolution, the rise of the Internet revolutionised communication and information exchange. This global network of interconnected computers enabled instant communication, access to vast information and facilitated e-commerce. The internet transformed various aspects of society, including education, business, and entertainment, leading to significant advancements in technology and connectivity. Its widespread adoption paved the way for further digital innovations and the emergence of the digital age.

**4. Fourth Industrial Revolution (2011 - Date)**

The Fourth Industrial Revolution, also known as Industry 4.0, is defined by the integration of cyber-physical systems, artificial intelligence, the Internet of Things (IoTs) and Big Data analytics. It has led to the digitalisation and connectivity of various industries, giving rise to smart homes, smart factories, and smart cities. Products and services are personalised based on data which is gathered and analysed with a special focus on sustainability. Robots are now at the forefront of this revolution, driven by the following advancements:

a. **Artificial Intelligence (AI) and Machine Learning (ML)**: AI and ML systems are systems designed to simulate human cognitive processes, such as learning, reasoning, problem-solving, perception, and decision-making. With this technological inclusion, robots are becoming smarter and capable of learning, adapting, and making complex decisions.

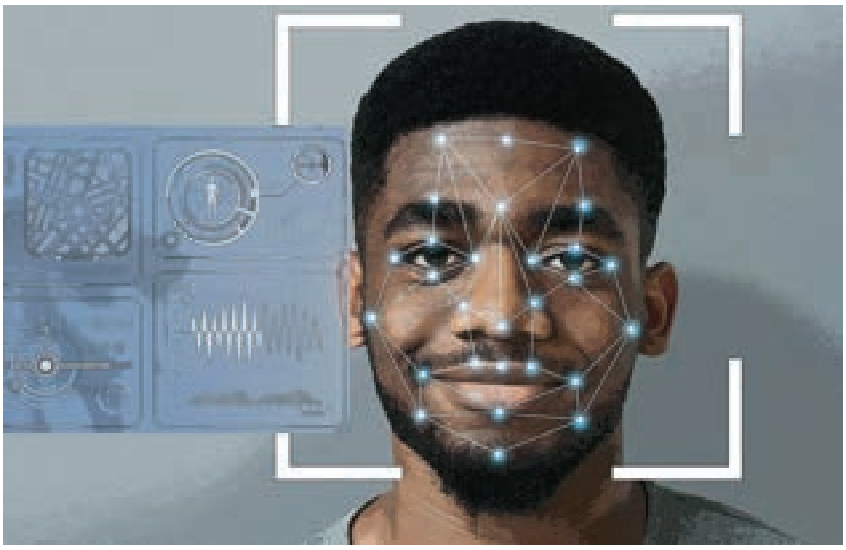

**Fig. 1.8:** *AI being used in facial detection and recognition systems (Players, 2020)*

b. **Internet of Things (IoT) integration**: IoT refers to a network of interconnected physical devices such as vehicles, appliances, and other objects that are embedded with sensors, software, and network connectivity, allowing them to collect and exchange data without human intervention. Robots are becoming an integral part of IoT, enabling them to collect and exchange data, optimise processes, and operate within interconnected systems like smart factories, smart homes, cyber-physical systems, smart cities, etc.


**Fig. 1.9:** *IoT in Agriculture*

c. **Augmented Reality (AR) and Virtual Reality (VR)**: AR and VR technologies are changing the narrative in various industries. Augmented reality overlays digital information onto the real world, enhancing user experiences by adding virtual elements to the physical environment. Virtual reality, on the other hand, immerses users in a completely digital environment, simulating real-life experiences through computer-generated environments. Both AR and VR are transforming fields such as manufacturing, healthcare, education, and entertainment by providing immersive and interactive experiences, improving training simulations, enhancing design processes, and enabling remote collaboration.

**Fig. 1.10:** *A Man using Virtual Reality (VR) Headsets (Amofa, 2023)*

As mentioned already, there are variations in research regarding each industrial revolution's precise start and end dates, reflecting differing interpretations of historical events and their impacts on society's evolution. Figure 1.11 shows a timeline of these revolutions.

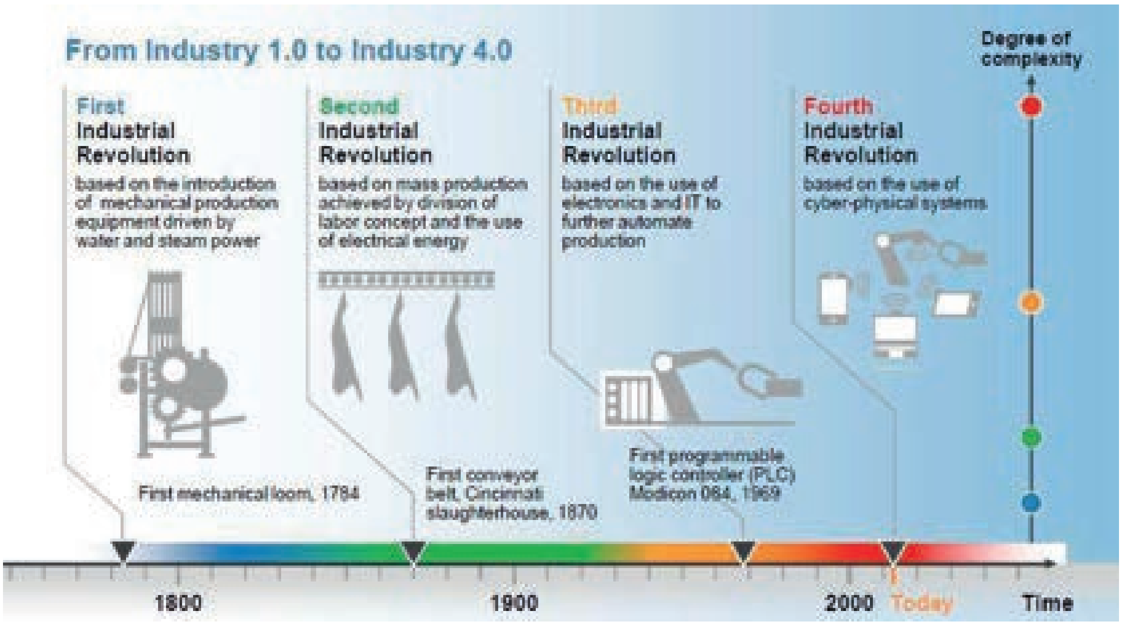


**Fig. 1.11:** *The Industrial Revolutions' Timeline (Rutkowska & Sulich, 2020)*

### Learning Tasks

Depending on the available time or resources, administer one or more of the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

1. Learners identify keywords unique to each industrial revolution and write them on flashcards with descriptions or definitions on the back.
2. Learners:

a. choose an industrial revolution of their interest and research additional significant advancements from that era not covered in the provided materials.

b. justify why these advancements were uniquely developed during that specific industrial revolution.

c. present their findings to the class, fostering a deeper understanding of the interconnectedness between historical events and technological advancements.

3. Learners structure their observations using a timeline to reflect the history of the Industrial Revolution and the features of the various transitions.

## Pedagogical Exemplars

The goal of this lesson is for all learners to describe the distinct features and advancements that characterise the transition from each of the industrial revolutions. Consider the following keynotes when administering the suggested pedagogical approaches in the curriculum:

1. Recognise and capitalise on the shared characteristics among students while also addressing their individual differences, including interests, readiness levels, and learning styles.
2. Offer multiple pathways for students to engage with the content. This could involve providing varying levels of detail, from basic concepts to in-depth explorations, to accommodate different learning needs. The key thing is that the learning outcomes set for the lesson are achieved among all learners.

3. **Experiential learning:** Learners engage in watching a short video(s) depicting the different industrial revolutions. They document keywords and personal observations and share them with the class, fostering active participation.
    a. While using this approach, to bring all learners up to speed, start off by introducing the key points of the industrial revolutions.
    b. Instead of generic observations, provide learners with a targeted viewing guide with questions. This will be helpful in scaffolding the activity and providing clarification on what learners are to look out for. The viewing guide may include the following questions:
        i. What are the distinct characteristics of machines in each industrial revolution?
        ii. Are there any keywords peculiar to each industrial revolution?
        iii. How did machines change how humans work in each revolution?
        iv. Did humans and machines work together, or did machines replace human roles?
    c. You can provide access to additional materials, such as summarised texts, articles, or visual aids, to deepen understanding and facilitate comprehensive exploration of the topic. Ensure that all students have opportunities to access the content in a way that best suits their learning preferences and abilities.
4. **Collaborative Learning**: Learners are made to sit in mixed-ability groups and discuss their observations on the peculiarities of each revolution and their transitions. Each group researches and classifies various machines under the identified industrial revolutions. Ask groups to structure their contributions using a timeline to reflect the history and features of the various transitions.
    a. While using this approach, consider learners' varying interests and abilities when forming mixed-ability groups.
    b. Also, encourage active participation from all learners by ensuring each group member has a role in the activity.
    c. Provide additional support or scaffolding for students who may struggle with the task. Provide clarification to learners who may need it.
    d. Allow flexibility in how students demonstrate their understanding, such as through verbal explanations or written responses.
    e. Provide feedback and reinforcement to reinforce learning and encourage continued engagement.

## Key Assessment

1. **Assessment Level 1:** List two key advancements from the Second Industrial Revolution.
2. **Assessment Level 1:** List two key advancements from the Fourth Industrial Revolution.
3. **Assessment Level 2:** Distinguish between machines of the first two Industrial Revolutions and robots that emerged in the Third Industrial Revolution.
4. **Assessment Level 3:** Consider the potential drawbacks alongside the advancements brought about by each Industrial Revolution. Discuss an example of such a drawback.
5. **Assessment Level 3:** How might the Fourth Industrial Revolution, with its emphasis on AI and data analysis, further transform the role of robots in industries?

**Conclusion**: By studying each revolution's distinct features, we have gained insights into the historical context of technological evolution, which laid the foundation of robots and their integration into various environments. Today, robots stand at the forefront of Industry 4.0, driven by advancements in AI, IoT, and AR/VR. Understanding this journey enriches our appreciation of robotics' role in shaping our past, present, and future.

## Theme or Focal Area: Interdependence of Humans and Robots — Impact on Organisational Performance Indicators

## Introduction

As humans and robots increasingly work together in 21st-century environments, it is essential to analyse how this interdependence affects organisational performance indicators. Four crucial indicators — price, quality, flexibility, and innovation — play a significant role in assessing the effectiveness and competitiveness of organisations. The focus of this content will delve into how the collaboration between humans and robots impacts these performance indicators in working environments.

## Organisational Performance Indicators Affected by Robot Integration

The following are the four key organisational performance indicators which are most likely to be affected when robots are integrated into 21st-century environments:

1. **Price:** Price refers to the cost at which goods or services are offered to customers. The interdependence of humans and robots influences pricing in the following ways:
    a. *Reduced production costs:* Robots can perform repetitive and labour-intensive tasks with high accuracy and speed, reducing production costs by minimising human labour requirements and human errors.
    b. *Economies of scale:* When robots are used in manufacturing, they can enable higher production volumes without a proportional increase in costs. This is known as economies of scale. By leveraging automation and robotics, manufacturers can produce goods in larger quantities, which can result in lower per-unit costs. These cost savings can be passed on to consumers through reduced prices.
    c. *Enhanced cost control:* With advanced data analysis and monitoring capabilities, robots contribute to improved cost control by identifying inefficiencies, reducing waste, and optimising resource utilisation.
    d. *Innovation and customisation:* The use of robots in manufacturing can enable greater innovation and customisation capabilities. Robots can be programmed and reconfigured to manage different tasks and product variations more efficiently. This flexibility allows manufacturers to offer a wider range of customised products to meet consumer preferences. While customisation may increase costs in some cases, it can also justify higher price points for unique or personalised products.
2. **Quality:** Quality represents the level of excellence or superiority of products or services. The interplay between humans and robots impacts quality in the following ways:
    a. *Consistency and precision:* Robots excel in consistently performing tasks with high precision, minimising errors, and variations in product quality, thereby enhancing overall quality control. However, for robots to achieve the required levels of precision, human expertise will be required to calibrate robot sensors, maintain mechanical parts and actuators, configure and programme robot functionalities, and much more.
    b. *Continuous improvement:* The collaboration between humans and robots allows for continuous improvement in quality through the analysis of data collected during production processes, leading to refined processes and higher product quality.
3. **Flexibility:** Flexibility refers to an organisation’s ability to adapt and respond quickly to changing market demands or customer requirements. The interdependence of humans and robots impacts flexibility in the following ways:
    a. *Task allocation:* Robots can manage repetitive or physically demanding tasks, freeing up human workers to focus on more complex, creative, and flexible activities, such as problem-solving and customer interaction.

b. *Reconfigurability:* Robots equipped with flexible programming and tooling capabilities can be easily reconfigured or reprogrammed to accommodate changes in production requirements or product variations, enhancing operational flexibility.
c. *Scalability:* The presence of robots allows organisations to scale their operations more efficiently by quickly adjusting production levels to meet changing market demands without incurring significant costs or delays.

4. **Innovation:** The act of one's own ingenuity and creativity in developing and implementing new ideas, processes, products, or services is referred to as innovation. The interdependence of humans and robots influences innovation in the following ways:
   a. *Enhanced research and development:* Robots can assist in research and development activities by performing tasks that require extensive data analysis, simulations, or testing, enabling humans to focus on creativity and innovation.
   b. *Collaborative problem-solving:* Humans and robots working together can leverage their unique strengths to tackle complex problems, combining human creativity, intuition, and adaptability with robot precision and computational capabilities.
   c. *Accelerated production of new technologies:* Robots can accelerate the production process of innovative technologies, allowing organisations to bring new products or services on to the market faster, gaining a competitive edge.

## Human Roles in Robot-Centred 21st-Century Working Environments

During all these achievements discussed above, it is key to note that humans are required significantly to achieve the performance indicators above. Below are some significant roles humans play in 21st-century environments where robots and humans co-exist

1. **Design and programming:** Humans play a crucial role in designing and programming robots to perform tasks with precision and consistency. This involves defining the specific requirements, parameters, and desired outcomes for the robot's operation. Human engineers and programmers create algorithms and code that govern the robot's behaviour, ensuring that it conducts tasks accurately and consistently.

2. **Calibration and configuration:** Humans calibrate and configure robots to operate within desired specifications. This includes setting up sensors, adjusting actuators, and fine-tuning control systems to ensure precise movements and reliable performance. Calibration helps eliminate any errors or deviations that may arise during robot operation, enabling more accurate and consistent results.

3. **Maintenance and upkeep:** Robots require regular maintenance and upkeep to sustain their precision and consistency. Human technicians are responsible for inspecting, cleaning, and repairing robots as needed. Maintenance activities include checking sensors, replacing worn-out components, and ensuring that the robot's mechanical and electrical systems are functioning optimally. By maintaining robots in good working conditions, humans contribute to their continued precision and consistency.

4. **Quality control and monitoring:** Humans play a vital role in quality control and monitoring processes to ensure that robots meet desired standards of precision and consistency. This involves conducting inspections, performing tests, and analysing data to assess the performance and output of robots. Humans may also oversee the robot's operations, monitoring its behaviour in real-time and intervening if any deviations or errors occur. This active supervision helps maintain precision and consistency throughout the robot's tasks.

5. **Continuous improvement and adaptation:** Humans are essential in improving and adapting robots. By analysing performance data and feedback, humans can identify areas for enhancement and refine the robot's programming and operation. Iterative processes, such as machine learning or algorithm updates, enable robots to learn from their experiences and improve their precision

and consistency over time. Human expertise and intervention guide these improvement efforts, ensuring that robots remain effective and reliable.

6. **Skill development and training:** The integration of robots in the workforce often necessitates new skills and knowledge for individuals to work effectively alongside these machines. This means that some people are needed to play the role of trainers, training others to supervise and collaborate effectively with robots in 21st-century working environments.

### Learning Tasks

Depending on the available time or resources, administer one or more of the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

1. **Robotics Era Performance Case Study:**

Learners

a. conduct a thorough performance analysis of at least one of the provided narratives below, which depict the transition from pre-robot to post-robot integration in a working environment.

b. examine and critique the selected narrative(s), focusing on key insights and observations.

c. present the analysis to the class, organising key observations into a comparative narrative, table and/or graph highlighting key differences between the two eras.

**Narrative 1 (Easier):**

In the pre-robot era of a maise-producing farm, people did most of the work by hand, like planting, watering, and harvesting. This made things expensive because it needed lots of workers and sometimes mistakes happened. Also, the quality of the maise could vary a lot because people did not always do things the same way.

But things changed when robots started helping on the farm, handling processes such as soil preparation, seed selection, planting, weed control, irrigation, fertilisation and harvesting with little supervision from humans. Robots could do repetitive tasks like planting and harvesting quickly and without mistakes. This made the whole farm production process cheaper because fewer workers were needed, and the robots were particularly good at what they did. Plus, the quality of the maise became more consistent because the robots did things the same way every time.

With robots, the farm became more flexible, too. Robots could do boring jobs, so people could focus on more interesting stuff like solving problems or producing new ideas. And if the farm needed to change what it was doing, the robots could easily be programmed to do something different.

**Narrative 2 (A Little Harder):**

In 2023, Mr. Kusi had a one-acre maise farm and employed a number of workers. In each quarter of the year, Mr. Kusi tasked his workers to handle soil preparation, seed selection, planting, weed control, irrigation, fertilisation and harvesting. Table 1.1 represents the data gathered in each quarter of the year. The **man hours per worker** attribute provides information on how many hours each worker was to work during the period. The **salary per worker** attribute represents the total salary paid to each worker during the quarter. The **cost of production** represents how much Mr. Kusi spent on buying seeds, fertilisers, weedicides and harvesting bags during the period. The **expected yield** represents how much yield in pounds (lbs) was expected from the one-acre maise farm during the period. The **marketable yield** represents how much quality yield, in pounds (lbs), was harvested and marketed. The **price per pound (lb)** displays the rate for selling each pound (lb) of the harvested produce.

**Table 1.1:**

| | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter |
|---|---|---|---|---|
| **Number of Workers** | 2 | 2 | 3 | 3 |
| **Man Hours per Human Worker (hrs)** | 720 | 720 | 720 | 720 |
| **Salary per worker (GHC)** | 1,200 | 1,200 | 1,300 | 1,350 |
| **Cost of Production (GHC)** | 10,800 | 10,350 | 10,700 | 10,200 |
| **Expected Yield (lbs.)** | 4.5 | 4.5 | 5 | 5 |
| **Marketable Yield (lbs.)** | 3.5 | 3.2 | 3.7 | 3.9 |
| **Price per lbs. (GHC)** | 4,500 | 4,600 | 4,500 | 4,800 |

That same year, Mrs. Nzoley also had a one-acre maise farm and employed some workers. In addition to her workers, she leased an agro-based robot from XYZ Technologies, paying a lease amount every quarter, adding up to her production cost. In each quarter of the year, Mrs. Nzoley tasked the leased robot to manage soil preparation, seed selection, planting, weed control, irrigation, fertilisation and harvesting. The human workers were also tasked to monitor the operations of the robot, gather, and analyse data on production activities and change the pre-programmed chips of the robot(s) depending on the task to be performed. Table 1.2 represents the data gathered in each quarter of the year.

**Table 1.2:**

| | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter |
|---|---|---|---|---|
| **Number of Workers** | 1 | 1 | 2 | 2 |
| **Man Hours per Human Worker (hrs)** | 360 | 360 | 360 | 360 |
| **Salary per worker (GHC)** | 900 | 900 | 1,000 | 1,000 |
| **Cost of Production (GHC)** | 8,200 | 8,100 | 8,000 | 8,100 |
| **Expected Yield (lbs.)** | 4.5 | 4.5 | 5 | 5 |
| **Marketable Yield (lbs.)** | 4.2 | 4.3 | 4.6 | 4.7 |
| **Price per lbs. (GHC)** | 4,500 | 4,600 | 4,500 | 4,800 |

The metrics provided in Table 1 and Table 2 give insights into both farmers' labour efficiency, production costs, yield expectations, and revenue generation throughout the year.

**2. Reflective Write-Up and Presentation:**

Learners

a. reflect on the positive impacts of robot integration on organisational performance indicators in 21st-century working environments.

b. select one or more performance indicators introduced in class and write down their understanding of the impact in their own words. Learners could, in addition, use any multimedia tool to create an illustrative presentation of their write-up.

c. share their write-up (and illustration) with at least three classmates and gather feedback.

d. document the feedback received and reflect on what new insights they gained from the feedback and what they learned from the perspectives shared by others.

## Pedagogical Exemplars

The goal of this lesson is for all learners to analyse how the four organisational performance indicators (price, quality, flexibility, and innovation) have been impacted by the interdependence of humans and robots in working environments. Consider the following keynotes when administering the suggested pedagogical approaches in the curriculum:

1. Offer tiered explanations for each performance indicator (price, quality, flexibility, innovation). For example,
   a. Start off by providing simplified explanations with clear examples (e.g., how robots reduce costs by minimising errors). This is to address the needs of learners approaching proficiency.
   b. Then, progress further by delving into concepts with technical details (e.g., discuss economies of scale and their impact on price).

2. **Problem-Based Learning:** Learners work in mixed-ability groups to do a comprehensive performance analysis of a narrative describing the pre-robot and post-robot integration in a working environment. Groups present their analysis for the class to comment on. The facilitator then summarises learners' presentations using a table comparing the two eras.
   a. Using this approach, consider creating groups with members having a mix of data analysis, communication, and presentation skills. This fosters collaboration and uses each student's strengths.
   b. Allow learners (groups) to choose the narrative (easier or harder) based on their comfort level with data analysis. However, after tackling the easier narrative, with some guidance, learners can be encouraged to try the harder one.
   c. Differentiate the comprehensive performance analysis task within the groups. Learners approaching proficiency may focus on simpler aspects of the task, whereas highly proficient learners may consider more complex aspects.
   d. For the more challenging narrative, you could ask highly proficient learners to focus on more complex tasks, such as calculating the cost reduction due to fewer workers and analysing the impact on farm profitability (considering robot leasing costs). They could also be tasked to analyse yield data (expected vs. marketable) and price per unit to calculate overall revenue for each farm and identify the impact of robots on efficiency and profit. Approaching proficiency or proficient learners may compare person-hours and salaries between the two farms, identifying labour cost differences. They can also focus on identifying changes in workload and product quality after robot integration.
   e. Allow flexibility in how students demonstrate their understanding. Some may simply create a comparative table highlighting key differences between pre-robot and post-robot eras. Others may develop a graph illustrating changes in cost, yield, or profit over time for both farms. More creative learners may design an infographic or short video summarising the analysis.
   f. Provide additional support or scaffolding for students who may struggle with the task. Provide clarification to learners who may need it. You could describe what the expected answers could look like.
   g. Provide feedback and reinforcement to reinforce learning and encourage continued engagement.

## Key Assessment

1. **Assessment Level 1:** How does robot flexibility contribute to an organisation's ability to adapt?

2. **Assessment Level 2:** Provide two examples of human roles crucial for robots to achieve performance indicators like price and quality.

3. **Assessment Level 3:** Analyse the potential benefits and drawbacks of increased robot integration on job availability in various industries.

4. **Assessment Level 3:** Consider a specific industry (e.g., healthcare, manufacturing) and discuss how human-robot collaboration might impact each of the four performance indicators mentioned.

5. **Assessment Level 4:** Imagine a future where robots seamlessly integrate into various aspects of society, not just the workplace. Explore the potential social, economic, and cultural implications of widespread human-robot collaboration. How might this collaboration redefine the nature of work, leisure, and human interaction? Consider potential challenges in areas like social inequality, human-robot trust, and the impact on human identity. Propose strategies to ensure that this future is designed for the benefit of all members of society.

**Conclusion:** The interdependence of humans and robots in working environments has a profound impact on organisational performance indicators. By leveraging the strengths of both humans and robots, organisations can achieve improved pricing strategies, higher quality standards, enhanced flexibility, and foster innovation. Understanding and harnessing this interdependence is crucial for organisations to thrive in today's dynamic and technologically advanced industrial landscape.

# WEEK 2

**Learning Indicator(s):** *Identify the economic and social benefits of using robots in 21st-century environments (workplaces, smartly built environments such as smart homes and smart cities, playgrounds, etc.) within the confines of accepted standards and ethics.*

## Theme or Focal Area: Economic and Social Benefits of Robots in 21st-Century Environments — Balancing Standards and Ethics

### Introduction

Robots have become increasingly prevalent in various 21st-century environments, contributing to economic and social benefits. However, it is crucial to consider these benefits within the context of accepted standards and ethics, known as Roboethics (Robot Ethics). This content will outline some essential economic and social benefits of using robots in different environments while also emphasising the importance of upholding ethical standards and inclusivity. By addressing these focal areas, learners will gain an understanding of the economic and social benefits of using robots in 21st-century environments while being mindful of accepted standards and ethics in robotics.

### Notable 21st-Century Environments that Integrate Robots

21st-century environments refer to modern contexts, settings, and conditions in which people live, work, and interact, characterised by advancements in technology. These environments encompass various aspects of life, including workplaces, educational institutions, urban spaces, and digital platforms. They are influenced by factors such as digitalisation, automation, interconnectedness, sustainability, diversity, and innovation.

1. **Smart homes:** Smart homes refer to residences equipped with interconnected devices and systems that automate and enhance various aspects of daily life, such as lighting, heating, security, and entertainment. Robots can be integrated into such environments, as they may help in achieving some level of automation.
2. **Smart cities:** They are urban areas that use advanced technologies and data-driven solutions to improve efficiency, sustainability, and overall quality of life for residents. These cities integrate various interconnected systems and infrastructure such as transportation, energy, communication, healthcare, and governance to optimise resource usage, enhance services and address the needs of citizens more effectively. Robots help in achieving these set objectives of smart cities
3. **Workplaces**: They encompass diverse environments where people conduct business, collaborate on projects, and perform tasks to achieve organisational goals. Robots are increasingly being integrated into these environments to facilitate the automation of processes.

**Fig. 2.1:** *A Collage of 21st-Century Environments*

## Significant Economic and Social Benefits Gained by Integrating Robots into 21st-Century Environments

As already witnessed in the previous lesson's case study learning task, the integration of robots into certain environments makes way for various benefits. The following are some significant economic and social benefits gained by integrating robots into 21st-century environments.

1. **Higher productivity:** Robots automate tasks, leading to increased productivity and efficiency in various industries. For example, in manufacturing, robots can automate repetitive tasks like assembly or packaging, allowing companies to produce goods at a faster rate with fewer errors.
2. **Job creation:** Despite concerns about automation replacing jobs, integrating robots creates new employment opportunities in specialised fields. For instance, skilled workers are needed to program robots, maintain their functionality, and supervise their operations. This leads to the development of a new workforce trained in robotics and automation technologies, contributing to job growth and economic advancement.
3. **Cost savings:** Automation reduces labour costs and minimises errors, leading to overall cost savings for businesses. For example, a company that automates its manufacturing line can reduce expenses related to labour, rework, and waste, improving profitability.
4. **Optimised resource management:** Robots optimise resource usage, minimising waste and enhancing sustainability. For instance, in agriculture, robotic systems can precisely apply water, fertilisers, and pesticides based on real-time data about soil moisture, nutrient levels, and crop health.
5. **Improved infrastructure:** Robots assist in infrastructure maintenance, prolonging lifespan and reducing long-term maintenance costs. For example, in construction, drones equipped with cameras and sensors can perform aerial surveys of bridges, buildings, and other structures to identify defects or potential hazards.

## Ethical Considerations (Roboethics)

Ethical guidelines, frameworks and standards play a critical role in ensuring that robots are developed, deployed, and used in a manner that upholds human values, respects individual rights, safeguards safety and privacy, promotes fairness and transparency and considers the broader societal implications.

These frameworks and standards help guide designers, engineers, and policymakers to make sure these technologies are used responsibly. For example, Isaac Asimov's "Three Laws of Robotics" and the IEEE's "Ethically Aligned Design" outline principles like being helpful, respecting people's independence, and being honest about what robots can and cannot do. There are also standards like ISO 13482 and ISO 31000 that help us make sure robots are safe and interact well with humans.

Different stakeholder groups, like governments, industries, and researchers, all have a role in ensuring robots are used well. Governments make rules to protect people's rights and safety while also encouraging new ideas. Industries need to follow these rules and think about ethics when they design and use robots. Researchers study how robots affect society and help make decisions about how to use them responsibly. By working together, these groups can make sure robots are helpful and safe for everyone.

By incorporating these ethical considerations, we can harness the benefits of robotics while minimising potential risks and aligning technological advancements with human well-being and societal values.

Here are some key ethical considerations and guidelines which are crucial when integrating robotics in 21st-century environments:

1. **Prioritise human safety:** Ensure that robots are designed and programmed to prioritise human well-being and safety, minimising the risk of harm, and incorporating fail-safe mechanisms. Simply put, make sure robots are made to look out for people's safety and do not do anything that could hurt them.
2. **Ensure transparency:** Require clear documentation of robot capabilities and responsibilities to promote accountability and transparency in development and deployment. That way, if something goes wrong, we know who is responsible.
3. **Protect privacy:** Establish protocols to safeguard privacy rights and securely manage sensitive data collected or accessed by robots. In other words, robots should be careful with our personal data, like secrets or private information. They should only use it in the right way and keep it safe.
4. **Promote fairness and non-discrimination:** Address biases in algorithms and ensure equal access to robotic technologies while eliminating potential reinforcement of social inequalities. Simply put, robots should not treat people differently because of things like how they look or where they are from. They should be fair to everyone and give everyone the same chances.
5. **Implement ethical decision-making:** Define principles for autonomous decision-making in robots, aligning with ethical values and respecting human autonomy while addressing complex ethical dilemmas. In other words, robots should make right and fair decisions, just like people do. They should think carefully before they do something and make sure it is the best choice.

### Learning Tasks

Depending on the available time or resources, administer one or more of the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

1. **Cost-Benefit Analysis:** Learners conduct a cost-benefit analysis for one or two of the top-ranked economic and social benefits gained by integrating robots into 21st-century environments. They should consider:

   a. The potential economic and social gains from robot integration.

b. Any potential drawbacks or ethical concerns associated with the chosen benefit.

c. How to mitigate these drawbacks while maximising the benefits.

2. **Debate:** Learners debate for or against the motion "Robots will create more jobs than they replace".

3. **Public Service Announcement (PSA) Creation:** Learners create a PSA raising awareness about the benefits and potential ethical concerns of robots in society. This can be done as a video, poster, or infographic.

4. **Ethical Dilemma Analysis:** Learners are presented with a complex ethical dilemma related to robot use in homes or workplaces (e.g., a robot caregiver prioritising efficiency over emotional well-being of an elderly person). They are to analyse the situation using the ethical frameworks and standards discussed in the lesson.

## Pedagogical Exemplars

The goal of this lesson is for all learners to identify the economic and social benefits of using robots in 21st-century environments within the confines of accepted standards and ethics. Consider the following keynotes when administering the suggested pedagogical approaches in the curriculum:

1. **Diamond Nine:** Each learner is allowed to list (at most) three perceived or researched economic and (at most) three social benefits these environments stand to benefit by integrating robots. Learners team up and work in groups of three to prioritise their (at most) nine benefits in order of most significant and share with class.
   a. Using this approach, you could start off by introducing learners to notable 21st century environments and explain some keywords related to the lesson. You could also mention one or more economic and social benefit of using robots in these environments.
   b. Encourage each learner to state down at most three (3) social benefits and three (3) economic benefits of using robots in any environment of their interest.
   c. Allow learners to form groups of three based on their selected environment to discuss their perceived or researched economic and social benefits of using robots in their selected environment of interest.
   d. Guide learner groups to rank their benefits and conduct cost-benefit analysis of their top-ranked benefits.
   e. Also, encourage learners to put down their top ranked benefits as a public service announcement or campaign which creates awareness about the benefits of using robots in their environment of interest.
   f. Try to find amicable ways of resolving disagreements in opinions among learner groups.

2. **Problem-Based Learning:** In mixed-ability, learners review ethical and standards documents, case studies and make personal ethical suggestions and elicit any ethical issues that apply to adopting and using robots in smart homes, smart cities, and workplaces. Learners share their thoughts with the class or other groups for comments.
   a. Using this approach, first introduce learners to the concept of roboethics. Stagger the lesson by first providing a simplified explanation of the concept and establishing its relevance. You can then progress to introducing various frameworks and standard documents that border on ensuring roboethics in different environments.
   b. Form mixed-ability groups by combining a number of the already formed groups of three. These groups can be formed based on learner social interest (e.g., social justice, human safety, law, and order, etc.).
   c. Depending on the abilities and interests of each group, provide each group with ethical frameworks, articles, documentaries, or standard documents to review and draw out

essential ethical considerations that are worth noting. These resources should be of varying degrees of detail to cater to the differing needs and preferences of learner groups.

d. Learner groups apply their researched and perceived roboethic summations to a given case study or motion of debate and present their thoughts.

## Key Assessment

1. **Assessment Level 1:** Identify two benefits of integrating robots into smart homes.
2. **Assessment Level 1:** List one way robots contribute to cost savings in workplaces.
3. **Assessment Level 2:** Provide an example of how ethical considerations like transparency can be applied in the development and deployment of robots.
4. **Assessment Level 3:** Analyse the potential economic benefits and drawbacks of widespread robot integration in the manufacturing sector.
5. **Assessment Level 3:** In this lesson you were introduced to ethical frameworks like "Isaac Asimov's Three Laws of Robotics" and "IEEE's Ethically Aligned Design." Research these frameworks and compare their approaches to ensuring ethical robot development and deployment.

**Conclusion**: As we have explored today, robots are becoming increasingly integrated into various aspects of our 21st-century lives. While they offer a wealth of economic and social benefits, from increased productivity and job creation to improved resource management and infrastructure maintenance, it is crucial to consider the ethical implications of this technological advancement.

Through ethical frameworks (Roboethics), we can ensure robots are developed and deployed responsibly, prioritising human safety, transparency, privacy, and fairness. By working together, governments, industries, and researchers can harness the power of robotics for good, ensuring robots remain helpful tools that complement human well-being and societal values.

# Section Review

In this section which covers a two-week period, we have seen how robots have become an integral part of most 21st-century environments. To understand their foundations required a visit to historical events - the Industrial Revolutions. The Industrial Revolutions, spanning from the 18th century to today, highlighted the evolution of technology and automation. Early revolutions focused on mechanisation and steam power, laying the groundwork for the true birth of robots in the Third Revolution with computers and processors. Today's Fourth Revolution integrates robots with AI and the Internet of Things, creating smart environments. As we have seen, this human-robot collaboration significantly impacts organisations. We saw how robots can reduce costs and improve quality control through precision, while humans ensure robots meet those standards in an ethical manner. Additionally, we were made to know that robots can be programmed to manage repetitive tasks, freeing humans for more creative and adaptable work. This interdependence allows organisations to be more flexible and innovative. This section also stressed on the need to ensure that robots are developed and deployed responsibly, prioritising safety, transparency, and fairness. This human-robot collaboration, guided by ethical principles, is key to success in the 21st century.

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# SECTION 2: ROBOTS AND SOCIETY 1

Strand: **Principles of Robotic Systems**

**Sub-Strand:** Robots and Society

**Learning Outcomes:**

1. *Assess various systems and classify whether they fall under robotic or non-robotic systems and outline the functions of the subsystems of robots.*
2. *Classify feedback and non-feedback loop systems and demonstrate the use of logic and loop diagrams in control systems design*

**Content Standards:**

1. Demonstrate knowledge and understanding of subsystems of robots and their functions.
2. Demonstrate knowledge of fundamental control principles in automation and robotics.

## INTRODUCTION AND SECTION SUMMARY

This section focuses on robots and how they operate. It will explore the key differences between robotic systems and non-robotic systems as well as uncover the essential building blocks that make robots work. Learners would be introduced to the interconnected subsystems like sensors, actuators, and control systems that allow robots to perceive their environment, make decisions, and perform tasks. This section will also look at robot control systems, differentiating between feedback and non-feedback loops. By the end, learners will be able to classify these systems and proficiently make use of logic and loop diagrams in designing robot control systems.

The weeks covered by the section are

**Week 3:**

1. Robots, Robotics Systems and Non-Robotic Systems
2. Subsystems of a Robot.

**Week 4:** Fundamentals of Control Principles in Automation and Robotics: Feedback and Non-Feedback Loop Systems

**Week 5:** Evaluating Logic and Loop Diagrams in Control Systems Design

## SUMMARY OF PEDAGOGICAL EXEMPLARS

This section employs a mix of engaging teaching strategies to equip learners with a foundational understanding of robots and control systems. Week 3 leverages Talk for Learning techniques to stimulate discussions and activate prior knowledge about robots and their subsystems. Learners will participate in Think-Pair-Share activities and interactive discussions to solidify their understanding. Additionally, experiential learning through documentaries and simulated robot manipulation will allow learners to observe concepts firsthand. Week 4 focuses on control systems. Questioning techniques and problem-based learning will guide students in defining and exploring feedback and non-feedback loop systems. Learners will work in mixed-ability groups to research and present their findings, fostering collaboration and critical thinking. Week 5 uses problem-based learning again, introducing learners to logic and loop diagrams used in control system design. By drawing and sharing diagrams, learners will solidify their understanding and receive constructive feedback from peers and instructors. Instructors of this section are encouraged to vary activity difficulty, group formation, and project options to cater to learner readiness, interests, and learning styles. Instructors should scaffold tasks and provide differentiated rubrics to maximise engagement and learning for all.

## ASSESSMENT SUMMARY

Following each thematic area in this section, assessments gauge student learning. These come in two forms: learning tasks and key assessments. Learning tasks, primarily formative, focus on solidifying understanding and acquiring new knowledge or skills. Facilitators guide these activities to enhance the learning process. In contrast, key assessments, typically summative, evaluate student mastery after instruction. These are often given as homework, mid-semester exams or end-of-semester exams, usually done outside the class. Instructors have the flexibility to choose the assessment types that best suit their learners and learning objectives. However, it is advisable that instructors at least guide learners to do one of the learning tasks.

# WEEK 3

**Learning Indicator(s):**

1. *Describe robots and identify the differences between robotic and non-robotic systems.*
2. *Describe the attributes and functionalities of a robot's subsystems and how they interconnect*

## Theme or Focal Area 1: Robots, Robotics Systems and Non-Robotic Systems

### Introduction

This lesson focuses on robots, robotic systems, and non-robotic systems, describing their key characteristics and functions. We examine the distinctions between robots and robotic systems as well as robotic systems and non-robotic systems, alongside their roles and applications in different environments.

### What is a Robot?

The term Robot was coined by Czech novelist Karel Čapek in 1920 and introduced in his play Rossum's Universal Robots (Čapek, 1920). In Czech, the word "robot" translates to "worker" or "servant." In today's world we describe a robot as a machine designed to perform tasks automatically or with minimal human intervention. Typically, robots are programmable devices that can conduct a variety of actions or movements based on predefined instructions.

Robots are typically composed of mechanical, electrical, and computational components that work together to enable its functionalities. These components are clearly the results of advancements from the first, second and third industrial revolutions, respectively. Currently, many robots incorporate technological advancements from the Fourth Industrial Revolution, including artificial intelligence and connectivity.

### Key Features of Robots

The following are the distinctive features of Robots:

1. **Autonomy**: Robots can operate independently or semi-independently, executing tasks without continuous human intervention. This is the evidence of some intelligence.
2. **Programmability**: Robots can be programmed to perform a wide range of tasks, allowing flexibility and adaptability in their functions.
3. **Sensing and Perception**: Robots are equipped with sensors to perceive their environment, enabling them to gather information and make decisions based on their surroundings.
4. **Mobility**: Many robots can move or manipulate objects in their environment, either through locomotion or manipulation mechanisms.
5. **Interactivity**: Robots often interact with humans and/or their environment in various ways. They can receive input or commands from humans and/or their environment through interfaces such as touch screens, voice recognition, or gesture recognition. They can also provide output or feedback through displays, speech, or other forms of communication.

## What is a Robotic System?

It is common for people to use the terms "robots" and "robotic systems" interchangeably, especially in casual conversation or general discussion. However, technically speaking, there is a distinction between the two.

A robotic system is a more complex arrangement designed to achieve specific objectives efficiently by integrating robots with additional elements to perform interconnected tasks or functions. In other words, Robotic systems are not only made up of single robots but also include additional components such as controllers, communication interfaces, software systems and multiple robots working together or in coordination with other external systems.

Robotic systems inherently have all the distinctive features of robots in addition to the features of the systems they integrate.

Examples of Robotic Systems integrated in some environments include the following:

1. **Manufacturing industry:** Robotic arms and automated assembly lines are extensively used in manufacturing plants to perform tasks such as welding, painting, assembly, and packaging. These robotic systems may consist of robotic arms, conveyor belts, sensors, controllers, communication modules, etc.
2. **Healthcare facilities:** Surgical robots assist surgeons in performing minimally invasive surgeries with greater precision and control. They can also automate repetitive tasks like medication dispensing, sterilisation, and patient transportation, improving patient outcomes and reducing healthcare worker strain. The automated Medication Dispensers may incorporate robotic mechanisms and medication management software for accurate dosing and dispensing. Also, the Surgical Robotic Systems may integrate robotic arms, end-effectors, cameras, a database of approved surgical methods, artificial intelligence models and control consoles for precise surgical procedures.
3. **Agriculture:** Agricultural robotic systems, such as Precision Farm Drones and autonomous tractors, help farmers monitor crops, apply fertilisers and pesticides, and harvest produce. These robotic systems increase efficiency, optimise resource usage, and enable precision agriculture practices for higher yields and reduced environmental impact. The Precision Farm Drones are usually equipped with cameras, sensors, GPS modules, and communication systems. Also, the autonomous tractors integrate GPS guidance systems, sensors, actuators, communication systems and controllers for automated farming tasks.
4. **Transportation:** Autonomous vehicles and drones are revolutionising transportation by providing safer, more efficient, and environmentally friendly mobility solutions. Robotic systems in transportation play roles in tasks such as delivery, surveillance, mapping, and maintenance. These autonomous vehicles would usually integrate the following Incorporate sensors (e.g., LiDAR, cameras), GPS receivers, actuators, communication modules, access to real-time traffic information and onboard computers for self-driving capabilities.

## What is a Non-Robotic System?

Non-robotic systems are systems which make use of human effort or mechanical machinery, or some automated system without the advanced capabilities of robots. They may have some of the features of robots, such as autonomy, sensing, and decision-making but not all the combined features of robots are present. They are typically designed for specific purposes and have limited interaction with the environment.

Examples of non-robotic systems include:

1. **Non-robotic automated systems:** These systems perform pre-programmed tasks but lack the adaptability and autonomy associated with robotic systems. A typical example of such

automated systems is the Automated Teller Machine (ATM). While ATMs automate certain banking transactions such as cash withdrawals, deposits, and balance inquiries, they do not incorporate all the features of robots. They lack robotic features such as autonomy, decision-making, or sensing. Other examples of non-robotic automated systems include vending machines, automatic doors, automatic conveyor belt systems, automatic car washers, self-service kiosks, etc.

2. **Mechanised systems:** Mechanised systems involve the use of machinery or mechanical devices to aid in specific tasks. They are typically controlled by human operators and do not possess the autonomous decision-making capabilities found in robotic systems. Some examples include vehicles, lawnmowers, combine harvesters, escalators, etc.
3. **Computerised systems:** Computerised systems are not necessarily considered robotic systems because they lack physical manipulation capabilities and autonomy, which are defining characteristics of robots. While computerised systems may automate certain processes or tasks using software and electronic controls, they do not typically involve physical actuators or robotic arms to interact with the environment. Instead, computerised systems rely on algorithms, sensors, and digital interfaces to execute predefined instructions or commands. Some examples of computerised systems, which are non-robotic systems, include Traffic Light Control Systems, Calculators, chatbots, web crawlers, Point of Sale (PoS) Systems, Home Security Systems, Automated Inventory management Systems, etc.
4. **Control systems:** Control systems are not considered robotic systems because they primarily focus on regulating and coordinating the operation of mechanical or electronic components without direct physical manipulation of the environment. While control systems may automate processes and provide feedback mechanisms to adjust parameters based on predefined criteria, they typically do not involve the integration of robotic actuators or manipulators for interacting with objects or performing tasks autonomously. Examples include Heating, Ventilation and Air Conditioning (HVAC) Systems, Industrial Process Control Systems, Water Level Control Systems, Aircraft Autopilot Systems, Speed Control Systems, etc.

### Learning Tasks

Depending on the available time or resources, administer one or more of the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

1. **Design Your Dream Robot:**
   Learners design their dream robot using readily available materials such as pen, pencil, paper, cardboard, etc. They are to label the parts of their designed robot and add a description on a separate sheet explaining what their robot does.
2. **Robotic or Not? Sorting Challenge**:
   Learners sort out pictures and/or descriptions of various systems as either robotic systems or otherwise. In addition, they provide justifiable reasons for categorising these systems as such.

## Pedagogical Exemplars

The goal of this lesson is for all learners to describe robots and identify the differences between robotic and non-robotic systems. Consider the following keynotes when administering the suggested pedagogical approaches in the curriculum:

1. **Initiating Talk for Learning:** Discuss what robotic systems are, emphasising their ability to provide intelligent services and interact with their environment. Review and critically analyse different encounters with systems that learners may have considered as robotic systems.

a. Bearing in mind that this may be the very first real lesson that learners may touch on the fundamentals of robotics, use a KWL approach to interactively explore what learners already know (K), want (W) to know, and learn (L) about this subject.
b. **K (Know):** Use simple prompts like "Have you ever seen a robot in a movie or cartoon?" or "Can you think of any machines that help people with tasks?".
c. Encourage them to ask questions about robots using prompts like "What can robots do?" or "How do robots work?". List these questions and address some of them briefly, piquing their curiosity for the lesson. You can tabulate their responses.
d. **W (Want to Know):** Briefly introduce the concept of robots and robotic systems, highlighting their ability to perform tasks and interact with their environment.
e. **L (Learn):** To get everyone on board, you can start off the class by focusing on basic definitions and clear distinctions between the 3 categories (robots, robotic systems, and non-robotic systems).
f. Progress to further describe the key features of these categories and provide some examples. Ensure that the examples provided for each category are relatable to learners and easy to understand. This will enable them to readily comprehend why these examples are classified under each of the categories.
g. For advanced learners, consider delving deeper into how technological advancements such as AI and connectivity have impacted the functions of robots and robotic systems.

2. **Talk for Learning:** Learners Think-Pair-Share observed characteristics of given systems and classify the systems as robotic or non-robotic systems. Using a think-pair-share approach, learners are given a few minutes to individually classify these examples by noting them in their books, then pair with any of their colleagues and share their justification for their classification. The pair then share their collective submissions and resolve their differences, if any, calling on the facilitator where need be. The facilitator finally asks various teams to share their joint classifications and justifications. Consider the following when using this learning approach.
   a. Address the identified needs of learners of different readiness, interest and learning profiles.
   b. For learners who are approaching proficiency, Use very simple and clear examples with pictures or real-life objects for classification. Examples could include a toy car (non-robotic), a robotic vacuum cleaner (robotic), or a remote control (non-robotic).
   c. For proficient and highly proficient learners, present them with a challenging set of examples (pictures and descriptions of systems) that may have some features of robots but not all (e.g., automated irrigation system, temperature control system, autonomous drone).
   d. Provide ample time for individual thinking before pairing up.
   e. Encourage learners to explain their reasoning in simple terms during the sharing phase. Allow flexibility in how students demonstrate their understanding, such as through verbal explanations or written responses.
   f. Go round the class and offer guidance where needed. Ask clarifying questions to promote deeper discussion within pairs. Provide feedback and reinforcement to reinforce learning and encourage continued engagement.
   g. Try to find amicable ways of resolving disagreements in opinions among learners.

## Key Assessment

1. **Assessment Level 1:** List two key features of robots.
2. **Assessment Level 2:** Give an example of a non-robotic system found in everyday life.
3. **Assessment Level 3:** Explain the difference between a robot and a robotic system.
4. **Assessment Level 2:** Describe two features a self-driving car (robotic system) might have that a regular car (non-robotic system) might not.

5. **Assessment Level 3:** Imagine a future where robots are going to be used for trash collection in your community. Come out with a pictorial design of this robot. Label it and provide a justification for each of its connected parts.

**Conclusion**: The lesson explored the world of automation, differentiating robots, robotic systems, and non-robotic systems. Robots are programmable machines, while robotic systems integrate robots with other elements for complex tasks (e.g., factory assembly lines). Non-robotic systems like ATMs may automate tasks but lack a robot's full capabilities. We see these systems in various fields, from manufacturing and healthcare to agriculture and transportation.

## Theme or Focal Area 2: Subsystems of a Robot

### Introduction

Robots rely on interconnected subsystems for autonomy and task execution. This section explores key components such as sensing, actuation, control, and power systems. Knowing these subsystems helps one to understand how robots perceive their environment, make decisions, and perform physical actions.

### Subsystems of a Robot

Robots encompass various subsystems that enable their autonomy and task performance. These subsystems work together in a coordinated manner to enable the robot to perform tasks and interact with the environment. After the robot has been powered using the **power subsystem**, the **sensing subsystem** perceives the environment, providing feedback to the **control subsystem**. The control subsystem processes the sensor data, makes decisions, and generates commands for the **actuating subsystem**. The actuating subsystem then actuates **effectors** to perform physical actions, allowing the robot to interact with objects and the surrounding environment. Effectors are end tools attached to actuators. Examples of effectors include grippers, end-of-arm tooling (EOAT), vacuum suction cups, cutting tools, welding torches, spray nozzles, dispensing nozzles, etc.

This continuous loop of sensing, processing, and actuation facilitates the robot's functionality and enables it to complete tasks autonomously or under human guidance. By integrating these subsystems and ensuring their proper coordination, robots can adapt to varying conditions, navigate environments, manipulate objects, and perform complex tasks, enhancing their usefulness across various industries and applications.

The main subsystems of robots are described in detail below:

1. **Sensing subsystem:** Like the sensory organs of the human body (such as eyes, ears, nose, and skin), the sensing subsystem of a robot perceives and collects information about the environment. A sensor is a device that detects a change in the environment and sends a signal to the processor for further action. Sensors such as cameras, lidar, proximity sensors, and touch sensors provide input that helps robots make informed decisions based on the data they gather.
2. **Control subsystem:** Like the nervous system in humans, the control subsystem processes sensory information, makes decisions, and coordinates the actions of the robot's components. The control system governs the overall operation of the robot. It includes hardware and software components responsible for processing sensor data, generating control signals for the actuation system, and coordinating the robot's actions. The control system enables robots to make decisions and execute tasks based on their programmed instructions. It usually consists of a processor and channels through which it transmits data or instructions to other components or subsystems.
3. **Actuation subsystem:** Comparable to the muscular system in humans, the actuating subsystem of a robot generates physical movements or actions based on commands from the control

system. The actuation system provides robots with the capability to physically interact with the environment. It comprises motors, servos, hydraulics, or other mechanisms that generate motion and enable robots to manipulate objects, navigate their surroundings, or perform specific tasks.

4. **Power subsystem:** Resembling the cardiovascular system in humans, the power subsystem provides energy to the other sub-systems of the robot, enabling them to function and perform tasks. It may consist of batteries, fuel cells, or other power sources, along with the necessary circuits and distribution mechanisms to ensure the robot's proper functioning. The power sub-systems supply electrical energy to the robot's actuators, sensors, and controllers, ensuring their proper functioning. They may also include mechanisms for recharging or replenishing energy sources.

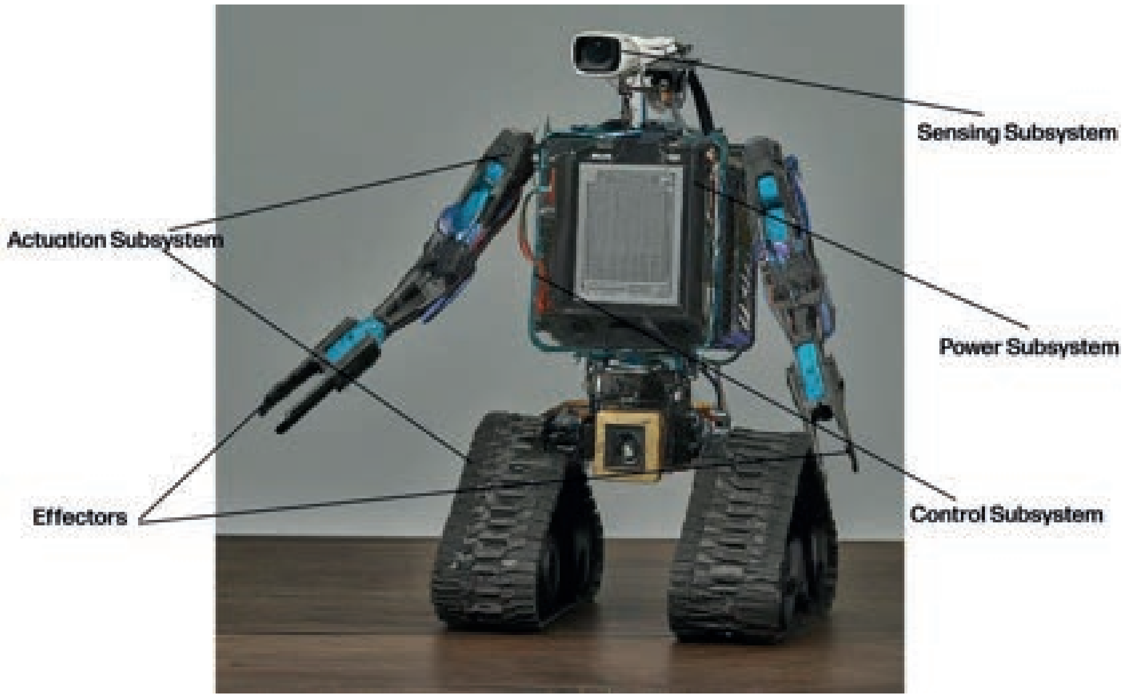



**Fig. 3.1:** *The subsystems of a robot*

## Learning Tasks

Depending on the available time or resources, administer the following learning task to help learners reinforce understanding and acquire new knowledge or skills.

1. **Matching Keywords to Meanings:**
   Learners match a random set of keywords representing robot subsystems to a set of descriptions of subsystem functions.

2. **Interactive Simulation and Troubleshooting:**
   Using a robot simulation program that allows learners to manipulate and interact with a virtual robot, learners manipulate a simulated robot and observe the effects on its functionality when they "disable" each subsystem. They observe and troubleshoot the malfunctions caused by disabling each subsystem.

3. **Robot Vacuum Cleaner – Subsystems in Action:**
   Learners
   a. carefully examine the provided technical description of a robot vacuum cleaner in Fig. 3.2 and classify each its labelled parts under the robot's main subsystems (sensing, control, actuation, power)

b. provide justification for each category by briefly explaining why it belongs to that specific subsystem.

c. present their results using at least of the following methods:

   i. Chart/Table: Fill out a chart or table with columns for "Part Name," "Subsystem," and "Justification."

   ii. Annotated List: Create a list of parts with annotations beside each one, specifying its subsystem and justification.

   iii. Mind Map: Develop a mind map where the central theme is "Robot Vacuum Cleaner Subsystems." Branch out from the centre, listing each subsystem and its corresponding parts with justifications.

   iv. Presentation: create a short presentation explaining the classification of parts and the role of each subsystem in the robot vacuum cleaner's operation.


**Fig. 3.2:** *Parts of a Robotic Vacuum Cleaner*

## Pedagogical Exemplars

The goal of this lesson is for all learners to describe the attributes and functionalities of a robot's subsystems and how they interconnect. Consider the following keynotes when administering the suggested pedagogical approaches in the curriculum:

1. **Talk for learning:** Through questioning, initiate a session with an interactive talk with learners on the sub-systems of robots and how they are interconnected. Structure thoughts of learners using concept maps.
   a. When using this approach, your questioning technique should range from asking some basic level open-ended questions in more straightforward language, such as "What does a robot sensor do?". Then, you could progress to questions that challenge advanced learners with higher order thinking questions, such as "How can these combinations of sensors and actuators be used to create robots for different tasks?". This hopefully is to set the stage for further interaction.
   b. You can progress further on the subsystems of a robot by doing the following:
      i. Focus on introducing the main subsystems (sensing, control, actuation, power) with simple analogies (sensing = sensory organs, control = nervous system, actuation = muscular system, power = cardiovascular system).
      ii. Use clear visuals and diagrams to represent each subsystem and its function.
      iii. Provide real-world examples of robots with these subsystems (e.g., vacuum robot cleaner - sensing = dirt sensors, control = navigation program, actuation = wheels and brushes, power = battery).
      iv. Go deeper into the functionalities of each subsystem. Explain how different types of sensors (cameras, LiDAR) work and provide specific examples of their use in robots.
      v. Introduce the concept of effectors as tools attached to actuators.
      vi. Discuss different power sources (batteries, fuel cells) and their advantages and disadvantages for robots.
   c. When structuring the thoughts of learners using concept maps you could provide pre-made concept maps with some key terms filled in for beginners while you challenge advanced learners to create their own complete concept map, showing the relationships between all robot subsystems.

2. **Experiential learning:** After identifying the various subsystems, learners work in groups using either a simulated robot, a real working robot or a robot product description from a datasheet. To help with their research on the role and significance of the various subsystems, they detach or disconnect the subsystems (in no particular order), one after the other, from the (simulated) robot while documenting and sharing their observed effects with the class. In cases where datasheets or robot product technical descriptions are used, they can read the functions of the parts and document which subsystem they belong to, as well as what may occur when those parts are taken off from the robot or malfunction.
   a. Using this approach, should there be more than one resource available (simulated robot, real working robot or robot product description from a datasheet), learner groups should be allowed to pick resources that match their interest, readiness, or learning profiles. Provide some guidance to help learners achieve learning outcomes. Be mindful of the level of difficulty in using each resource. For example, some datasheets could be simplified with clear diagrams and concise explanations, whereas others may be more complex with technical specifications, requiring further research.
   b. Consider creating mixed-ability groups to encourage collaboration and knowledge sharing between advanced and beginner learners.

c. Encourage active participation from all learners by ensuring each group member has a role in the activity. You can suggest roles members can play. These roles can include researchers, facilitators, analysts, recorders or secretaries, presenters, timekeepers, etc.

3. Provide access to diverse resources to cater to the varying preferences of learners. These resources may include videos, images, technical datasheets, podcasts, and other multimedia formats.
4. Ensure that all students have opportunities to access the content in a way that best suits their learning preferences and abilities.

## Key Assessment

1. **Assessment Level 1:** List the four main subsystems that robots rely on for autonomy and task execution.
2. **Assessment Level 1:** Identify one real-world example of an effector used by robots.
3. **Assessment Level 2:** Describe the relationship between the sensing subsystem and the actuation subsystem.
4. **Assessment Level 2:** Compare and contrast the power subsystem with a similar system in the human body.
5. **Assessment Level 3:** A robot is not functioning properly. It can sense its environment but cannot move. Based on your understanding of robot subsystems, which subsystem is most likely malfunctioning? Explain your reasoning.
6. **Assessment Level 4:** Apply the four subsystems to design a robot for a specific task (e.g., planting cocoa in your district's plantation). Explain how each of the four main subsystems would be crucial for its operation. Consider the specific environment and challenges the robot might face.

**Conclusion:** Robots function like well-coordinated orchestras. Just as instruments work together to create music, a robot's sensing, control, actuation, and power subsystems work in unison. Sensors gather information, the control system processes it, actuation generates movement, and power keeps everything running. This seamless interplay allows robots to perceive their surroundings, make decisions, and perform tasks, making them valuable tools across various fields.

# WEEK 4

**Learning Indicator(s):** *Contrast non-feedback loop systems and feedback loop systems.*

## Theme or Focal Area: Fundamentals of Control Principles in Automation and Robotics - Feedback and Non-Feedback Loop Systems

## Introduction

This week's lesson focuses on the fundamental concepts of feedback and non-feedback loop systems. Control systems are essential in regulating processes and ensuring desired outcomes in the functioning of robots. This section will focus on the two main types of control systems, feedback, and non-feedback loop systems, and how to draw diagrams to understand them better. By the end of this session, learners will be able to classify feedback and non-feedback loop systems effectively. In addition, learners will learn how to design and analyse control systems using logic and loop diagrams.

## Feedback Loop Systems

Feedback loop systems, also known as closed-loop systems, are control systems that incorporate a feedback mechanism to continuously monitor and adjust output based on a comparison with a desired value or reference input. In feedback loop systems, the output is fed back and compared with the desired value, and any differences or errors are used to generate a corrective action to regulate and maintain the output at a desired level.

### Key characteristics of feedback loop systems

Feedback loop systems have the following key characteristics:

1. **Continuous monitoring:** Feedback loop systems continuously monitor the output to compare it with a desired value or reference input.
2. **Error detection:** These systems detect errors or deviations between the system output for a given reference input and the desired output value for the same reference input.
3. **Adjustment and error correction:** Feedback loop systems generate corrective actions or adjustments based on the detected errors or deviations to regulate and maintain the output at desired levels. Systems that can dynamically adjust their behaviour based on feedback, allowing for self-correction and adaptation, are known as Self-correcting Systems.

### Components of feedback loop systems

Feedback loop systems have the following key components:

1. **Reference Input (Input):** The reference input is a signal intended to drive a desired output value or set point that the feedback loop system aims to achieve. It is the input deliberately channelled through the system targeting a specific system's performance. The controller compares the actual output with an ideal expected output with respect to the reference input and measured feedback(error) to generate the control signal.
2. **Error Signal:** The error signal is the difference between the reference input and the feedback information. It represents the deviation or error between the desired and actual system performance. The error signal serves as the basis for the controller to generate the appropriate control action
3. **Controller (Control Element):** The controller is the core component of the feedback loop system. It receives information from the sensor and compares it to the desired output value with

reference to the reference input. Based on this comparison, the controller generates a control signal or action that is sent to the actuator to adjust the plant's behaviour.

4. **Control Signal (Manipulating Variable):** The control signal is generated by the controller based on the comparison between the desired value and the feedback information. It represents the corrective action needed to regulate or adjust the plant's behaviour. The control signal is sent to the actuator to effect the necessary changes.
5. **Actuator:** The actuator is responsible for translating the control signal from the controller into physical action or manipulation. It could be a motor, a valve, a heating element, or any device that can modify the plant's state or behaviour.
6. **Feedback Signal/Path:** The feedback signal/path feeds the output of the actuator back to the controller. It provides information on the actual performance or output of the plant to compare with the desired value with respect to reference input. This feedback enables the controller to adjust and regulate the system.

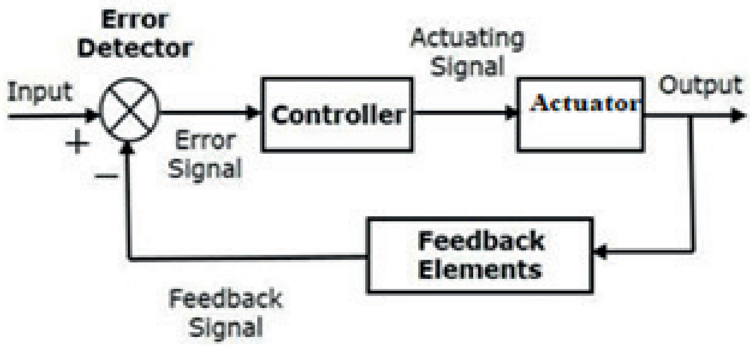



**Fig. 4.1:** *The structure of feedback loop systems (Chandni et al, 2017)*

The diagram above illustrates a closed-loop feedback system. The reference input sets the desired output for the system. The sensor plays a critical role by continuously measuring the system's actual output. This measured value is fed back to the controller. The controller compares the actual output (feedback signal) with the desired output (reference input) to calculate the error signal. This error signal represents the difference between what the system is doing and what it is supposed to be doing. Based on this error, the controller generates a control signal that is sent to the actuator. The actuator translates this control signal into physical action, adjusting the system's behaviour to reduce the error and bring the actual output closer to the desired output. This continuous cycle of measurement, comparison, adjustment, and measurement again ensures the system maintains the desired performance. By utilising feedback loops, systems can achieve stability, accuracy, and regulation of the desired output.

**Real-world example:**

Imagine a home heating system with a thermostat. The desired room temperature (reference input) is set on the thermostat. A sensor (usually a thermometer) measures the actual room temperature (feedback signal). The controller in the thermostat compares the desired temperature with the measured temperature and calculates the error. If the room is too cold (negative error), the controller sends a signal to the actuator (furnace) to turn on and heat the room. The sensor continues to monitor the temperature, and the cycle repeats until the desired temperature is reached

**Fig. 4.2:** *A Heating System with a thermostat*

## Non-Feedback Loop Systems

Non-feedback loop systems, also known as open-loop systems, are control systems where the output does not influence or affect the control action. In these systems, the control action or output is determined solely based on the input or pre-determined instructions without actively monitoring the output. Non-feedback loop systems operate in a one-way fashion, where the output is not fed back for comparison or adjustment. Examples include electric bulbs, non-smart televisions, traffic light systems, etc.

### Key characteristics of non-feedback loop Systems:

The following are the key characteristics of non-feedback loop systems:

1. **One-way flow:** Non-feedback loop systems operate in a one-way flow, where the output is determined solely by the input or pre-determined instructions.
2. **Lack of self-correction:** These systems do not actively monitor or adjust the output based on feedback or error detection.
3. **Fixed response:** The response of non-feedback loop systems is predetermined and does not change based on the output or external factors.
4. **Simple implementation:** Non-feedback loop systems are often simpler to design and implement compared to feedback loop systems.

### Components of non-feedback loop systems

The following are some key components of non-feedback loop systems:

1. **Input:** The input is the signal or information that is provided to the system to initiate a specific action or operation. It can be a predefined instruction, a set of parameters, or any other input data required for the system to function.

2. **Controller:** The controller is responsible for processing the input and generating the control action based on the predefined instructions. It determines the behaviour of the system and how it responds to the input. The controller can be implemented through various means, such as electronic circuits, software algorithms, or mechanical mechanisms.
3. **Actuators:** Actuators are the components that conduct the physical actions or operations as directed by the controller. They receive the control signals from the controller and translate them into mechanical movements, electrical signals, or any other form of energy required to perform the desired action.
4. **Output:** The output is the result or outcome of the system's operation based on the input and the control action. It can be in the form of a physical movement, a generated signal, a specific output value, or any other output characteristic defined by the system.

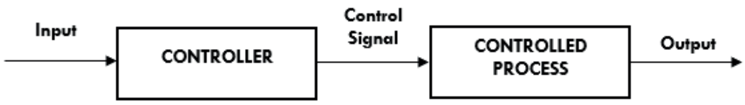



**Fig. 4.3:** *The structure of a non-feedback loop system (Chandni et al, 2017)*

Non-feedback loop systems are commonly found in applications where the output requirements are well-defined, and there is no need for continuous monitoring or adjustments based on feedback.

## Real-world example: Pop-Up Toaster

A pop-up toaster is a classic example of a non-feedback loop system. Here is a breakdown of its components and operation:

1. **Input:** You place bread slices into the toaster (providing the initial input).
2. **Controller:** The toaster has a built-in timer or a pre-determined heating element setting (acting as the controller). This determines the toasting duration or level of heat applied.
3. **Actuator:** The heating elements inside the toaster function as the actuator. They receive the "on" signal from the controller and generate heat.
4. **Output:** The toasted bread (slightly browned and warm) is the final output.

A pop-up toaster is a typical example of a non-feedback loop system because the desired outcome is well-defined: toasting bread to a predetermined level of crispness. There is no need for the toaster to constantly monitor the bread's temperature and adjust the heating based on feedback. The timer or fixed heating element setting ensures consistent results (though slight variations might occur due to bread type or environmental factors).

**Fig. 4.4:** *A Pop-Up Toaster (Gemini, 2024)*

**LEARNING TASK**

Depending on the available time or resources, administer the following learning task to help learners reinforce understanding and acquire new knowledge or skills.

1. **Design Challenge - Build Your Own System:**

   Learners

   a. review the key characteristics of feedback and non-feedback loop systems.

   b. select one of the following real-world scenarios that require a control system.

      i. Automatically watering a potted plant

      ii. Automatically maintaining water temperature in a fish tank

      iii. Automatically regulating room temperature in an office space

      iv. Thoroughly blending powdery ingredients

   c. identify if their selected scenario will require a feedback or non-feedback control system and provide justification.

   d. design their selected control system to address the scenario. The design could be as simple as a labelled block diagram or done with simple materials (cardboard, straws, etc.) or both. Learners may incorporate additional features into their design, such as adjustable settings or automatic shut-off mechanisms.

   e. present their design to the class; explaining how it functions and provide a justification for it being a feedback or non-feedback loop control system.

## Pedagogical Exemplars

The goal of this lesson is for all learners to contrast non-feedback loop systems and feedback loop systems. Consider the following keynotes when administering the suggested pedagogical approaches in the curriculum:

1. Stagger the instruction level of difficulty, starting first from a basic level, through intermediate to an advanced level to cater to the varying needs of learners. You could adopt the following approach:
   a. **Basic**: Provide a simplified explanation of feedback and non-feedback loops, focusing on core concepts and real-world examples like the heating system and toaster. Use clear and concise language with minimal technical jargon.
   b. **Intermediate**: Expand on the basic explanation by introducing the terminology associated with each system (reference input, error signal, controller, etc.). Include additional real-world examples relevant to the learners' context (e.g., irrigation systems in agriculture).
   c. **Advanced**: Delve deeper into the technical aspects of feedback and non-feedback loops. Discuss the advantages and disadvantages of each system and introduce concepts like stability and self-correction in feedback loops.

2. Ensure that the examples provided at each level are relatable to learners and easy to understand. This will enable them to readily comprehend why these examples are classified as either feedback loop systems or non-feedback loop systems.

3. **Problem-Based Learning Approach:** Learners work in balanced mixed-abilities groups to research and present on either non-feedback loop or feedback loop systems.

a. Using this approach, based on your observed profile of learners, form mixed-ability groups and help assign roles to each member of the group. This is to ensure that each member plays a part.
b. Provide additional support for learners who might need it (scaffolding).
c. Offer pre-reading materials or vocabulary lists for key terms.
d. Allow learners to choose which system (feedback or non-feedback) they want to research, catering to their interests.

4. **Managing Talk for Learning:** In a moderated discussion, guide learners to draw out contrasting differences from their research findings and share them with the class for feedback.
   a. Using this approach, focus the discussion on drawing out contrasting differences between the two systems. You may use a Venn diagram and/or a chart to visually represent the similarities and differences in researched differences between the two systems.
   b. Encourage all learner groups to share their thoughts based on their carried-out research and receive constructive feedback. Provide a framework for feedback using phrases like "I liked how you explained..." or "One way you could improve your presentation is..."
   c. Try to find amicable ways of resolving disagreements in opinions among learner groups.
5. Provide access to diverse resources to cater to the varying preferences of learners. These resources may include videos, images, articles, podcasts, infographics, and other multimedia formats.
6. Ensure that all students have opportunities to access the content in a way that best suits their learning preferences and abilities.

## Key Assessment

1. **Assessment Level 1:** State whether the following statement is true or false - A thermostat in a home heating system is an example of a non-feedback loop system.
2. **Assessment Level 1:** Match the following terms with their definitions:

| Term | Definition |
|---|---|
| Reference Input | The result of a system's operation. |
| Error Signal | A signal used to initiate a specific action in a non-feedback loop system. |
| Output | The difference between the desired output and the actual output in a feedback loop system. |

3. **Assessment Level 2:** Describe the key difference between a feedback loop system and a non-feedback loop system.
4. **Assessment Level 3:** Identify a real-world example of a non-feedback loop system and explain how it works. Briefly explain why a feedback loop system would not be suitable for this application.
5. **Assessment Level 3:** Imagine a simple watering system for a potted plant. Explain why a feedback loop system would be a better choice compared to a non-feedback loop system for this application.
6. **Assessment Level 3:** Design a simple feedback loop system to regulate the room temperature in a building. Include a labelled diagram showing the components and how they interact. Explain how your system would maintain a comfortable temperature.

7. **Assessment Level 3:** Some traffic light systems incorporate feedback loops to optimise traffic flow. Research a specific example of a traffic light feedback loop system. Evaluate the advantages and disadvantages of using a feedback loop system for traffic control compared to a traditional non-feedback loop system.
8. **Assessment Level 4:** Imagine you are designing a robot that needs to navigate a maze. How could feedback loop systems be incorporated into the robot's design to help it navigate the maze efficiently? Explain the specific feedback loops you would use and how they would function.

**Conclusion**: We have explored two control system types: feedback and non-feedback loops. Feedback loop systems continuously monitor output, comparing it to a desired state and adjusting achieve the target outcome. Examples include thermostats and automatic coffee makers. Non-feedback loop systems operate on pre-programmed instructions without monitoring output. Traditional traffic lights and toasters are some examples. Understanding these systems is important in automation and robotics, where desired outcomes are key.

# WEEK 5

**Learning Indicator(s):** *Evaluate the use of logic and loop diagrams and demonstrate their use in control systems' design.*

## Theme or Focal Area (s): Evaluating Logic and Loop Diagramsin Control Systems Design

### Introduction

Logic and loop diagrams are essential tools for designing and representing control systems. They help engineers and designers understand the behaviour and structure of control systems, allowing for effective analysis, troubleshooting, and optimization. In this week we will focus on how each of these diagrams contribute to the control system design process.

### Control Logic Diagrams

Control Logic diagrams sometimes known as Logic Diagrams are graphical representations used in system design to illustrate the logical relationships between various components, inputs, processes, and outputs within a control system. These diagrams help engineers, designers, and stakeholders understand and communicate the flow of information, decision-making processes, and overall functionality of a system. Logic diagrams are particularly common in fields like electronics, computer science, control systems, and software engineering.

Logic diagrams can be represented in several ways, each with its own advantages and applications. Some common ways to represent Logic diagrams include flowcharts, Ladder Diagrams (LDs), Karnaugh Maps (K-maps), State Diagrams, truth tables etc. However, in this section we will focus on using Flowcharts because of their ease of use in representing control systems' design.

### Flowchart Diagrams

A flowchart is a visual representation of a process, typically depicted using a standardized set of symbols. These symbols represent actions, decisions, inputs, outputs, and the flow of information between them. By connecting these symbols with arrows, flowcharts create a clear, step-by-step illustration of how a system operates. These symbols and their meanings are illustrated in Fig. 5.1.

Flowcharts excel at graphically depicting the step-by-step sequence of operations within a control system. They use these standardised symbols to create a clear visual representation of how the system reacts to inputs and produces outputs. Flowcharts are adept at simplifying complex control systems. By deconstructing the system into smaller, manageable steps, they aid engineers in identifying potential issues, optimising sequences, and ensuring logical flow.

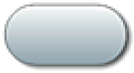
| Symbol | Name | Function |
|---|---|---|
|  | Start/end | An oval represents a start or end point. |
|  | Arrows | A line is a connector that shows relationships between the representative shapes. |
|  | Input/Output | A parallelogram represents input or ouptut. |
|  | Process | A rectangle represents a process. |
|  | Decision | A diamond indicates a decision. |

**Fig. 5.1:** *Basic Flowchart Symbols and their meanings*

**How to Represent a Control System using a flowchart:** To represent a control system with flow charts, follow the steps below:

1. *Define the problem*: Clearly articulate the problem you want to solve or type of control system, including the desired inputs and outputs.
2. *Identify inputs, processes, and outputs:* Determine the reference inputs, the controllers, processes/plants etc. required, and the desired outputs for the control system.
3. *Develop the flowchart:* Use the appropriate flowchart symbols to represent each step of the workflow of the control system. Connect the symbols with arrows to show the flow of execution.
4. *Test the flowchart:* Walk through the flowchart step-by-step, verifying the logic and ensuring that it produces the desired outputs for different scenarios.

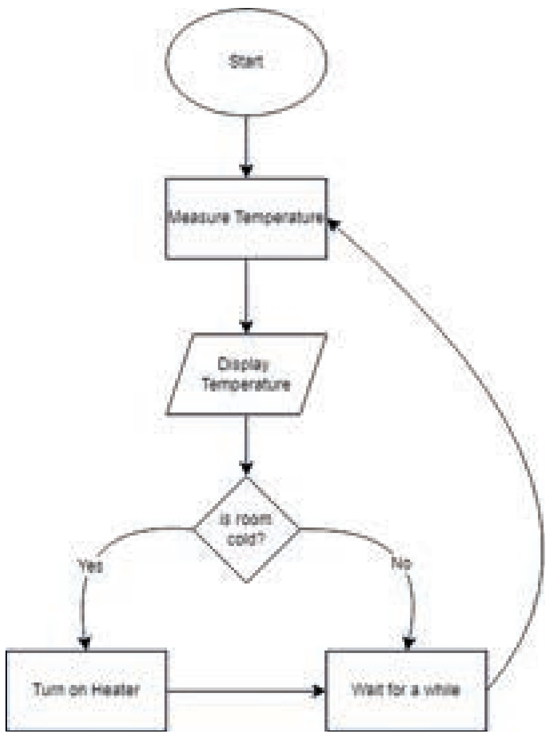



**Fig. 5.2:** *Basic flowchart of a control system which regulates room temperature*

## Loop Diagrams

Loop diagrams provide a visual representation of the feedback loop in a control system. They show the flow of information, including the measurement, error calculation, and control action, helping to visualise the closed-loop structure. Loop diagrams, also known as loop sheets, are detailed blueprints specifically used in control system design and engineering. They can be used to represent both feedback and non-feedback loop control systems.

These are the key elements that could appear in a typical loop diagram:

1. **Blocks**: Rectangular boxes represent system components such as sensors, controllers, actuators, and processes (plant)

**Fig. 5.3:** *Rectangular Block represent system components in a Loop Diagram*

2. **Lines**: Lines indicate signal flow. Solid lines are used to represent the flow of information or control signals while dashed lines often signify power connections

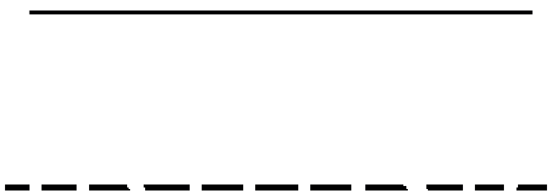


**Fig. 5.4:** *Solid and Dashed Lines used in Loop Diagrams*

3. **Circular Shapes**: Circular shapes in loop diagrams are less common than rectangular blocks, but they are used to represent the following:
   a. *Summation Point*: A circle with multiple lines entering it can represent a point where several signals are summed or averaged before proceeding further in the loop. This might be used, for example, to combine data from multiple temperature sensors in a building automation system.
   b. *Logic Operation*: In some loop diagram notations, a circle can signify a logical operation like AND, OR, or NOT. This would be like how logic gates are represented in logic diagrams. For instance, a circle with "AND" written inside could indicate that two conditions need to be met (signals entering the circle) before a certain action is taken.
   c. *Special Process*: Occasionally, a circle might be used to represent a specific process within the control loop that is too complex to depict with a simple block. This could be a mathematical function, a lookup table, or another sub-system with its own internal workings. The circle would have a label explaining its function.

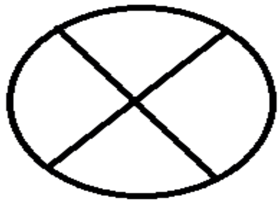


**Fig. 5.5:** *Circular Shape used in a Loop Diagram*

### Evaluating Loop Diagrams

When evaluating loop diagrams, we consider the following guidelines:

1. **Signal flow representation**: Loop diagrams should clearly depict the flow of signals within the control loop, highlighting the interactions between different components, such as sensors, controllers, actuators, and feedback loops.
2. **Feedback connections**: The presence and proper representation of feedback connections in loop diagrams are crucial for understanding how the system adjusts and regulates its behaviour based on feedback information.
3. **Clarity and completeness**: Loop diagrams should be clear and complete, ensuring that all relevant components and connections within the control loop are accurately represented.

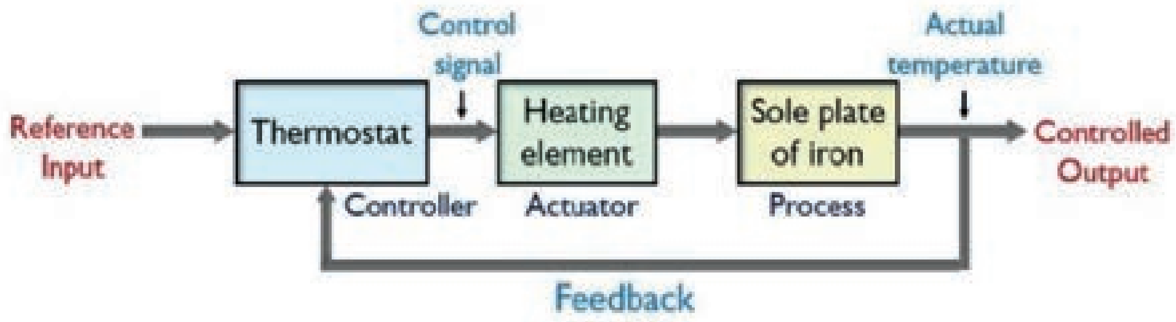



**Fig. 5.6:** *A control Loop Diagram of an automatic Electric Iron*

**LEARNING TASK**

Depending on the available time or resources, administer the following learning task to help learners reinforce understanding and acquire new knowledge or skills.

1. Learners depict the design and function of at least one of the control systems below using both logic and loop diagrams:
   a. a basic traffic light control system for a four-way intersection. The system needs to ensure safe and efficient traffic flow.
   b. a control system to maintain a comfortable room temperature. The system will use a temperature sensor and a heater to regulate the room's temperature based on a user-defined setpoint.

## Pedagogical Exemplars

The goal of this lesson is for all learners to contrast non-feedback loop systems and feedback loop systems. Consider the following keynotes when administering the suggested pedagogical approaches in the curriculum:

1. **Problem-Based Learning:** Introduce learners to standard loop and logic diagram representations of components and how they are used in control systems design. Learners are guided to draw loop and logic diagrams to represent given system narratives. Learners share drawings with the class for feedback.
    a. Using this approach, as a starter, through questioning, remind learners by assessing their understanding of basic control system concepts like sensors, actuators, feedback loops, etc., which were covered in previous lessons.
    b. Proceed by providing a tiered delivery on logic and loop diagrams. Flowchart diagrams seem to be the easiest of the two, so it may be prudent to start with. Represent some basic examples of real-life scenarios, such as controlling an outdoor light switch based on the time of day with flowchart diagrams using the symbols introduced in the content.
    c. Provide other basic examples and allow learners to practise representing them. Provide guidance and feedback where necessary.
    d. Follow the same approach using loop diagrams.
    e. After learners have demonstrated understanding of both diagrams, proceed to task the learner to attempt more detailed or complex examples (e.g. traffic light control system, the control system for maintaining room temperature, etc.). For advanced learners, you may consider examples such as robots moving in a maze or following a guiding line.
    f. Provide additional support for learners who might need it (scaffolding).
2. Provide access to diverse resources to cater to the varying preferences of learners. These resources may include videos, images, infographics, and other multimedia formats.
3. Ensure that all students have opportunities to access the content in a way that best suits their learning preferences and abilities.

## Key Assessment

1. **Assessment Level 1:** State the function of loop diagrams
2. **Assessment Level 1:** Match the following shapes of a flowchart diagram with their corresponding purpose:

| Shape | Purpose |
|---|---|
| Rectangle | Decision Box |
| Diamond | Input/Output |
| Rhombus | Process |

3. **Assessment Level 2:** Create a flowchart for controlling a water pump that fills a tank with water using a defined start and end point, including decision points and actions.
4. **Assessment Level 3:** Create a flowchart diagram and a control loop diagram for an adaptive traffic light control system. Compare and contrast the two diagram representations, highlighting the advantages and disadvantages of each.
5. **Assessment Level 4:** Research and present advanced loop diagram notations used in specific control system applications (e.g., chemical process control).

**Conclusion**: Evaluating logic and loop diagrams in control systems design is crucial for designing efficient and reliable control systems. By understanding the importance of these diagrams, assessing their clarity, readability, and completeness, and conducting practical demonstrations, senior high school students in Ghana can gain valuable insights into the practical applications and benefits of logic and loop diagrams in control systems design. These skills will equip them with the knowledge necessary to contribute to the field of automation and robotics in the future, aligning with the learning indicator for this lesson.

## Section Review

This three-week course explored robots, robotic systems, and control systems. We learned that robots are programmable machines with autonomy, while robotic systems integrate robots with other elements for more complex tasks. Non-robotic systems include automated systems with limited adaptability, mechanised systems controlled by humans, and computerised systems lacking physical manipulation. Robots themselves rely on interconnected subsystems to sense their environment, make decisions, and take physical actions. Finally, the course covered control systems, including feedback loop systems that adjust actions based on errors and non-feedback loop systems that rely on pre-programmed instructions. We also learned how to design these control systems using logic and loop diagrams

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# SECTION 3: SENSORS AND ACTUATORS 1

Strand: **Principles of Robotic Systems**

**Sub-Strand:** Sensors and Actuators

**Learning Outcomes**

1. *Critically analyse the similarities between robots and living organisms.*
2. *Outline significant scientific principles that underpin how sensing is achieved in robots.*
3. *Experiment with varying linear sensors, explain their outputs and apply linear equations to calibrate them.*

**Content Standards**

1. Relate nature-inspired sensing, mechanics, and controls to applications in robot sensory, architecture and control systems.
2. Examine and calibrate sensor outputs for performance improvement in robotic systems.
3. Demonstrate knowledge and understanding of sensor outputs for performance improvement in robotic systems**.**

## INTRODUCTION AND SECTION SUMMARY

This section focuses on robotic sensors, exploring the principles behind their operation and how they draw inspiration from nature. It examines the dynamic relationship between humans and robots by analysing the critical role of sensors in robotic perception, like how living organisms gather information about their environment. It also focuses on linear sensors, their diverse functionalities, and the importance of calibration for achieving accurate and reliable measurements. This will help learners to explore how to make use of linear equations to calibrate these sensors thereby ensuring optimal performance in robotic systems. They will apply this knowledge to critically assess real-world scenarios, enabling informed decision-making in the field of robotics and automation.

**The weeks covered by the section are:**

**Week 6:** Exploring Nature-Inspired Sensors, Actuators and Controllers.

**Week 7:**

1. Understanding the principles underlying the operation of robotic sensors.
2. Exploring Linear Sensors: Understanding Variations in Sensor Outputs.

**Week 8:** Calibrating Linear Sensors for Optimal Performance in Robotic Systems

## SUMMARY OF PEDAGOGICAL EXEMPLARS

This section integrates a range of pedagogical approaches to engage learners in understanding the intricate dynamics between robots and society. Using talk for learning, the facilitator guides learners to come out with their understanding of the term ‘nature-inspired’ by breaking it into syllables. Through experiential learning, learners will observe some nature-inspired robots by watching videos and conducting individual research. They will share their reflections and engage in class discussions to deepen comprehension. Collaborative and problem-based learning approaches using mixed-ability groups will also be employed to help learners clearly indicate the similarities between robots and living organisms, the connection between sensors, processors and actuators, the scientific principles underpinning various sensors' operation and how linear sensors can be calibrated using linear equations for optimal performance in robotic systems.

Facilitators of this section are encouraged to employ effective methods of differentiation by proactively recognising and capitalizing on the shared characteristics among students while also addressing their individual differences that lie in interests, readiness levels, and learning styles. In addition, facilitators are also advised to provide access to diverse resources to cater to the varying preferences of learners.

## ASSESSMENT SUMMARY

Following each thematic area in this section, assessments gauge student learning. These come in two forms: learning tasks and key assessments. Learning tasks, primarily formative, focus on solidifying understanding and acquiring new knowledge or skills. Facilitators guide these activities to enhance the learning process. In contrast, key assessments, typically summative, evaluate student mastery after instruction. These are often given as homework or quizzes, mid-semester, and end-of-semester examination. Instructors have the flexibility to choose the assessment types that best suit their learners and learning objectives. However, it is advisable that instructors at least guide learners to do one of the learning tasks.

# WEEK 6

**Learning Indicator(s):** *Draw a parallel relationship that relates the coordination of senses, brain and moving parts in living organisms to the coordination of sensors, processors, and actuators in robots.*

**Theme or Focal Area: Exploring Nature-Inspired Sensors, Actuators and Controllers**

## Introduction

This section will compare robots with living organisms to highlight the similarities that exist between the two. This will unearth and help in appreciating some of the scientific principles underlying the architecture and coordination of the subsystems of robots. This knowledge will deepen our understanding of nature-inspired sensing, actuation, and control in robots.

## Similarities Between Robots and Living Organisms

Earlier in Week 3, while looking at the subsystems of a robot, we drew some parallels between these subsystems and the organ systems in humans. We saw how the sensing subsystem is likened to the sensory organs of humans, such as the nose, ears, and skin. We also likened the control subsystem to the nervous system, the actuation subsystem to the muscular system and the power subsystem to the cardiovascular system. This clearly shows the similarities that robots have with living organisms. These similarities are not only limited to human organ systems but also those found in other living organisms.

These similarities exist because the makers of robots (roboticists and robotic engineers) sometimes draw inspiration from nature, therefore making robots and the sub-components of robots in a similar fashion. This has led to the creation of several nature-inspired (bionic) sensors, actuators, and controllers. Some of specific examples of these nature-inspired parallels are described below:

**Nature-inspired Sensors**

1. **Cameras and colour sensors:** Like the function of the eyes, robots may use sensors like cameras and colour sensors to recognise images and colours.
2. **Odour sensors:** Just as humans and animals use the nose to detect odours, so do some robots rely on odour sensors to realise the same function.
3. **Audio sensors:** Like the function of the ear, robots use audio sensors such as the microphone to detect sound waves.
4. **Ultrasonic/infrared proximity sensors:** Just as some sea creatures, such as dolphins and certain species of whales, as well as bats, use echolocation or sonar to navigate and detect objects in their environment, so do some robots use ultrasonic and infrared proximity sensors to achieve similar functions.
5. **Compound eye sensors:** Just as insects use compound eyes to attain wide-angle vision and detect motion, so do some robots use artificial compound-eye sensors to achieve similar functions.
6. **Tactile sensors:** Like how rodents and cats use whiskers to detect vibrations, pressure and touch, some robots use tactile sensors to achieve the same.
7. **Thermoreceptors:** Like how pit vipers and some insects detect infrared radiation emitted by warm-blooded prey or environmental heat sources so do some robots use thermal sensors or thermoreceptors to detect temperature changes in the environment

### Nature-inspired Actuators

1. **Muscle-like actuators:** Just as biological muscles found in animals, including humans, contract and relax in response to electrical signals from the nervous system, allowing organisms to move their limbs and perform various actions, so do robots use muscle-like actuators to function in enabling robots to perform flexible and precise motions.
2. **Pneumatic actuators:** Pneumatic actuators use compressed air or gas to generate mechanical motion, providing robots with lightweight and efficient actuation. This is like the movement of certain animals, such as arthropods, insects, and spiders.
3. **Hydraulic actuator:** Like how large mammals and reptiles use fluid/liquid pressure to move parts of their body, such as their jaws or tails, some robots use fluid pressure to produce linear or rotary motion.
4. **Shape Memory Alloys (SMAs):** In nature, certain plants exhibit shape-changing behaviours in response to environmental stimuli, such as temperature changes or pressure. Also, SMAs used in some robots change shape in response to temperature variations, allowing robots to achieve self-reconfiguration or actuation without external power sources.

### Nature-inspired Controllers

Biological brains found in humans and animals are responsible for processing information and making informed decisions. In a similar manner, robots employ processors, such as microcontrollers or microprocessors, to process data from one or more sensors as well as other (already stored) sources of data, analyse them, and generate appropriate output, which may be in the form of control signals for actuation.

### Coordination of Sensors, Processors, and Actuators

In both living organisms and robots, the coordination of sensors, processors, and actuators is essential for effective decision-making and control. This coordination allows organisms and robots to perceive their environment, process sensory information, and execute appropriate actions.

In living organisms, sensory organs such as eyes, ears, and skin detect stimuli from the external environment. This sensory input is then transmitted to the brain, where it is processed and interpreted. The brain integrates information from multiple senses, assesses the situation, and generates signals to initiate appropriate responses. These signals are then transmitted to muscles and other effectors, which conduct the desired actions.

Similarly, in robots, sensors collect data about the surrounding environment, including visual, auditory, tactile, and other stimuli. This sensory information is processed by the robot’s processor, which analyses the data and determines the appropriate course of action. The processor generates control signals that are sent to actuators, such as motors or pneumatic systems, to execute the desired movements or tasks.

Feedback loops are crucial in both living things and robots. They help them adjust and improve what they do based on what they sense. In living things, these loops help keep everything balanced inside and react to changes outside. For robots, they make sure they are doing their tasks exactly right by using feedback from their sensors to make quick changes when needed.

**Learning Tasks**

To reinforce understanding,

Learners should:

1. Identify observable similarities between robots and living organisms.
2. Identify some nature-inspired sensors, actuation, and control in robots.
3. Discuss the rationale behind the design: connecting the design with its application or purpose
4. Compare the coordination of senses, brain, and body parts in living things to the coordination of sensors, processors, and actuators in robots.

## Pedagogical Exemplars

1. **Experiential learning:** To cater to diverse learner interests, the instructor begins by outlining the key points of the lesson. Learners then engage in watching a short video(s) of some bio-inspired robots, and for each robot, draw parallel feature maps to living organisms. Instead of generic observations, provide students with a viewing guide with questions. This will be helpful in scaffolding the activity and providing clarification on what learners are to look out for. The viewing guide may include the following questions:

   a. What are the distinct similarities between bio-inspired robots and living organisms?
   b. How do robots move as compared to living organisms?
   c. How can the sensors, processors and actuators in robots be linked to the senses, brain, and limbs of living organisms?

   Learners document personal observations and share them with the class, fostering active participation. Additional materials, such as summarised texts, articles, or visual aids, are provided to deepen understanding. The facilitator ensures accessibility to various resources like websites and podcasts, enhancing engagement and facilitating comprehensive exploration of the topic.

2. Inquiry-based learning: Learners are made to sit in mixed-ability groups with guided questions to briefly describe how they and other living organisms move from one place to another within a given environment in connection to their body parts responsible for the movement. Offer tiered viewing guides. Some learners can simply focus on basic observations of similarities between robots and living organisms. Advanced learners can analyse and draw a parallel relationship that relates the coordination of senses, brain and moving parts in living organisms to the coordination of sensors, processors, and actuators in robots.

   a. The facilitator summarises the inputs made by learners, linking them to nature-inspired actuators and controllers of robots and establishing the connection between sensors, processors, and actuators.
   b. Ensure that all students have opportunities to access the content in a way that best suits their learning preferences and abilities.

## Key Assessment

1. **Assessment Level 1:** Identify two similarities between humans and a robot, either in terms of sensing, processing, or actuation.
2. **Assessment Level 1**: Identify any two nature-inspired sensors that function similarly to that of a named living organism.
3. **Assessment Level 2:** Distinguish between a light sensor and a tactile sensor.

4. **Assessment Level 3:** Describe the parallel functional similarities between the human brain, senses and moving parts and that of sensors, processors, and actuators in robots.

5. **Assessment Level 3:** Briefly explain how the following nature-inspired actuators function and link them to a named biological organism.
   a. Muscle-like
   b. Pneumatic
   c. Hydraulic

**Conclusion**: In conclusion, exploring nature-inspired sensors, actuators, and controllers reveals intriguing parallels between robots and living organisms. Drawing from biological systems, robots emulate sensory capabilities, muscular movement, and decision-making processes. Nature-inspired sensors, such as cameras and audio sensors, mimic human senses like sight and hearing, while actuators replicate muscle-like movements and shape-changing behaviours found in nature. Coordinating sensors, processors, and actuators allows both organisms and robots to perceive their environment, process information, and execute actions. Feedback loops play a crucial role in adaptation and optimisation, ensuring efficient task performance. By understanding these parallels, we gain insights into the innovative potential of robotics and its applications in various fields.

# WEEK 7

**Learning Indicator(s):**

1. *Discuss the scientific principles underlying the operation of sensors*
2. *Observe varying outputs of different linear sensors and explain the variations observed.*

**Theme or Focal Area: Understanding the Principles Underlying the Operation of Robotic Sensors**

## Introduction

Robotic sensors are crucial for robots to understand, interact and navigate their environment or surroundings. There are many types of sensors like proximity sensors to detect objects or vision sensors to see. These sensors convert physical signals like light or sound into electrical signals for the robot to process. However, some fundamental principles apply across various sensor technologies. In this section, most of the sensors to be discussed will centre around the principle of Transduction. Sensors built on the principle of transduction convert physical stimuli, such as light, sound, or pressure, into electrical signals that the robot's control system can process. A better understanding of the principles underlying the operations of sensors will go a long way to help designers develop robust and intelligent robotic systems capable of fulfilling a wide range of tasks across various domains.

## Visual Perception in Humans and Robots

The principle of vision in humans and how vision is achieved in robots represent fascinating examples of natural and artificial systems designed to interpret and interact with the world. Both human and robotic vision systems rely on light as the primary source of information. Light reflects off objects and enters the human eye or is captured by a camera or light sensors in robots, initiating the process of vision. In humans, light enters the eye through the cornea, passes through the lens, and focuses on the retina. The retina, which contains photoreceptor cells (rods and cones), converts the light into electrical signals which are sent to the brain via the optic nerve for processing. Robotic vision systems, on the other hand, may use cameras to capture light. These cameras function as the robot's "eyes," but instead of a retina, they have an image sensor (usually a CCD or CMOS sensor) that converts light into electronic signals. The captured information then goes through some form of image or data processing. In humans, the retina pre-processes visual signals into electrical signals before they are transmitted to the brain. The human brain plays a crucial role in processing visual information, using a vast network of neurons and an incredibly complex system of pathways and regions (like the visual cortex) dedicated to different aspects of vision (colour, depth, movement, etc.). This process is highly efficient and adaptable, capable of learning and recognising a vast number of objects and scenes with minimal energy consumption.

In robots, algorithms process the captured images to extract information. Robotic vision relies on computational algorithms to process and interpret visual data. This includes tasks like edge detection, pattern recognition, and object classification. The effectiveness of a robotic vision system depends on the sophistication of its algorithms and the computational power available, which can be resource-intensive and less efficient than the human brain.

The processed data then goes through recognition and interpretation. Both human and robotic vision systems can recognise patterns and interpreting them. Humans do this instantaneously thanks to the brain, while robots use some fixed algorithms or machine learning models to identify patterns and make sense of the visual data.

Human vision is part of a learning system, capable of adapting to new visual tasks and environments over time. From infancy, humans learn to interpret complex scenes, understand depth, and recognize faces among countless other tasks. Robotic vision systems can also learn and adapt, but this depends on their programming and the machine learning models they use. Advances in AI and deep learning have significantly improved the adaptability of robotic vision systems, enabling them to learn from vast datasets and improve their performance over time. However, they lack the innate intuition and contextual understanding that humans have.

It is worth noting that, while there are parallels between how humans and robots "see," the underlying mechanisms, processing capabilities, and efficiency of these systems are vastly different. Human vision is the result of millions of years of evolution, offering an incredibly efficient and adaptive system. Robotic vision, although rapidly advancing, relies on artificial sensors and computational algorithms, requiring significant energy and computational resources to approach the capabilities of human sight. Each has its advantages and limitations, reflecting the distinction between biological evolution and technological innovation.

## Auditory Perception in Humans and Robots

Auditory perception starts with sound waves entering the ear, vibrating the eardrum, and being transmitted through the ossicles to the cochlea. Robots also use microphones to capture sound waves, which function similarly to the human ear's role in capturing sound vibrations from the environment. In humans, the cochlea converts these vibrations into electrical signals that the auditory nerve sends to the brain for processing. Robots, on the other hand, convert sound waves captured by microphones into electrical signals, which are then processed by algorithms to interpret the sound's properties.

The human auditory system is extraordinarily complex, allowing for the perception of a wide range of frequencies and nuances in sound, including tone, pitch, and emotional intonation. The brain's auditory cortex plays a crucial role in deciphering complex layers of sound and language, enabling humans to understand speech, music, and environmental sounds. On the contrary, while advanced, robotic auditory systems rely on programmed algorithms and artificial intelligence to process sound. These systems can be designed to recognize speech and other auditory patterns but lack the biological system's depth of processing and emotional interpretation.

Human auditory perception is tightly integrated with other sensory systems, such as visual and tactile senses, allowing for a comprehensive understanding of the environment. This multisensory integration is crucial for tasks like localising sound sources and understanding speech in noisy environments. In robots, achieving a level of sensory integration that mimics human perception requires complex algorithms and significant processing power, and it still falls short of the natural integration seen in biological systems.

While the principle of auditory perception in robots is inspired by human auditory systems, with both relying on the transformation of sound waves into electrical signals for analysis, the depth of processing, learning and adaptation capabilities, and the integration with other senses and emotional responses highlight fundamental differences. Human auditory perception is deeply interwoven with emotional, cognitive, and social processes, aspects that robotic systems attempt to mimic to varying degrees of success through advanced algorithms and artificial intelligence.

**Touch (Tactile) Sensing**: Robots can integrate touch sensors that detect pressure, force, and texture. These sensors may use various technologies, such as capacitive sensing, resistive sensing, or piezoelectric sensing. By capturing tactile information, robots can interact with objects, recognise different surfaces, and perform tasks that require precise manipulation. The scientific principles underlying tactile sensing involve converting mechanical stimuli into electrical signals and interpreting those signals to extract information about the object being touched.

**Spatial Sensing**: Robots often use environmental sensors such as proximity sensors, range finders, and infrared sensors to gather information about their surroundings. Proximity sensors detect the presence or absence of objects near the robot. Rangefinders measure distances to objects using techniques like ultrasonic waves or laser beams. Infra-red sensors detect infrared radiation emitted by objects to determine their temperature or proximity. These sensors enable robots to detect obstacles, navigate autonomously, and interact safely with the environment.

## Components of a Sensor

A sensor is the robot's device for knowing what is going on in its environment. Without a sensor a robot cannot perceive what is going on around it to make the right decision. Even though a sensor is a device, it is made up of electrical components that make sensing possible and accurate. The components of a sensor can vary depending on its type, purpose, and complexity. However, most sensors consist of several fundamental components:

1. **Sensing element**: This is the core component of the sensor that interacts with the property being measured (physical stimulus). The sensing element could be made of various materials or technologies depending on the type of measurement required. For example, in a temperature sensor, the sensing element could be a thermistor or a temperature-sensitive semiconductor.
2. **Transducer**: A transducer is an electronic device that converts energy from one form to another. In sensors, the transducer is responsible for converting the physical stimulus sensed by the sensing element into an electrical signal. This conversion process allows the sensor to produce an output that can be easily processed and interpreted by electronic circuits or systems. Common types of transducers include *resistive, capacitive, inductive, or optical transducers*.
3. **Signal conditioning circuitry**: In many cases, the electrical signal produced by the transducer needs to be conditioned or processed before it can be used effectively. Signal conditioning circuitry may include amplifiers, filters, Analog-to-Digital Converters (ADCs), and other electronic components designed to enhance the accuracy, stability, and reliability of the sensor output.
4. **Output interface**: The output interface of a sensor provides a means for the processed electrical signal to be transmitted to external devices or systems for further analysis or control. The output interface may take various forms depending on the application and requirements of the sensor, such as analogue voltage or current outputs, digital signals, or communication protocols like I2C, SPI, or UART.
5. **Housing and packaging**: Sensors are often housed in protective enclosures or packages designed to shield them from environmental factors such as moisture, dust, temperature variations, and mechanical stress. The housing also provides mechanical support and facilitates the integration of the sensor into larger systems or assemblies.
6. **Power supply**: Most sensors require a power source to operate, typically provided by batteries, external power supplies, or energy harvesting techniques. The power supply ensures that the sensor's internal components receive the necessary electrical energy to perform their functions reliably.

### Why do Sensors need Calibration?

Sensor calibration is an adjustment or set of adjustments performed on a sensor or instrument to make that instrument function as accurately or as error-free as possible.

There are a lot of good sensors these days and many are 'good enough' out of the box for many non-critical applications. But to achieve the best possible accuracy, a sensor should be calibrated in the system where it will be used for some of the following reasons:

1. Manufacturing variations during the production of sensors mean that even two sensors from the same manufacturer production run may yield slightly different readings.
2. During transportation and even in the assembling of a robot, sensors are usually subject to heat, cold, shock, humidity etc. These can cause changes in the sensor's response during use.
3. Differences in sensor design mean that different sensors may respond differently in similar conditions. This is especially true of 'indirect' sensors that calculate a measurement based on one or more actual measurements of some different but related parameter.
4. Some sensor technologies 'age' and their response will naturally change over time - requiring periodic re-calibration.
5. The Sensor is only one component in the measurement system and, therefore will need to be calibrated to fit and work with other systems and even the environment. For example, with analogue sensors, your ADC is part of the measurement system and subject to variability as well. Temperature measurements are subject to thermal gradients between the sensor and the measurement point. Light and colour sensors can be affected by spectral distribution, ambient light, specular reflections, and other optical phenomena. Inertial sensors always have some 'zero offset' error and are sensitive to alignment with the system being measured

In summary - No sensor is perfect all require calibration before they can function within the environment and system they operate and produce values which are accurate and reliable.

## What makes a good sensor?

Precision and Resolution mostly measure the quality of a sensor.

**Precision** - means the sensor will always produce the same output for the same input.

**Resolution** - is the degree to which the sensor reliably detects small changes in the measured parameter

Even though Precision and Resolution are the real 'must-have' qualities, there are a couple of other 'nice-to-have' qualities, such as **Linearity** and **Speed** that you may consider when selecting a good sensor.

**Linearity** - A sensor whose output is directly proportional to the input is said to be linear. This eliminates the need to do any complex curve-fitting and simplifies the calibration process.

**Speed** - All things being equal, a sensor that can produce precise readings faster is a good thing to have.

## What affects sensor precision?

**Noise** - All measurement systems are subject to random noise to some degree. Measurement systems with a low Signal to Noise Ratio will have problems making repeatable measurements. In the diagrams below, the sensor on the right shows much better precision than the noisy one on the left.

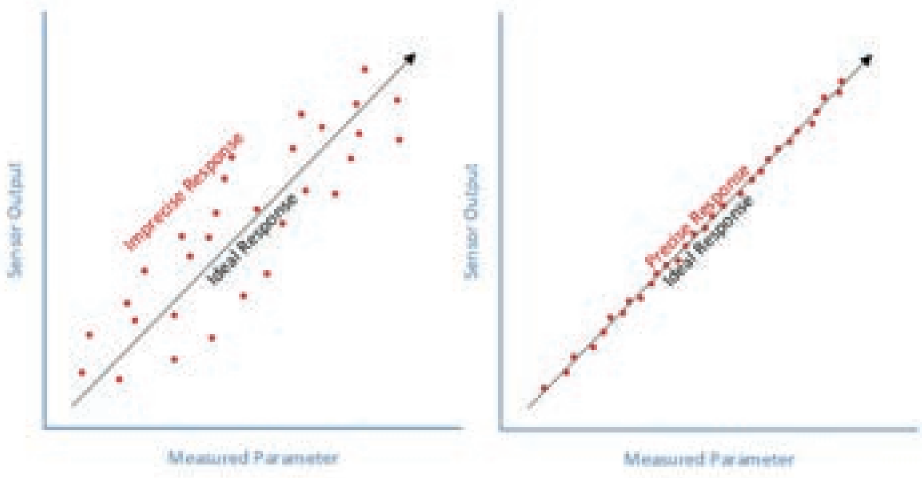



Fig 7.1 Sensor Precision (Earl, 2024)

**Hysteresis** - Some types of sensors also exhibit hysteresis. Hysteresis refers to the phenomenon where the output of a system depends not only on its current input but also on its past inputs or history. In cases like this, the sensor may read low with an increasing signal and high with a decreasing signal as shown in the graph below. Hysteresis is a common problem with many pressure sensors. To paraphrase George Santayana: “Those who ignore hysteresis are doomed to unrepeatable results.”

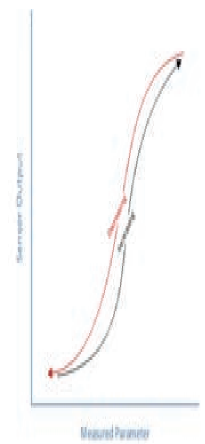


**Fig. 7.2 Sensor Hysteresis (Bill Eari, 2024)**

Bill Earl (2024). *Sensor Hysteresis*. (https://learn.adafruit.com/calibrating-sensors/why-calibrate)

## What about accuracy? Isn’t accuracy the most important thing?

Accuracy is a combination of precision, resolution, and calibration. If you have a sensor that gives you repeatable measurements with good resolution, you can calibrate it for accuracy.

## How Do We Calibrate Sensors?

1. **Standard Reference**

   The first thing to decide is what your calibration reference will be. We will need a **Standard Reference** to calibrate against. This standard reference can be:

   a. **A calibrated sensor**: If you have a sensor or instrument that is known to be accurate. It can be used to make reference readings for comparison. Most laboratories will have instruments that have been calibrated against global standards. These will have documentation including the specific reference against which they were calibrated, as well as any correction factors that need to be applied to the output.

b. **A standard physical reference:** Reasonably accurate physical standards can be used as standard references for some types of sensors. For example, Rulers and Meter sticks can be used as standard reference for rangefinders and ultrasonic sensors. Boiling Water - 100°C at sea level and Ice-water Bath - The "Triple Point" of water is 0.01°C at sea level and can be used as standard reference for Temperature Sensors. Gravity, being constant 1G on the surface of the earth, can be used as a standard reference for an Accelerometer.

2. **The Characteristic Curve**

   Once appropriate standard reference(s) have been determined. The characteristics curve of the sensor will have to be determined. Every sensor has a 'characteristic curve' that defines the sensor's response to an input. The calibration process maps the sensor's response to an ideal linear response. How to best accomplish that depends on the nature of the characteristic curve.

   The figure below shows the characteristic curves from different types of Thermocouples.

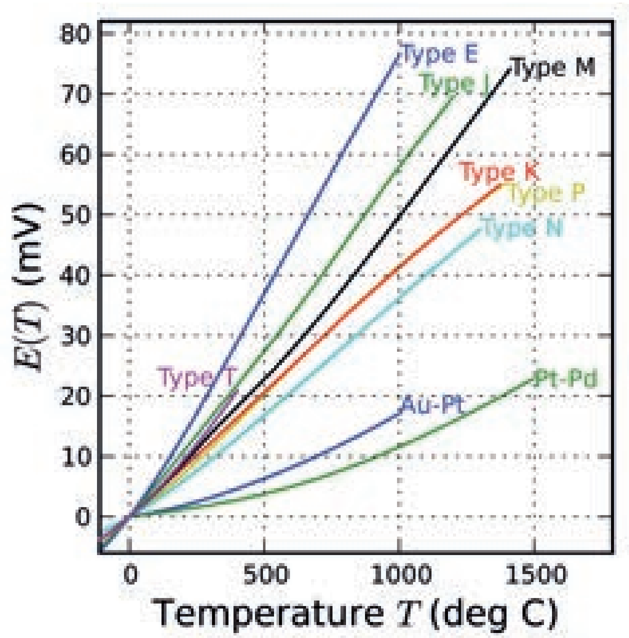



**Fig. 7.3 Thermocouple functions**

## Calibration Methods

We will discuss three different types of calibration:

1. One Point Calibration
2. Two Point Calibration
3. Multi-Point Curve Fitting

The characteristic curve of a sensor is characterised by an offset and a slope/sensitivity, and it shows the linearity of the sensor. An offset means that the sensor output is higher or lower than the ideal output. Offsets are easy to correct with a single-point calibration. A difference in slope means that the sensor output changes at a rate different from the ideal. The Two-point calibration process can correct differences in slope. Very few sensors have a completely linear characteristic curve. Some are linear enough over the measurement range that it is not a problem. However, some sensors will require more complex calculations to linearise the output.

## One Point Calibration

One-point calibration is the simplest type of calibration. If your sensor output is already scaled to useful measurement units, a one-point calibration can be used to correct for sensor offset errors in the following cases:

1. **Only one measurement point is needed**: If you have an application that only requires accurate measurement of a single level, there is no need to worry about the rest of the measurement range. An example might be a temperature control system that needs to maintain the same temperature continuously.
2. **The sensor is known to be linear and have the correct slope over the desired measurement range**: In this case, it is only necessary to calibrate one point in the measurement range and adjust the offset if necessary. Many temperature sensors are good candidates for one-point calibration.

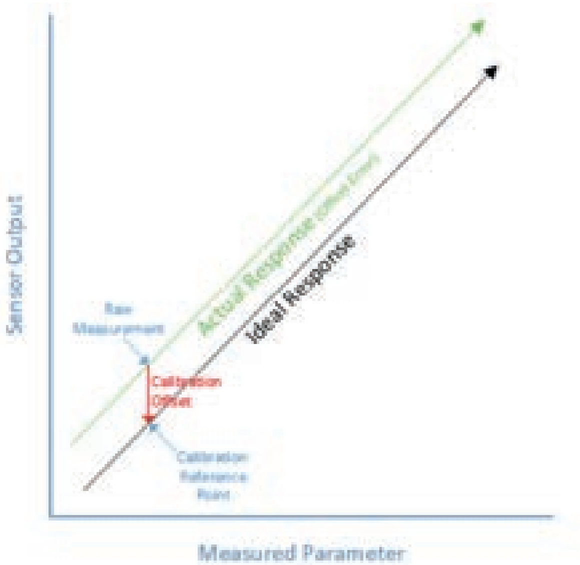



**Fig. 7.4:** *One-point calibration offset*

**How to perform One Point Calibration**:

To perform a one-point calibration:

1. Measure with your sensor.
2. Compare that measurement with your reference standard.
3. Subtract the sensor reading from the reference reading to get the offset.
4. In your code, add the offset to every sensor reading to obtain the calibrated value.

**Example**: Imagine that you have a competition robot that needs to position itself exactly 6” from a goal in preparation for scoring, and you have an ultrasonic rangefinder for your distance sensor, as shown in the picture below.

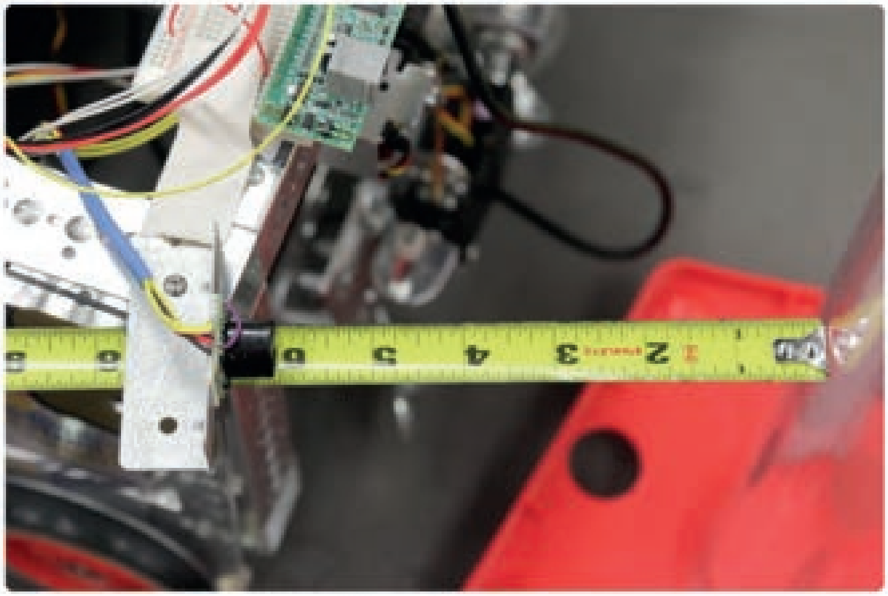


**Fig. 7.5:** *One-point calibration*

*Bill Earl (2024). One-point calibration. (https://learn.adafruit.com/calibrating-sensors/single-point-calibration)*

Since you only require maximum accuracy at one distance, a one-point calibration is a simple and effective solution. To perform one-point calibration in this situation:

- Using a measuring tape as your reference standard, position the robot exactly 6" from the goal.
- If you take a reading with your sensor and it says 6.3", then you have a -0.3" offset.
- Now edit your code to subtract 0.3" from every reading. Since this is known to be a linear sensor, it will be pretty accurate over most of its range.

With this calibration done, you know with great confidence that it will be spot-on at the critical distance of 6".

**Learning Tasks**

This task focuses on the scientific principles underlying the operation of sensors and how to calibrate them accurately.

Learners:

1. observe some sensors provided and pictures of some that may not be available and describe them.
2. identify what each sensor measures and document their importance to a robot.
3. identify any real-world example(s) of how these sensors are used in robots.
4. discuss scientific principles underpinning the operation of light sensors, ultrasonic sensors, temperature sensors, location sensors and other additional sensors.
5. discuss the essence of sensor calibration for maintaining accurate measurements for a smooth operation of the robot.

## Pedagogical Exemplars

The goal is for all learners to identify the scientific principles underlying the operation of sensors, what they measure and how to calibrate them for optimal performance. Differentiation allows them to reach this goal through activities tailored to their strengths and interests. Consider the following keynotes on differentiation when administering the suggested pedagogical approaches:

1. **Talk for Learning:** The facilitator introduces learners to the various types of sensors through guided questioning. Consider creating groups with members having a mix of research, communication, and critical thinking skills.
2. Form groups based on learner interest to research and present specific scientific principles underlying the operation of sensors and variations observed during the testing period.
3. **Problem-Based Learning Approach:** Learners work in balanced mixed-abilities groups to research and present on how to calibrate various sensors.
    a. Using this approach, based on your observed profile of learners, form mixed-ability groups and help assign roles to each member of the group. This is to ensure that each member plays a part.
    b. Provide additional support for learners who might need it (scaffolding).
    c. Offer pre-reading materials or vocabulary lists for key terms.

## Theme or Focal Area(s): Exploring Linear Sensors: Understanding Variations in Sensor Outputs

## Introduction to Linear Sensors

Linear sensors in robotics are devices that detect and measure linear displacement or **movement along a straight path**. These sensors are crucial in robotics for various applications where precise measurement and control of linear motion are required, such as distance, displacement, force, light intensity, and pressure. This section will examine different linear sensors, explore their varying outputs, and explain the variations observed. By understanding these variations, informed decisions can be made about sensor selection, calibration, and usage in robotic systems. Some common types of linear sensors include:

### Types of Linear Sensors

1. **Potentiometers**: Potentiometers are variable resistors with a sliding contact that moves along a resistive element. As the contact position changes, the resistance between the two ends of the element varies linearly, producing an output voltage or resistance proportional to the displacement.

**Fig. 7.6:** *Potentiometer Evan-Amos (2019).*

2. **Linear variable differential transformers (LVDTs)**: LVDTs are transducers that generate an output voltage proportional to the displacement of a movable core within a transformer assembly. They are highly accurate and used for precise displacement measurements (position along a given direction).

3. **Linear hall effect sensors**: These sensors measure the magnetic field's strength to determine the position or displacement of a magnet or a magnetic object. They produce a voltage output that is linearly related to the magnetic field strength.

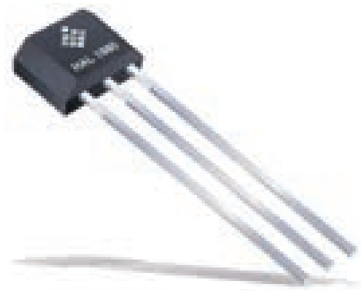


**Fig. 7.7:** *Linear Hall Effect Sensor*

## Factors Influencing Variations in Sensor Outputs:

The outputs of linear sensors can vary due to several factors, including:

1. **Environmental conditions**: Temperature, humidity, and other environmental factors can impact the performance of linear sensors. For instance, temperature changes might affect the resistance or magnetic properties of the sensor materials, leading to variations in the output.
2. **Calibration**: The accuracy of sensor calibration plays a significant role in determining the reliability of the sensor's output. Poor calibration can introduce errors and discrepancies in the measurements.
3. **Linearity**: The linearity of a sensor refers to how closely its output follows a straight-line relationship with the input. Some sensors may exhibit non-linearity, resulting in output variations.
4. **Mechanical wear and tear**: In some cases, the mechanical components of linear sensors, such as sliding contacts in potentiometers, can experience wear and tear over time. This can lead to inconsistencies in the sensor's output.
5. **Supply of voltage**: Some linear sensors are sensitive to variations in the supply voltage, which can affect their output readings.

### Learning Tasks

**Comparing Linear Sensor Outputs**:

In this experiment, learners will compare the outputs of different linear sensors under controlled conditions. This will allow them to observe and understand the variations in their outputs.

1. Obtain different types of linear sensors, such as potentiometers, LVDTs, Light Sensors or linear Hall effect sensors. Connect each sensor to a data acquisition system or microcontroller capable of recording and displaying sensor readings.
2. Apply a controlled input to each sensor. For example, if using potentiometers, vary the sliding contact's position manually. For LVDTs, move the core within the transformer assembly, and for Hall effect sensors, change the position of a magnet.
3. Record the sensor outputs for different input positions. Repeat the process several times to capture data and identify any trends or variations.
4. Analyse the recorded data to observe variations in sensor outputs. Compare the linearity and accuracy of each sensor's response to the input.

## Pedagogical Exemplars

The focus is for all students to observe varying outputs of different linear sensors and be able to explain the variations observed.

1. **Experiential Learning**: Facilitators Test and discuss the behaviour of the various sensors assigned to learners in mixed-ability groups. Learners record the limits/boundary values for each of the sensors assigned to them and discuss real-life situations where and how these sensors can be employed. Groups share discussions and observations with the class.
2. **Collaborative Learning**: Differentiate the comprehensive performance analysis task within the groups. Learners approaching proficiency may focus on simpler aspects of the task, whereas highly proficient learners may consider more complex aspects.
3. Encourage active participation from all learners by ensuring each group member has a role in the activity. You can suggest roles members can play. These roles can include researchers, facilitators, analysts, recorders or secretaries, presenters, timekeepers, etc.

## Key Assessment

1. **Assessment Level 1:** Describe how a robot moves on its own (autonomous) in a given environment.
2. **Assessment Level 1:** List two linear sensors that robots can use to avoid obstacles in their environment.
3. **Assessment Level 2:** State any 2 factors that influence variations in sensor output and explain how they could be controlled
4. **Assessment Level 2:** Map the following sensors to their respective scientific principle:

| Sensors | Scientific Principle |
|---|---|
| Light sensor | Measuring light intensity |
| Temperature sensor | Measuring Proximity |
| Location sensor | Measuring the voltage across the diode terminals |
| Ultrasonic sensor | Measuring and detecting the position of an object using a built-in GPS receiver. |

5. **Assessment Level 3:** Experiment and write short notes on the observable variations in light and ultrasonic sensor readings under different environments.
6. **Assessment Level 4:** Explain in your own words what you think may have accounted for the observed variations.

**Conclusion:** After conducting the experiment and analysing the data, discuss the variations observed in the sensor outputs. Consider the factors influencing these variations, such as environmental conditions, linearity, calibration, mechanical wear, and supply voltage. Discuss the importance of selecting appropriate sensors for specific robotic applications and the significance of calibration to ensure accurate measurements. By understanding the variations in sensor outputs, students can make informed decisions when designing, implementing, and calibrating sensors in robotic systems.

# WEEK 8

**Learning Indicator(s):** *Apply knowledge from linear equations to calibrate linear sensors and to scale sensor readings to fit within a desired max-min range.*

**Theme or Focal Area: Calibrating Linear Sensors for Optimal Performance in Robotic Systems.**

## Introduction

In the previous section, linear sensors and the variations in their outputs were explored. This section will delve deeper into the process of calibrating linear sensors to improve their performance in robotic systems. Calibration ensures that sensor readings are accurate and reliable, making them essential for precise measurements and control. Additionally, this section will explore how to scale sensor readings to fit within a desired maximum-minimum range, enabling us to tailor sensor data for specific robotic applications.

## Two Point Calibration

A Two Point Calibration is a little more complex. But it can be applied to either raw or scaled sensor outputs. A Two Point calibration re-scales the output and is capable of correcting both slope and offset errors. Two-point calibration can be used in cases where the sensor output is known to be linear over the measurement range.

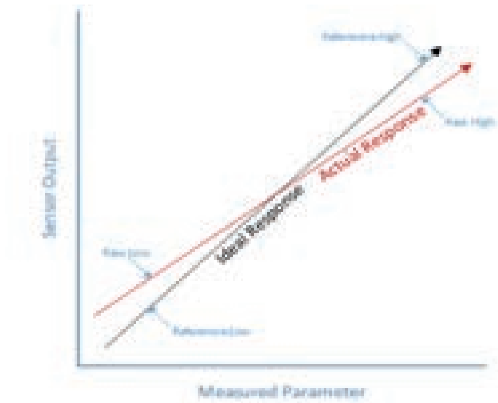



**Fig. 8.1:** *Two-point Calibration.*

Bill Earl (2024). *Two-point Calibration.* (https://learn.adafruit.com/calibrating-sensors/two-point-calibration)

**To perform a Two Point Calibration**

1. Take two measurements with your sensor: One near the low end of the measurement range and one near the high end of the measurement range. Record these readings as "RawLow" and "RawHigh"
2. Repeat these measurements with your reference instrument. Record these readings as "ReferenceLow" and "ReferenceHigh"
3. Calculate "RawRange" as RawHigh – RawLow.
4. Calculate "ReferenceRange" as ReferenceHigh – ReferenceLow
5. Calculate the "CorrectedValue" using the formula below:

$$\textbf{CorrectedValue} = (((\text{RawValue} - \text{RawLow}) * \text{ReferenceRange}) / \text{RawRange}) + \text{ReferenceLow}$$

Note that the RawValue is a measurement taken directly by using the sensor in a practical situation, for example in a cup of water straight from a tap.

**Example 1**:

Calibrate a light sensor to the conditions expected in an environment before a robot is made to function in that environment.

In an ideal environment, the light sensor should record a reflected light intensity of 100% when pointing to a white surface and 0% when pointing to a black surface. This is because in theory a white surface will reflect all the light incident on it and a black surface will absorb all the light incident on it. However, in practice values between 10 to 70 from the light sensor readings might be recorded for black to white surfaces.

Our goal is to calibrate the light sensor against theoretical readings of 100 for white and 0 for black.

1. We will start by taking 4 readings of white values and finding their average. Let us say for example, our average for white is 65.
2. We will do the same for black, 4 readings and let us say the average was 45.
3. The equation of a straight line is as follows: Y=mx + c, where m is the gradient and c is the intercept on the Y axis. X is the light sensor reading, Y is the calibrated output of the light sensor
4. So, for our light sensor, we have the average for white as 65 and the average for black as 45. The gradient of the curve is calculated by dividing the change in Y by the change in X. 100/20 = 5. Having the gradient c, the intercept of the curve on the Y axis, can be calculated in the following way: When Y = 0, x = 45. Then substituting these values into y=mx + c, 0 = 5*45 + c, therefore c = -225. The equation of the line can now be written as Y = 5x – 225. (see figure 8.1)

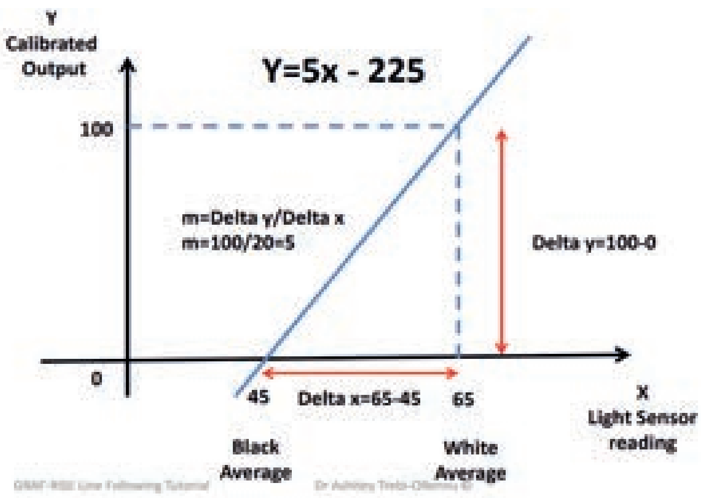



Fig 8.1 Light Sensor Calibration

5. The equation y = 5x – 225 can be used to transform raw light sensor reading into calibrated readings. An example of how this is used in robotics is as shown below for calibrating a sensor from the Lego Mindstorm kit.

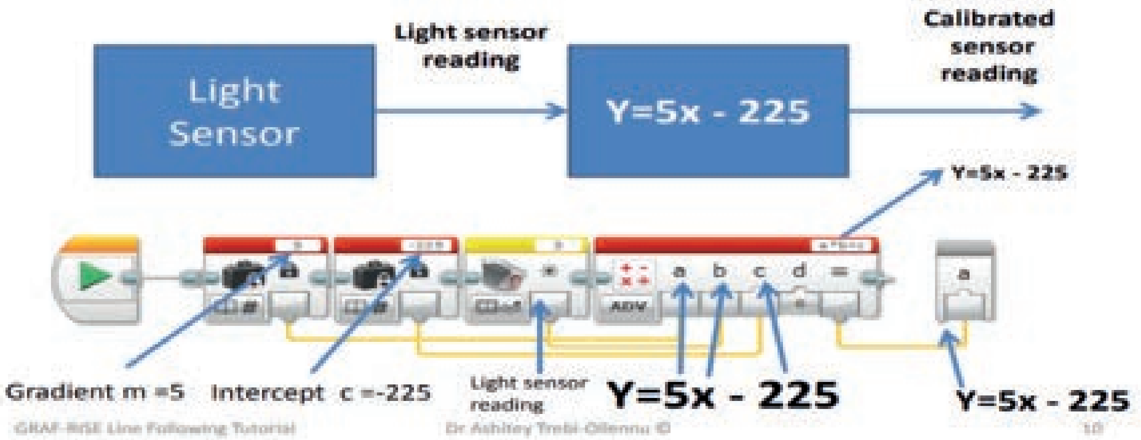



**Fig 8.3:** *Light Sensor Calibration Example in Lego EV3 Classroom*

**Example 2**:

Calibrate a temperature sensor using an ice-water bath and boiling water for the two references.

Since these are physical standards, we know that at normal sea-level atmospheric pressure, water boils at 100°C and the "triple point" is 0.01°C. We can use these known values as our reference values:

ReferenceLow = 0.01°C

ReferenceHigh = 100°C

ReferenceRange = 99.99°C

Here, we will show a two-point calibration of a laboratory thermometer. But the same principles apply to any temperature sensor:

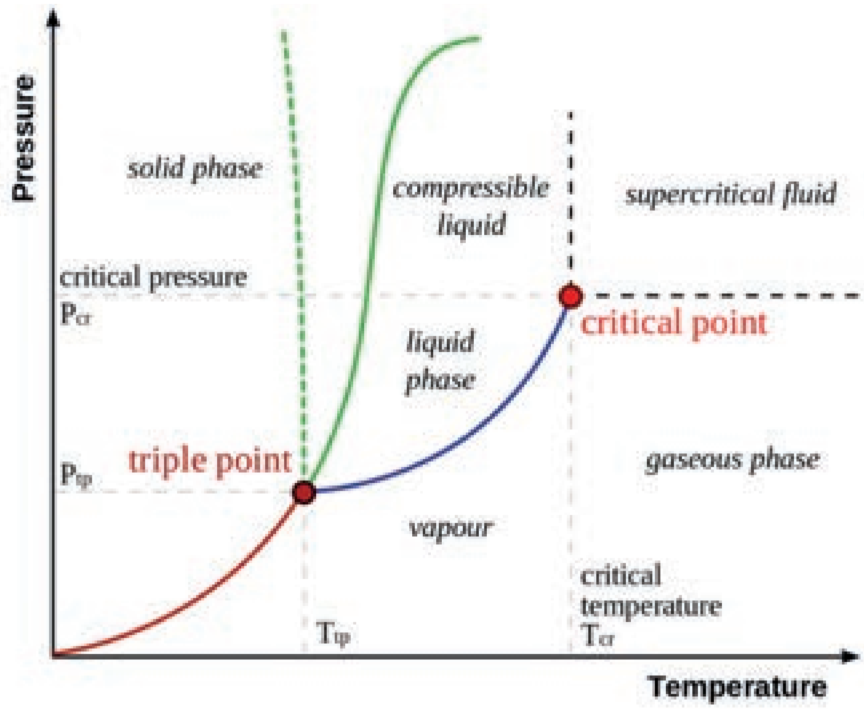



**Fig 8.4:** *Phase Diagram*

Suppose a thermometer is put in boiling water for about a minute, we can note the reading.

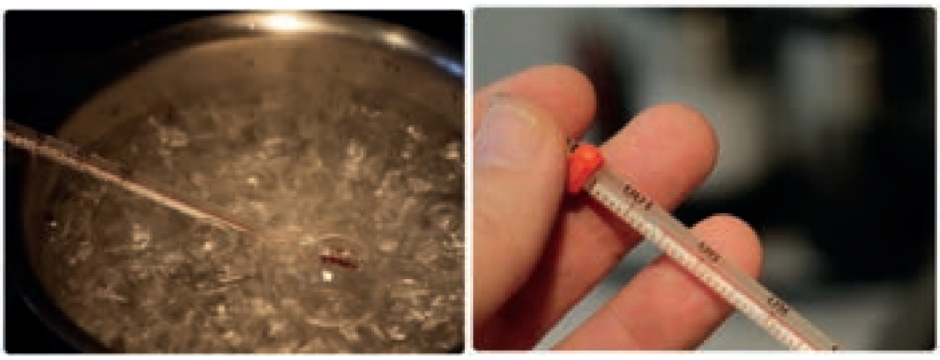


**Fig 8.5:** *Thermometer in boiling water*

As you can see, this lab thermometer shows a reading of 4 degrees less than at the boiling point of the water.

Next, we put the thermometer in an ice water bath for a minute or two and observe the readings.

**Fig 8.6:** *Thermometer in an ice water bath*

The same thermometer registers 0.5 degrees below zero degrees in the ice water bath.

So, the "Raw" readings are:

RawLow = -0.5°C

RawHigh = 96.0°C

RawRange = 96.5°C

So, if we get a raw reading of 37°C with this thermometer, we can plug the numbers into the corrected value equation to get the corrected reading:

$(((37 + 0.5) * 99.99) / 96.5) + 0.01 = 38.9°C$

## Multi-Point Curve Fitting

Sensors that are not linear over the measurement range require some curve-fitting to achieve accurate measurements over the measurement range.

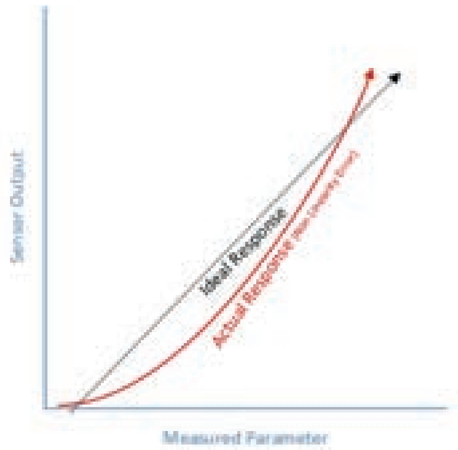



**Fig. 8.7:** *multi-point-curve-fitting (Bill Earl, 2024)*

A common case requiring curve-fitting is thermocouples at extremely hot or cold temperatures. While linear over a wide range, they do deviate significantly at extreme temperatures. The graphs below show the characteristic curves of high, intermediate, and low-temperature thermocouples. Note how the lines start to curve more at the extremes.

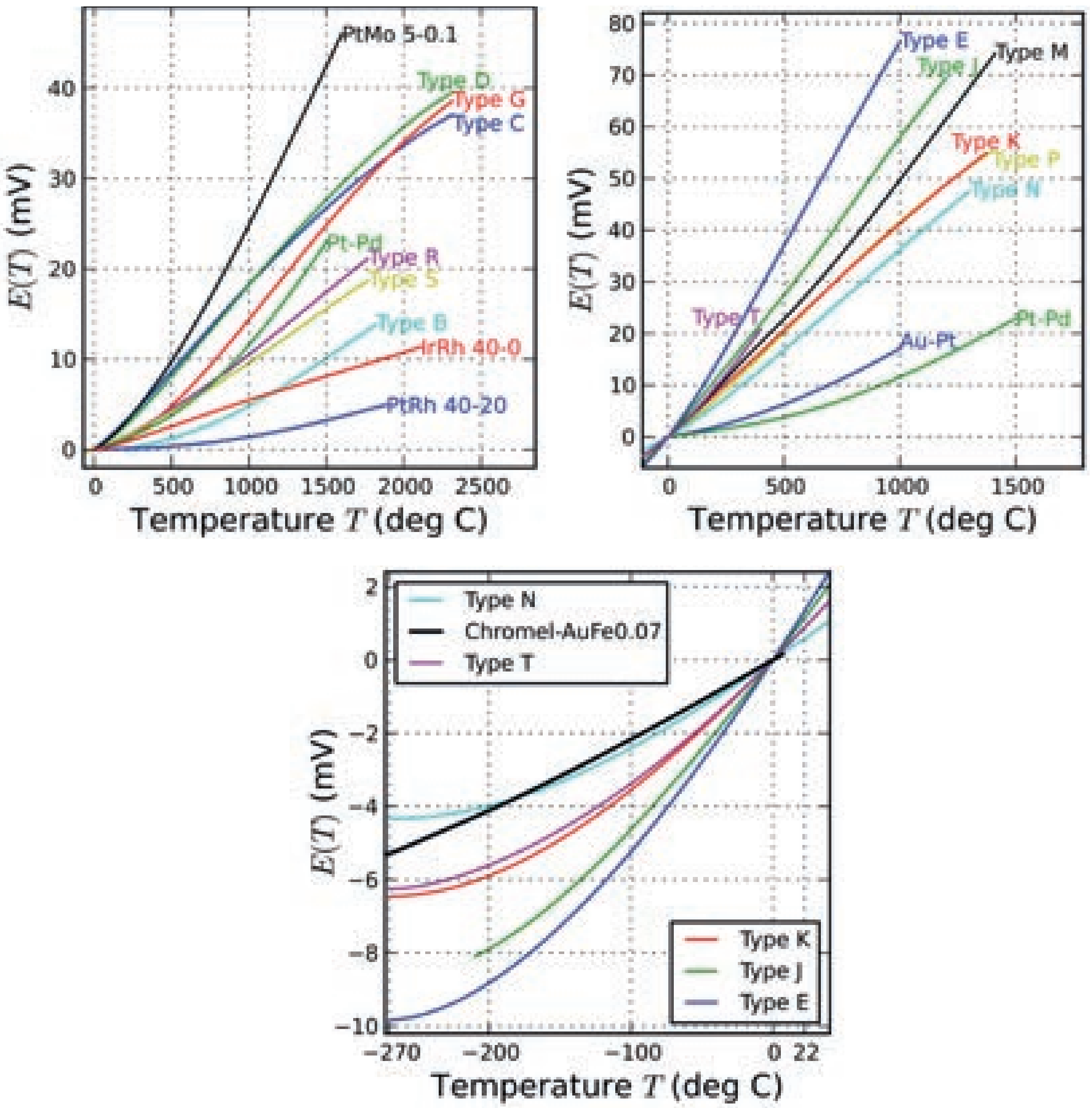



**Fig. 8.8:** *Thermocouple characteristic curves for high, intermediate, and low temperatures (Bill Earl, 2024)*

Fortunately, the characteristic curves of standard thermocouple types are well understood, and curve-fitting coefficients are available from NIST and other sources. However, if you are working with a home-brew DIY sensor, you may need to do some characterisation to determine the characteristic curve and derive a linearisation formula for your sensor. Excel and similar spreadsheet-type programs have some built-in tools to assist with curve fitting.

**Learning Tasks**

**Calibrating and scaling linear sensors**

In this experiment, students will work with different linear sensors and apply the calibration and scaling processes to improve their accuracy and fit within a desired range.

1. Obtain different types of linear sensors and connect them to a data acquisition system or microcontroller.
2. Collect calibration data by applying known inputs to the sensors and recording their outputs.
3. Analyse the data and derive the calibration equation for each sensor.
4. Choose a desired maximum-minimum range for the sensor readings. Calculate the scaling factors 'a' and 'b' for each sensor and apply the scaling equation to transform the sensor readings.
5. Verify the calibration and scaling results by comparing the transformed sensor readings to the known inputs and desired range.

## Pedagogical Exemplars

The goal is for all learners to be able to calibrate linear sensors for optimal performance in robotic systems and scale each sensor reading to a desired range for the effective performance of a robot under certain given conditions. Differentiation allows them to reach this goal through activities tailored to their strengths and interests. Consider the following keynotes on differentiation when administering the suggested pedagogical approaches:

1. **Initiate talk for learning:** The Facilitator initiates the lesson by asking learners to come out with their own understanding of the word **'calibrate'** and give examples of calibrated instruments in their immediate environment. The facilitator explains some keywords related to the lesson. Based on the availability of sensors, learners team up and work in mixed-ability groups to explore how to calibrate a given sensor, scale it to a desired range and think and ink their findings in relation to the real-life application of a named sensor. Consider students' varying interests and abilities when forming mixed-ability groups. Groups should also be encouraged to select one or more of the learning tasks above. Learners share with the class.
2. **Project-Based Learning:** In pairs or in mixed-ability, learners demonstrate how linear sensors (light, proximity etc.) can be calibrated using linear equations. Differentiate the comprehensive performance analysis task within the groups. Learners approaching proficiency may focus on simpler aspects of the task, whereas highly proficient learners may consider more complex aspects. Allow flexibility in how students demonstrate their understanding, such as through verbal explanations or written responses. Provide feedback and reinforcement to reinforce learning and encourage continued engagement.
3. **Collaborative learning**: In pairs, learners follow the same procedures to calibrate different kinds of linear sensors and share with the class for feedback. Encourage active participation from all learners by ensuring each group member has a role in the activity. You can suggest

roles members can play. These roles can include researchers, facilitators, analysts, recorders or secretaries, presenters, timekeepers, etc.

## Key Assessment

1. **Assessment Level 1:** What is the main benefit of calibrating a linear sensor in a robotic system?
2. **Assessment Level 1:** Two-point calibration is suitable for sensors with which characteristic?
3. **Assessment Level 2:** Explain the steps involved in performing a two-point calibration of a linear sensor.
4. **Assessment Level 2**: A temperature sensor reads 50°C raw output. After a two-point calibration with ice water (0°C) and boiling water (100°C) as references, the calculated corrected value is 52°C. Explain how this correction improves the sensor's performance.
5. **Assessment Level 3:** You are designing a line-following robot that uses a light sensor to detect the line. The raw sensor readings range from 20 (dark) to 80 (bright). However, you want the calibrated output to range from 0 (off track) to 100 (centred on the line).

   a. Follow the procedure for two-point calibration to convert the raw sensor readings to the desired calibrated output range (0-100).

   b. Explain how this calibration improves the robot's line-following performance.

**Conclusion:** Calibrating linear sensors and scaling their readings to fit within a desired range are essential techniques for improving the accuracy and reliability of sensor data in robotic systems. By applying linear equations, students can calibrate sensors effectively and tailor the data to meet specific application requirements. This knowledge empowers students to make informed decisions in sensor selection, calibration, and usage, ensuring optimal performance in robotic systems.

## Section Review

We have seen how robots have become an integral part of most 21st-century environments. This section, which covers three weeks, brings to light an overview of robotic sensors, emphasising their connection to biological sensory systems. It also explored the fundamental scientific principles that govern how robots interact with their environment or surroundings, mimicking how living organisms gather information from their surroundings as well. A particular focus was placed on linear sensors, their varied functions, and the critical role of calibration in ensuring accurate and reliable measurements. The idea of varying point calibrations was studied, and learners now have more ways of calibrating any sensor they come across, considering the environment under consideration. We have learned how to apply linear equations to calibrate these sensors. This knowledge empowers learners to make informed decisions in sensor selection, calibration, and usage, ensuring optimal performance in robotic systems.

## References


1. Bill Earl (2024). *Sensors Precision*. (https://learn.adafruit.com/calibrating-sensors/why-calibrate)
2. Bill Earl (2024). *Multi-point-curve-fitting. (https://learn.adafruit.com/calibrating-sensors/multi-point-curve-fitting)*
3. Bill Earl(2024).Thermocouple characteristic curves (https://learn.adafruit.com/calibrating-sensors/multi-point-curve-fitting)

# SECTION 4: DIGITAL AND ANALOGUE SYSTEM DESIGN 1

Strand: **Robot Design Methodologies**

**Sub-Strand:** Digital and Analogue System Design

**Learning Outcome:** *Assemble electronic circuits from schematic diagrams and analyse their application in discrete and continuous time machine design*

**Content Standard:** Demonstrate familiarity of the concepts and principles that underpin the application of analogue and digital components in circuit building.

## INTRODUCTION AND SECTION SUMMARY

This section focuses on Robot Design methodologies. It dives into the fundamentals of electronic circuits used in robots, focusing on both digital and analogue systems. It will help learners explore the underlying principles behind digital and analogue components, giving them a solid foundation for understanding how they work together in robots. It will also help explore how different circuits function and how they are used in robots. They will be able to read and understand schematic diagrams based on this knowledge. They will also apply this knowledge in assembling circuits based on given schematic diagrams.

**The weeks covered by the section are:**

**Week 9:** Understanding Electronic Circuit Components and Design Principles

**Week 10:** Schematic Block Diagram Representation of Electronic Systems and System Inputs/Outputs

**Week 11:** Hands-on Electronic Circuit Assembly: Building and Testing Circuits on a Solderless Breadboard

**Week 12:** Exploring Digital and Analogue Systems in Discrete and Continuous-Time Machine Design

## SUMMARY OF PEDAGOGICAL EXEMPLARS

This section dives into building robots using digital and analogue systems. Students will gain a strong foundation through a mix of engaging teaching methods.

Teachers will utilise discussions, questioning techniques, and project-based learning (PBL) to cater to diverse learning styles. Problem-based learning projects will be progressively used to build skills like identifying components, understanding schematics, constructing circuits, and analysing signals. Real-world examples will solidify the concepts of discrete and continuous time machines.

By the end, through these interactive pedagogies, students will not only grasp the theory of electronic circuits and components but also be able to build them based on schematics. They will differentiate between analogue and digital signals and classify machines based on their operation.

## ASSESSMENT SUMMARY

Following each thematic area in this section, assessments gauge student learning. These come in two forms: learning tasks and key assessments. Learning tasks, primarily formative, focus on solidifying understanding and acquiring new knowledge or skills. Facilitators guide these activities to enhance the learning process. In contrast, key assessments, typically summative, evaluate student mastery after instruction. These are often given as homework, mid-semester exams and end-of-semester exams outside of class. Instructors have the flexibility to choose the assessment types that best suit their learners and learning objectives. However, it is advisable that instructors at least guide learners to do one of the learning tasks.

# WEEK 9

**Learning Indicator(s):** *Identify the components of an electronic circuit and their functions.*

**Theme or Focal Area:** **Understanding Electronic Circuit Components and Design Principles**

## Introduction

In the field of robotics, electronic circuits are vital components that control various aspects of a robot's operation. Understanding the concepts and principles behind analogue and digital components is essential for designing and building efficient circuits. This section will explore electronic circuit components, their functions, and how to interpret block and schematic diagrams to gain familiarity with digital and analogue system design.

### Introduction to Electronic Circuit Components:

Electronic circuits consist of various components that perform specific functions in controlling the flow of electrical signals. Some common electronic circuit components include:

1. **Resistors**: Resistors are passive components that restrict the flow of current. They are used to control voltage levels, limit current, and divide voltage in a circuit.

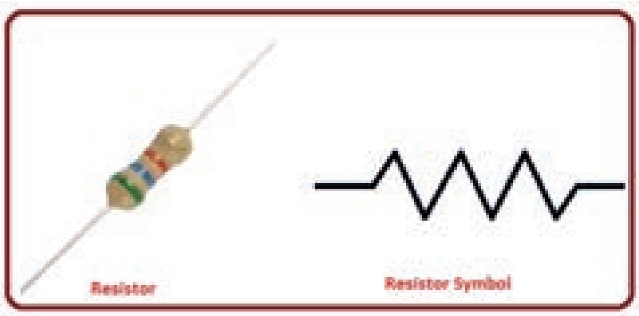



**Fig. 9.1:** *An actual Resistor and a Resistor Symbol*

David Watson (2020). Introduction to Resistors.

(https://www.theengineeringprojects.com/2018/01/introduction-to-resistors.html)

2. **Capacitors**: Capacitors store electrical charge and are used in filtering, coupling, and timing applications. They are essential in smoothing voltage fluctuations and blocking direct current.

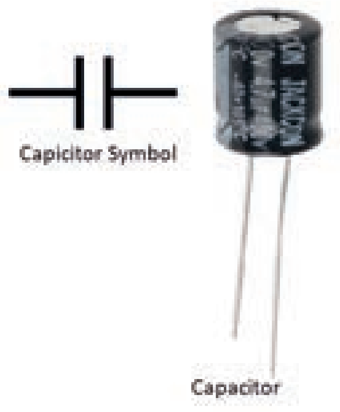



**Fig. 9.2:** *Symbol of a capacitor and an actual capacitor*

3. **Inductors**: Inductors store energy in the form of a magnetic field and are used in filtering and energy storage applications. They resist changes in current flow and play a crucial role in AC circuits.

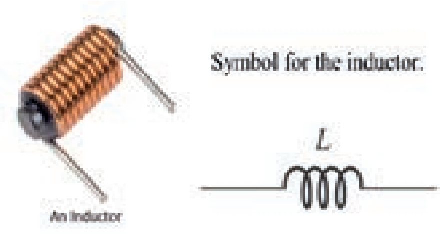



**Fig 9.3:** *An actual Inductor and the symbol for an inductor*

4. **Diodes**: Diodes are semiconductor devices that allow current to flow in one direction only. They are used in rectification, voltage regulation, and signal demodulation.

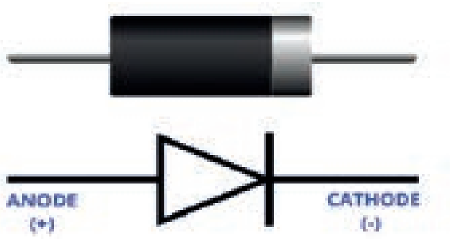



**Fig. 9.4:** *An actual Diode and the symbol for a diode*

5. **Transistors**: Transistors are active components that amplify or switch electronic signals. They form the building blocks of digital logic circuits and amplifiers.

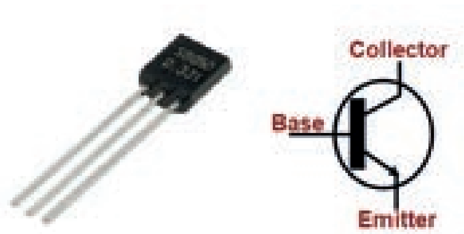



**Fig. 9.5:** *A Transistor and a symbol of a transistor*

6. **Integrated Circuits (ICs)**: ICs are complex assemblies of multiple electronic components integrated into a single package. They are used for various functions, such as microcontrollers, memory, and signal processing.


**Fig 9.6:** *An Integrated Circuit and a symbol of an IC*

7. **Relay**: A relay is an electrically operated switch that consists of a coil of wire around an iron core, an armature, and one or more sets of contacts. When an electrical current flows through the coil, it creates a magnetic field that attracts the armature, causing the contacts to close or open.

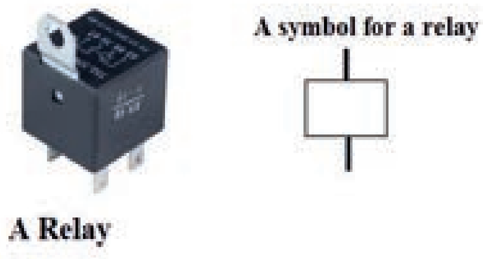



**Fig. 9.7:** *An image of a relay and a symbol for a relay*

Relays are used to control circuits electromechanically. They allow a low-power signal to control a high-power circuit, which is useful for applications where a low-power signal, such as from a microcontroller, needs to control a high-power device like a motor of a heater.

8. **Circuit breaker**: A circuit breaker is an electrical switch designed to protect an electrical circuit from damage caused by excess current. It automatically interrupts the flow of electricity in a circuit when it detects a fault, such as a short circuit or an overload. Circuit breakers are designed to trip (open the circuit) when the current exceeds a certain threshold for a specified period. This helps prevent overheating of wires, damage to equipment, and electrical fires.

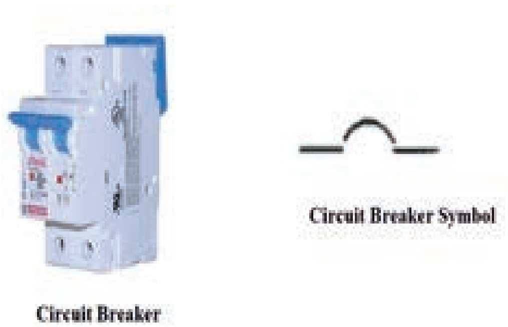



**Fig. 9.10:** *A circuit breaker and a symbol of a circuit breaker*

9. **LED (Light-Emitting Diode)**: An LED is a semiconductor device that emits light when an electric current passes through it. It consists of a semiconductor chip mounted on a reflector cup and encapsulated in a transparent or coloured epoxy resin.

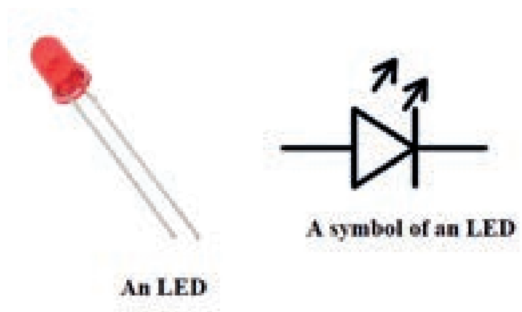



**Fig. 9.11:** *An LED and a symbol of an LED*

**Learning Tasks:**

Depending on the available time or resources, administer the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

Learners:

1. identify as many components as possible within the provided circuit's schematic and specify each component's function within the circuit. Refer to the explanations for the components provided in the lesson (resistors, capacitors, etc.).
2. present their findings to the class.

## Pedagogical Exemplars

1. Engage learners through discussion to tease out the meaning of the term circuit and develop their understanding of what electronic circuits and components are.
2. Using the technique of questioning, guide learners to think and ink what passive and active components are.
3. **Project-Based Learning**: Provide learners with pictures of various basic electronic components (e.g., Resistors, Capacitors, LEDs, Inductors, Circuit Breakers, Relays, Diodes, Transistors, etc.). Learners are then given electronic circuits from which they are to identify the components on the board and their indicated ratings.
   a. Using this **Project-based learning** approach, offer learners varying levels of detail required for component identification and function explanation. This caters to students with different levels of understanding.
   b. Strategically group students for this activity. Consider pairing advanced students with those who might need more support to foster peer learning and collaboration.
   c. Provide scaffolding and resources for students who may struggle with specific components or functions. This could include pre-labelled diagrams or short video tutorials on specific components.
   d. Prepare tiered discussion prompts with varying levels of complexity. Beginners can start with broad questions like "What makes a light bulb turn on?" while advanced students can delve deeper into concepts like "How do components control the flow of electricity?"
   e. Consider alternative identification methods for students who might benefit from a different approach. This could involve matching component images with symbols on a reference sheet or using online component identification tools.

## Key Assessment

1. **Assessment Level 1:** For a given electronic board, identify and list all major components.
2. **Assessment Level 2**: What is the main function of a capacitor?
3. **Assessment Level 3:** Describe a situation where a relay would be useful in a robotic circuit.
4. **Assessment Level 2:** How does a diode control the flow of current in a circuit?
5. **Assessment Level 3:** Design a simple circuit with a battery, resistor, and LED that could light up the LED. Explain how each component contributes to the circuit's function.
6. **Assessment Level 3:** How can understanding electronic circuit components be beneficial for designing robots with specific functionalities?
7. **Assessment Level 4:** Propose an innovative application of electronic circuits in robotics that addresses a current challenge in the field. Explain the components you would use and how they would work together.

**Conclusion:** Understanding electronic circuit components and their functions, as well as how to interpret block and schematic diagrams, are fundamental skills for digital and analogue system design. These skills empower students to build, troubleshoot, and optimise electronic circuits used in various robotic systems and applications. By correctly identifying components and understanding their functions, students can effectively design circuits to meet specific requirements and enhance the performance of robotic systems.

# WEEK 10

**Learning Indicator(s):** *Properly label and explain block and schematic diagram representation of electronic systems, system inputs and outputs.*

**Theme or Focal Area: Block and Schematic Diagram Representation of Electronic Systems and System Inputs/Outputs**

## Introduction

In the world of robotics, electronic systems play a critical role in controlling and coordinating various components to achieve specific tasks. Block diagrams provide a clear and concise representation of these complex systems. This section will explore the concept of block and schematic diagram representation for electronic systems, understand system inputs and outputs, and use appropriate diagrams to illustrate these concepts.

## Understanding Block Diagram Representation

A block diagram is a graphical representation that simplifies complex electronic systems by breaking them down into functional blocks connected by arrows representing signal flow. Each block represents a specific function or subsystem within the electronic system. For example, a block might represent a microcontroller, sensor module, or motor driver. The arrows between blocks indicate the direction of information or signal flow between different subsystems.

### System Inputs and Outputs in Block Diagrams

Inputs and outputs are essential aspects of any electronic system and are represented in block diagrams to illustrate the system's functionality and interactions with the external environment.

1. **System inputs**: Inputs represent the information or signals that enter the electronic system from external sources. These inputs can come from sensors, user interfaces, or other connected devices. In a block diagram, inputs are typically shown as arrows entering the respective blocks.
2. **System outputs**: Outputs represent the results, actions, or data generated by the electronic system and sent to external components or devices. Outputs can control motors, display information, or communicate data to other systems. In block diagrams, outputs are typically shown as arrows leaving the respective blocks.

### Block Diagram Representation in Robotics:

To illustrate the concept of block diagrams in robotics, let us consider a simple robotic system that includes three main functional blocks:

1. **Sensing block**: This block represents the sensors used in the robot to perceive the environment. Sensors could include cameras, ultrasonic sensors, or infra-red sensors.
2. **Control block**: The control block houses the microcontroller or microprocessor responsible for processing sensor data and making decisions. It takes inputs from the sensing block and generates control signals for the actuation block.
3. **Actuation Block**: This block includes the actuators responsible for physical actions in the robot, such as motors or servos. The actuation block receives control signals from the control block and executes the required actions.

**Robotic System Block Diagram**

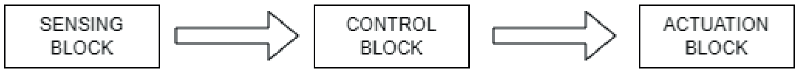



**Fig. 10.1:** *Block diagram representation of the robotic system with appropriate labels for each block and arrows indicating signal flow between the blocks.*

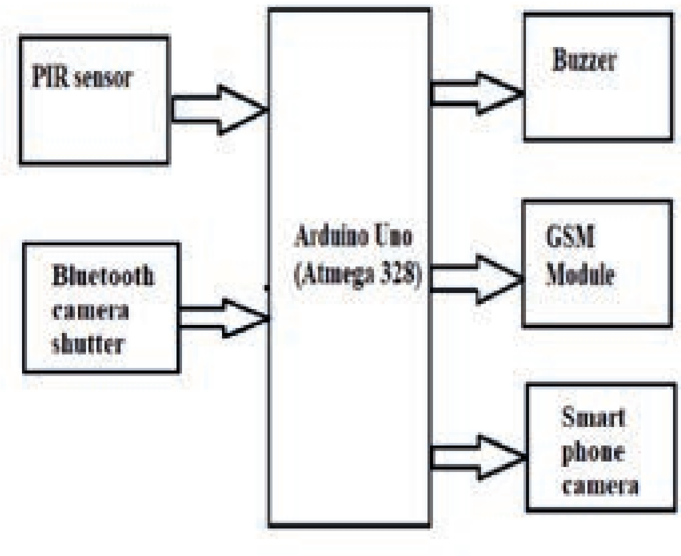



**Fig. 10.2:** *Block diagram of an Arduino system*

**Sensing block**: This block represents the sensors used in the robotic system to perceive the environment and gather data. These sensors could include cameras, ultrasonic sensors, infra-red sensors, or any other type of sensor required for the specific robot's task.

The Sensing Block provides inputs to the Control Block, passing on the information collected from the environment.

**Control block**: The Control Block houses the microcontroller or microprocessor responsible for processing the sensor data and making decisions.

It receives inputs from the Sensing Block and processes the data to determine the appropriate actions for the robot to take.

The Control Block generates control signals that govern the behaviour of the robot.

**Actuation block**: The Actuation Block includes the actuators responsible for executing physical actions in the robot, such as motors, servos, or other types of actuators.

It receives control signals from the Control Block, which instruct the actuators to perform specific movements or actions.

The Actuation Block produces the robot's outputs, which manifest as physical movements or operations.
**Arrows indicating signal flow**: An arrow points from the Sensing Block to the Control Block, representing the flow of information from the sensors to the micro controller for processing.

Another arrow points from the Control Block to the Actuation Block, symbolising the transmission of control signals from the microcontroller to the actuators, directing their actions.

This Schematic block diagram provides a simplified representation of a robotic system, emphasising the flow of information from sensing to processing and control, leading to physical actions executed by the actuators. The block diagram format is an essential tool for understanding and designing complex electronic systems in robotics.

### Understanding Schematic Diagram Representation

A schematic diagram is a simplified symbolic representation of an electronic circuit. It uses symbols to depict electronic components like resistors, capacitors, transistors, and integrated circuits (ICs). Lines connecting these symbols represent wires that carry electrical signals between components. By following the connections and understanding the symbols, you can visualize how the electronic system functions.

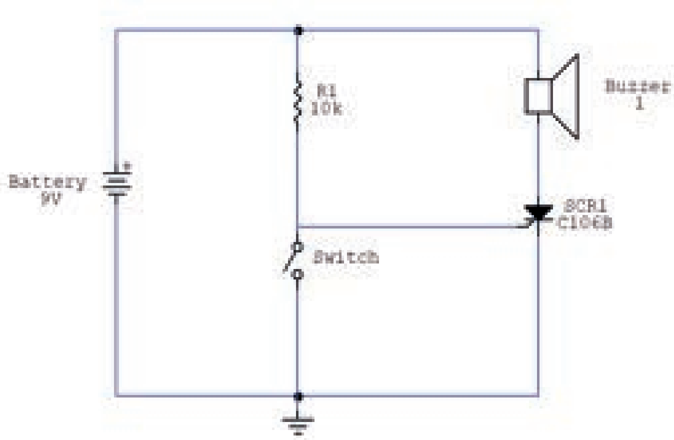



**Fig. 10.3:** *A simple schematic diagram*

### Components of a Schematic Diagram

1. **Symbols**: Schematic diagrams use standardized symbols to represent various electronic components such as resistors, capacitors, transistors, sensors, motors, and microcontrollers.
2. **Lines and Connections**: Lines in a schematic represent wires or conductive traces, while connections between components indicate how they are electrically linked.
3. **Labels and Annotations**: Components and connections are often labeled with values, part numbers, or annotations to provide additional information.

### Interpreting Schematic Diagrams

1. Component Identification: Begin by identifying the symbols for each component in the schematic and understanding their functions.
2. Circuit Flow: Follow the flow of the circuit from the input to the output, tracing how signals or power move through the system.
3. Connection Understanding: Pay attention to how components are connected and the paths signals take, including series and parallel connections.
4. Grounding: Identify the ground symbol and understand its role in providing a reference point for voltage levels.

### Creating and Reading Schematic Diagrams:

1. Use Standard Symbols: Always use standardized symbols to ensure clarity and consistency in your schematics.
2. Organize Neatly: Arrange components and connections logically to enhance readability and understanding.

3. Label Components: Clearly label components, connections, and important nodes to aid comprehension.
4. Document Changes: Document any modifications or updates made to the schematic to maintain accuracy over time.

Some schematic diagrams might look more realistic and some might just use symbols to represent various components as demonstrated below:

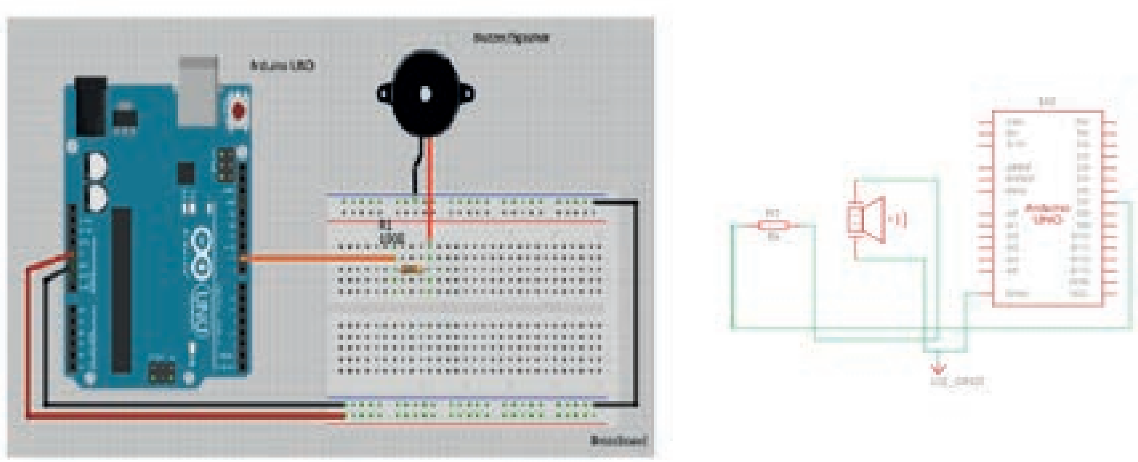


**Fig. 10.4:** *Schematic diagrams of Arduino buzzer*

**Differences between Block Diagram and Schematic Diagram**

Block diagrams use simple blocks to represent the main functional parts of a system and their connections, offering a high-level overview. Schematic diagrams, on the other hand, delve deeper with detailed symbols for specific electronic components and their precise connections, providing a blueprint for actual construction.

**Learning Tasks**

Depending on the available time or resources, administer one or more of the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

**Task 1: Identify Inputs and Outputs for block diagrams**

Learners identify the inputs and outputs in a block diagram of a simple electronic system used in robotics and explain their functions. (For example, identify the sensors as inputs and the actuators as outputs.)

**Task 2: Analyse a Schematic Diagram**

Learners identify the components, trace the connections, and explain how the circuit would function based on the schematic diagram.

**Task 3: Create Block Diagrams**

Learners create block diagrams for their assigned robotic systems, considering the different functional blocks and their interconnections. Discuss the significance of each block in achieving the system's overall objective with the whole class.

**Task 4: Analyse Signal Flow**

Learners analyse a block diagram with missing arrows representing the signal flow and draw the missing arrows to complete the signal flow path between the blocks and explain the functionalities to the whole class.

**Task 5: Design a Robotic System**

Learners design a simple robotic system for a specific task, such as an autonomous line-following robot. They should create a block diagram for their design, including inputs, control elements, and outputs. They should discuss the importance of each block in the system's operation.

**Task 6: Design Your Own Robot**

Learners brainstorm ideas for a simple robot they would like to build and sketch a basic schematic diagram for their robot, including the necessary components and connections. They then share their ideas and explain the function of their robot schematics.

## Pedagogical Exemplars

**Project-Based Learning**: Introduce learners to block and schematic notations. Develop block and schematic representations of given circuit narratives. Learners then pick other block abd schematic diagrams, write descriptive summaries of what they observe, and share them with the class.

1. Before introducing block or schematic diagrams, discuss familiar system representations (e.g., flowchart for a recipe). This builds a foundation for understanding the concept of breaking down processes into steps.
2. Highlight real-world robotic systems and their corresponding block or schematic diagrams. This helps students connect the abstract concepts to practical applications.
3. Briefly introduce the concept of block diagrams for beginners, focusing on the basic idea of breaking down systems into functional blocks. Do same when talking about schematic diagrams breaking it down to the various symbols, lines and connections.
4. Use annotated block diagrams alongside explanations. Highlight key components within each block and the direction of signal flow with clear labels.
5. Provide opportunities for kinaesthetic learners to build a simple physical model of a robotic system using Lego or building materials. Each block can represent a functional unit (e.g., sensor block, control block, motor block).
6. Offer project variations with different levels of complexity. Beginners can focus on developing block diagrams from simple circuit narratives, while advanced students can create both block and schematic representations from more intricate narratives.
7. Provide a range of circuit narratives with varying difficulty levels. Students can choose narratives that match their understanding and challenge themselves appropriately.
8. Form groups with a mix of learning styles and abilities. This fosters peer learning and collaboration. Advanced students can support those who might need help understanding the concepts.
9. Offer a variety of resources alongside the project. This could include pre-labelled block and schematic diagrams, online tutorials on schematic symbols, or peer tutoring sessions for additional support.
10. Provide graphic organisers to help students structure their analysis and summarise their observations of existing schematic and block diagrams.
11. Allow students to choose how they present their summaries. Some might prefer written reports, while others might excel at creating short video explanations or visual presentations using diagrams and annotations.

## Key Assessment

1. **Assessment Level 1:** What are the two main elements represented in a block diagram?
2. **Assessment Level 1:** How are system inputs typically shown in a block diagram?
3. **Assessment Level 2:** Explain the purpose of using block diagrams in robotics.
4. **Assessment Level 2:** Explain the purpose of using schematic diagrams in robotics.
5. **Assessment Level 3:** For a given PCB circuit, identify and list all components, describe their fundamental purpose, and develop their block diagrams and schematic
6. **Assessment Level 3:** Design a block diagram to represent a robotic system with a specific function (e.g., line following robot, obstacle avoiding robot). Explain the purpose of each block and the signal flow within the system.

**Conclusion:** Block and Schematic diagrams are powerful tools for representing electronic systems, particularly in robotics, as they simplify complex structures and highlight the interactions between different subsystems. Understanding block and schematic diagrams allows students to grasp the overall functionality of the system, identify inputs and outputs, and visualise the flow of signals and information within the system. By completing the learning tasks, students reinforce their skills in creating and interpreting block diagrams, enabling them to effectively design, analyse, and optimise electronic systems in robotics to achieve specific tasks and functionalities.

# WEEK 11

**Learning Indicator(s):** *Assemble and test electronic circuits on a solderless breadboard using pre-designed schematic diagrams*

**Theme or Focal Area: Hands-On Electronic Circuit Assembly: Building and Testing Circuits on a Solderless Breadboard**

## Introduction

This practical section will focus on building and testing electronic circuits on a solderless breadboard. Assembling circuits is a fundamental skill for robotics enthusiasts and engineers alike. We will follow pre-designed schematic diagrams to assemble circuits step-by-step. The hands-on experience of building circuits on a solderless breadboard will reinforce your practical skills and competency in electronic circuit assembly.

## Introduction to Solderless Breadboards:

A solderless breadboard is a reusable platform used for prototyping electronic circuits without the need for soldering. It consists of a grid of interconnected metal clips that allow components to be inserted and connected easily. Components placed on the breadboard remain secure and can be easily repositioned or removed.

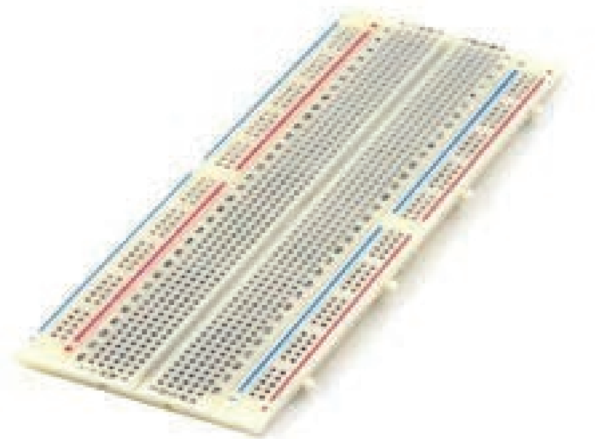


**Fig. 11.1:** *Solderless Breadboard*

**Safety Precautions**

Before starting the practical session, ensure that you follow safety guidelines such as working in a well-ventilated area, handling electronic components with care, and turning off power sources when necessary.

**Assembling Circuits on a Solderless Breadboard**:

For this lesson, we will work with pre-designed schematic diagrams for three different electronic circuits:

1. LED Flasher Circuit: A simple circuit that makes an LED flash on and off.

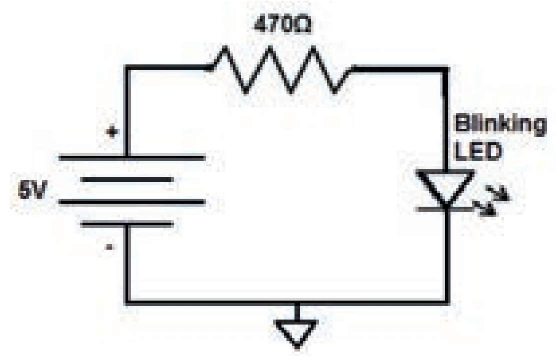



**Fig. 11.2:** *Simple LED light flasher circuit*

2. Light-sensitive LED Circuit: A circuit that lights up an LED when exposed to light.

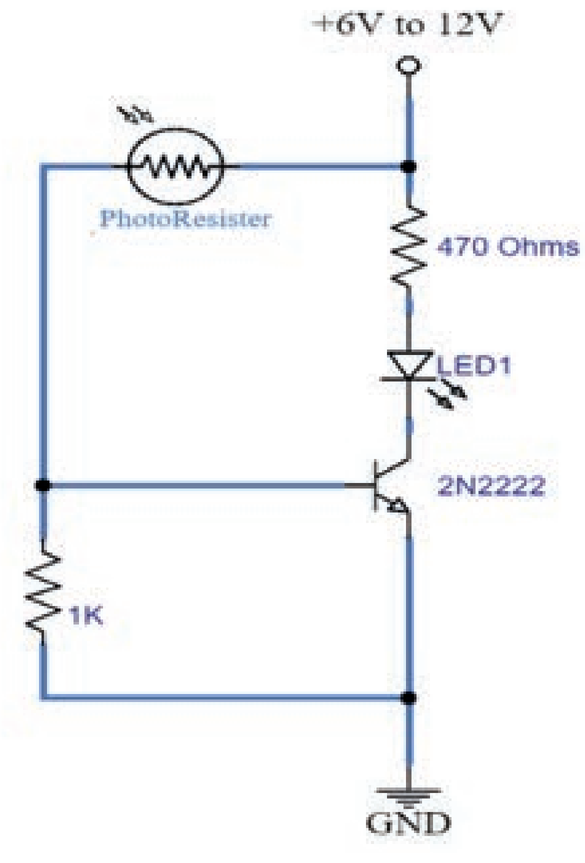



**Fig. 11.3:** *A circuit that lights up an LED when exposed to light (Beig, 2023).*

**3.** Motor Control Circuit: A circuit that controls the direction of a DC motor.

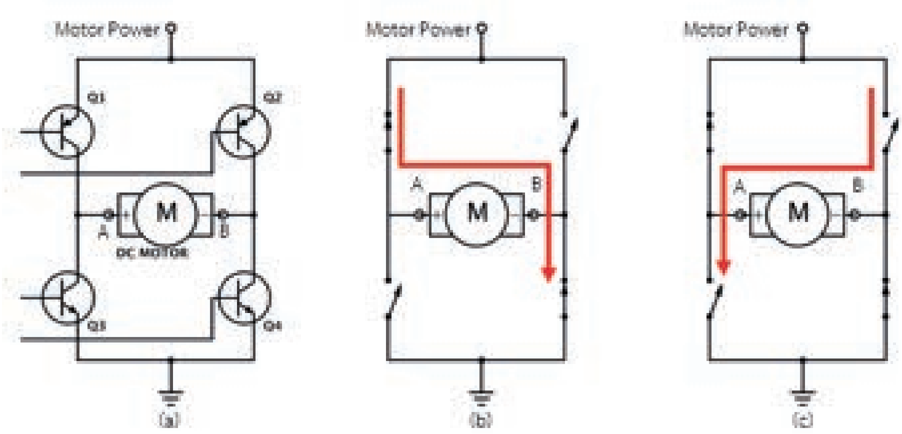



**Fig. 11.4:** *A circuit that controls the direction of a DC motor. (HELPDESK_WJ (Waijung))*

## Learning Tasks

Depending on the available time or resources, administer one or more of the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

**Task 1: LED Flasher Circuit Assembly**

Learners:

1. Follow a provided schematic diagram to assemble the LED flasher circuit on a solderless breadboard.
2. Identify and gather the necessary components: resistors, capacitors, transistors, and LEDs.
3. Insert each component into the breadboard according to the schematic, making sure to connect them correctly.
4. Use jumper wires to connect the components and create the circuit paths.
5. Test the circuit by applying power and observing the LED's flashing behaviour.

**Task 2: Light-sensitive LED Circuit Assembly**

Learners:

1. Follow the schematic diagram to assemble the light-sensitive LED circuit.
2. Gather the components: photoresistor, resistor, transistor, and LED.
3. Carefully position the components on the breadboard, adhering to the circuit design.
4. Connect the components using jumper wires, ensuring correct connections.
5. Test the circuit's responsiveness to light by exposing the photoresistor to different light levels and observing the LED's behaviour.

**Task 3: Motor Control Circuit Assembly**

Learners:

1. Work with the provided schematic to build the motor control circuit.

2. Gather the components: H-bridge IC, resistors, capacitors, and DC motor.
3. Place each component on the breadboard as per the circuit design.
4. Connect the components and motor using jumper wires.
5. Test the circuit by providing power and observing the motor's response to control inputs.

## Pedagogical Exemplars

**Project-Based Learning**

Explain the configuration of breadboards to learners and guide them in using monitoring tools like the digital multimeter. Assemble and test electronic circuits on a solderless breadboard using pre-designed schematic diagrams

1. Before the hands-on activity, break down the circuit assembly process step-by-step using the chosen schematic diagram. Explain the function of each component and how they connect on the breadboard.
2. Use clear and well-annotated schematic diagrams with colour coding for different component types (resistors, capacitors, etc.). This can aid visual learners in understanding the circuit layout.
3. Offer project variations with different levels of complexity. Beginners can focus on developing block diagrams from simple circuit narratives, while advanced students can create both block and schematic representations from more intricate narratives.
4. Provide a range of circuit narratives with varying difficulty levels. Students can choose narratives that match their understanding and challenge themselves appropriately.
5. Form groups with a mix of learning styles and abilities. This fosters peer learning and collaboration. Advanced students can support those who might need help understanding the concepts.
6. Offer a variety of resources alongside the project. This could include pre-labelled block diagrams, online tutorials on schematic symbols, or peer tutoring sessions for additional support.
7. Provide graphic organisers to help students structure their analysis and summarise their observations of existing schematic and block diagrams.
8. Allow students to choose how they present their summaries. Some might prefer written reports, while others might excel at creating short video explanations or visual presentations using diagrams and annotations.
9. Complement the project with kinaesthetic learning activities. Students can build simple circuits using physical components like breadboards and wires to solidify their understanding of the connection between real circuits and their representations.
10. Offer clear and concise visual aids throughout the project. This includes providing well-labelled examples of schematic symbols and block components.

## Key Assessment

1. **Assessment Level 1:** What is a solderless breadboard used for?
2. **Assessment Level 1:** List two safety precautions one must observe before starting a practical session.in robotics.
3. **Assessment Level 2:** Explain the benefits of using a solderless breadboard compared to traditional soldering for circuit assembly.

4. **Assessment Level 3:** Explain why it is important to follow a schematic diagram when building an electronic circuit.
5. **Assessment Level 4:** Review online resources and identify appropriate schematic diagrams for useful electronic circuits. Use the identified schematic diagrams to build and test the corresponding circuits.

**Conclusion:** By assembling and testing electronic circuits on a solderless breadboard using pre-designed schematic diagrams, you have gained practical skills in electronic circuit assembly. This hands-on experience is essential for robotics enthusiasts, as it enables you to prototype and test various circuits without the need for soldering. The learning tasks provided reinforced your competency in following schematic diagrams, correctly placing components on the breadboard, and verifying circuit functionality. These skills will be invaluable as you continue to explore and design electronic circuits for robotics projects and beyond.

# WEEK 12

**Learning Indicator(s):** *Critically analyse analogue and digital systems and observe how they relate to both discrete and continuous-time machine designs.*

**Theme or Focal Area: Exploring Digital and Analogue Systems in Discrete and Continuous-Time Machine Design**

## Introduction

This section will dive into the world of digital and analogue systems and their significance in discrete and continuous-time machine design. Electronic circuits are fundamental building blocks in robotics, enabling robots to process information, perform computations, and interface with the physical world. By the end of this lesson, you will gain practical skills in assembling electronic circuits from schematic diagrams and understand their critical applications in both discrete and continuous-time machine design.

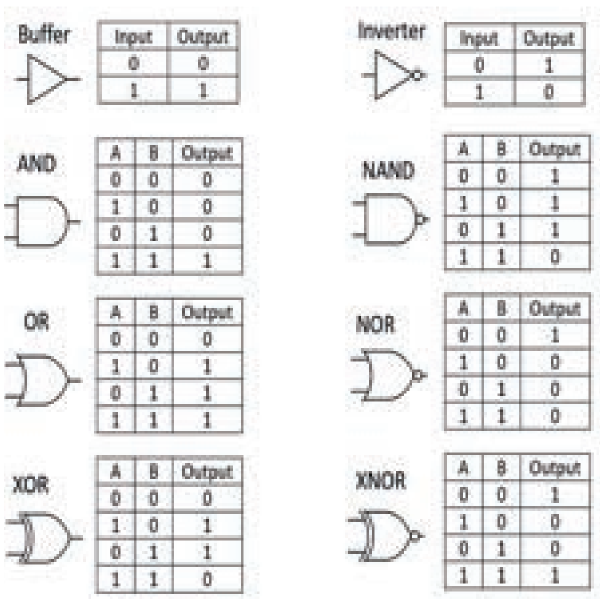
## A. Understanding Digital Systems

Digital systems are built with digital circuits which process information in binary digits (0 and 1). These binary digits form discrete signals. A discrete signal is a signal that is either on or off, true, or false. Digital systems are based on logic gates that perform logical operations by processing discrete signals, enabling computation and decision-making in robotics. A logic gate is an electronic circuit designed by using electronic components like diodes, transistors, resistors, and more. As the name implies, a logic gate is designed to use binary digits to perform logical operations in digital systems like laptops, telephones, and tablets.

Therefore, we can say that the building blocks of a digital circuit are logic gates

**Simulating digital circuits**: To simulate digital (logical) circuits from schematic diagrams:

1. ***Identify logic gates***: Learn about common logic gates, such as AND, OR, NOT, NOR and XOR, and understand their truth tables.




| Input | Output |
|---|---|
| 0 | 0 |
| 1 | 1 |

| Input | Output |
|---|---|
| 0 | 1 |
| 1 | 0 |

| A | B | Output |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 1 | 1 |

| A | B | Output |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 1 | 0 |

| A | B | Output |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 1 | 1 |

| A | B | Output |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 1 | 0 |

| A | B | Output |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 1 | 0 |

| A | B | Output |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 1 | 1 |

**Fig. 12.1:** *Basic Logic Gates and their Truth Table*

| Name | Symbol & notation | Explanation |
|---|---|---|
| NOT | $\overline{A}$ | The inverter<br>NOT simply accepts an input and **outputs the opposite**. |
| AND | $AB$ | **All inputs** must be positive (1) before the output is positive (1 or ON) |
| NAND | $\overline{A.B}$ | Same as AND, but the **outcome is the inverse** (NOT).<br>So, perform **AND first, then apply NOT** to the output. |
| OR | $A+B$ | **At least** one input must be positive (1) to give a positive output (1 or ON).<br>**All** inputs could also be positive. |
| NOR | $\overline{A+B}$ | Same as OR, but the **outcome is the inverse** (NOT).<br>So, perform **OR first, then apply NOT** to the output. |
| XOR | $A \oplus B$ | **Only one** input can be positive (1) to give a positive output (1 or ON).<br>If both are positive, the output is negative (0 or OFF) |
| XNOR | $\overline{A \oplus B}$ | **All inputs** must be the same (either high or low) for a positive output (1).<br>Otherwise, the output is negative (0 or OFF) |

**Fig. 12.2:** *Logic gate symbols showing how they control inputs to create desired outputs.*

2. ***Logical circuit design***: To design a logical circuit, the following steps can be followed:

   a. ***Understand the given specifications***: Before designing a digital circuit, you must understand the given specifications. It will help you know why you need to create the digital logic and what output the system requires

   b. ***Find the number of inputs and outputs***: It is essential to find the number of inputs and outputs for the given logic circuit. It is like determining the components of a diagram

   c. ***Create a truth table***: After determining the number of inputs, you can create the truth table for your logical circuit. A truth table tells you the outputs for your logic designs given the number of inputs. The columns of the truth table represent the outputs and inputs.

   d. ***Draw the circuit diagram***: The final step in designing a digital logic is making a circuit diagram. Make sure there are no changes between the inputs and outputs of your diagram based on the truth table you created earlier.

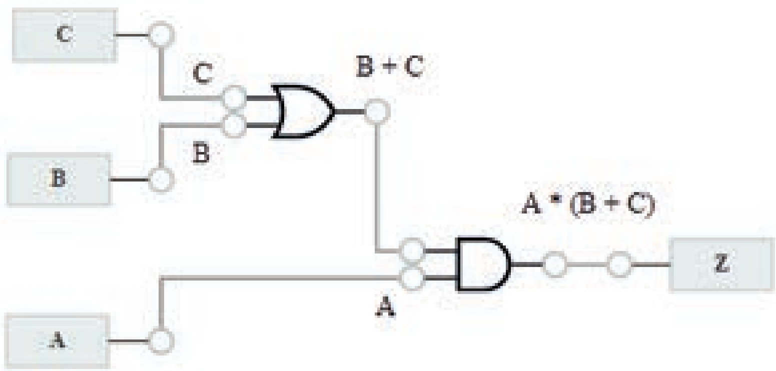



**Fig. 12.3:** *A circuit diagram to show 2 logic gates used to determine the output Z from three inputs, A, B and C.*

## B. Understanding Analogue Systems

An electrical analogue is a way of representing the operation of a logic gate such as OR gate, AND gate, NOT gate in the form of an electric circuit. The operation of a logic gate is determined using selected circuit components like resistors, diodes, and capacitors. An analogue circuit works with analogue signals in the form of continuous waves. Analogue systems process information as continuous signals (analogue audio, voltage levels or temperature readings), which represent real-world physical quantities with varying voltage or current levels. Analogue circuits are essential for sensor interfacing and real-time control in robotics.

### Assembling Analogue Circuits

To assemble analogue circuits from schematic diagrams:

1. **Component selection**: Understand the roles of resistors, capacitors, and operational amplifiers in analogue circuits.

   Resistors, capacitors, and operational amplifiers (op-amps) are essential components in analogue circuits. They serve distinct roles and are fundamental to various functionalities within these circuits. Let us explore their roles in more detail:

   a. ***Resistors*****:** Resistors are passive components that resist the flow of electrical current. They play several critical roles in analogue circuits:

      i. *Current Limiting*: Resistors are used to limit the current flow in specific parts of the circuit, preventing damage to components and maintaining stable operation.

      ii. *Voltage Division*: In voltage divider circuits, resistors divide the voltage across two points in the circuit, allowing for precise voltage regulation.

      iii. *Biasing*: Resistors are used in biasing circuits to establish the appropriate operating points for transistors and other active devices.

      iv. *Load Resistance*: In amplifier circuits, resistors function as load resistances to ensure the correct amplification of signals.

   b. ***Capacitors*****:** Capacitors are passive components that store electrical charge and play significant roles in analogue circuits:

      i. *Filtering*: Capacitors are used in filtering circuits to block certain frequencies and allow only specific frequencies to pass through.

      ii. *Timing Elements*: Capacitors, along with resistors, create timing elements in oscillators and timer circuits, determining the frequency of output waveforms.

      iii. *Coupling*: Capacitors are used for coupling AC signals between different stages of an amplifier, allowing the DC component to be blocked while passing the AC signal.

iv. *Energy Storage*: Capacitors store energy and function as temporary power sources in circuits, helping to stabilise voltage levels during voltage fluctuations.

c. ***Operational Amplifiers (Op-Amps)*:** Op-amps are active devices that are widely used in analogue circuits due to their high gain and versatility. They serve various essential functions, including:

i. **Amplification**: Op-amps amplify weak signals, making them suitable for various applications, such as audio amplification and sensor interfacing.

ii. **Summing and Difference Amplification**: Op-amps can sum multiple input signals or compute the difference between two input signals.

iii. **Voltage Follower**: Op-amps can function as voltage followers, providing high input impedance and low output impedance, ensuring minimal signal loss.

iv. **Integrators and Differentiators**: In combination with resistors and capacitors, op-amps can perform integration and differentiation operations on input signals.

v. **Comparato**r: Op-amps can compare two input voltages and output a high or low signal based on the comparison, making them suitable for decision-making tasks.

In summary, resistors, capacitors, and operational amplifiers are essential components in analogue circuits, each contributing unique functionality to achieve specific tasks. Understanding their roles and characteristics is crucial for designing and building effective analogue circuits used in various applications, including sensors, filters, signal conditioning, and power regulation in robotics, as well as many other electronic devices and systems.

2. **Circuit design**: Follow schematic diagrams to connect analogue components and create specific analogue functions.

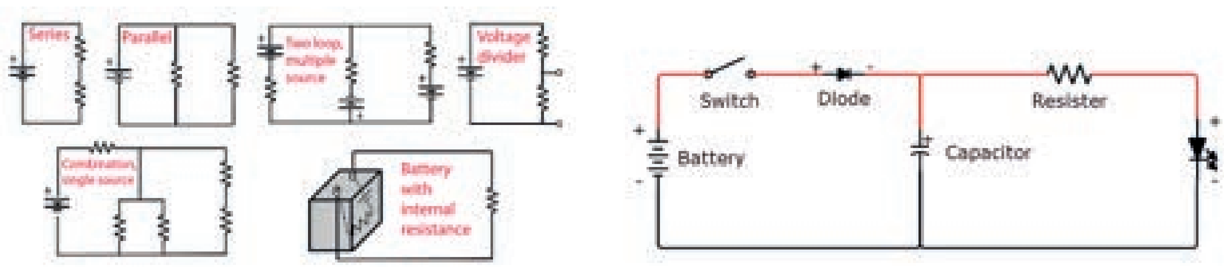



**Fig. 12.4:** *Different Analogue Circuits*

## C. Discrete-Time Machine Design

Exploring how digital systems are used in discrete-time machine design:

In discrete-time systems, events occur at distinct, well-defined intervals, and digital circuits provide the necessary framework to manage these discrete events effectively. Here are some ways digital systems are used in discrete-time machine design:

1. **Signal processing and computation**: Digital systems excel in processing discrete signals and performing complex computations. Sensors in discrete-time machines generate discrete data, which is sampled and converted into digital form by analogue-to-digital converters (ADCs). Once in digital form, micro controllers, or digital signal processors (DSPs) can process the data through algorithms, filtering, and transformations to make decisions and control the machine's actions.

2. **Logic-based control**: Digital logic gates and circuits are the backbone of discrete-time control systems. Logic gates (AND, OR, NOT, etc.) are used to evaluate conditions and determine

the appropriate control actions based on predefined rules or algorithms. Decision-making processes, such as switching on or off specific actuators or motors, are accomplished through digital control logic.

**Finite State Machines:** Finite State Machines (FSMs) are widely used in discrete-time machine design. FSMs enable robots to model complex behaviours and decision-making based on different states and transitions. Each state represents a specific condition or behaviour, and digital logic is used to determine state transitions based on inputs from sensors or user commands.

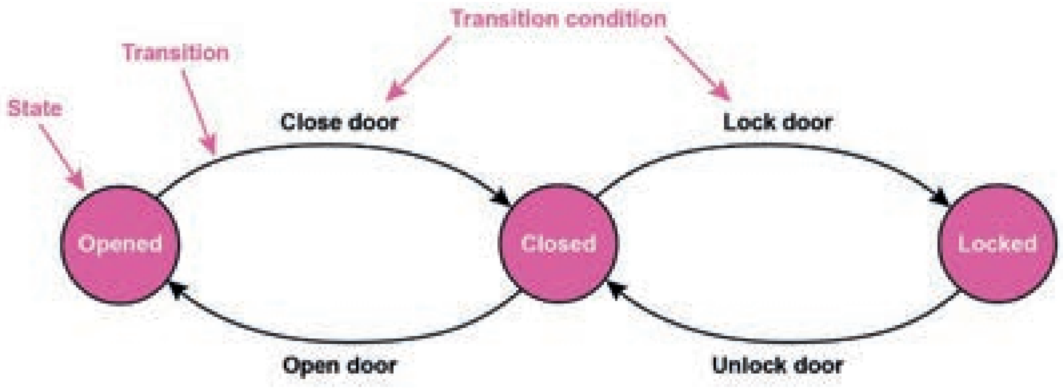



**Fig. 12.5:** *illustration of a Finite State Machine*

**Timers and Clocks**: Digital systems can incorporate timers and clocks to control the timing of events in discrete-time machines. Timers can be programmed to trigger specific actions or tasks at predefined intervals, allowing precise control over the machine's operations is depicted in the illustration of the FSM above.

**Pulse-Width Modulation (PWM)**: PWM is a widely used digital control technique in discrete-time machine design. PWM signals allow robots to control motor speeds, actuator positions, and light intensity by varying the duty cycle of the digital pulse. This technique is particularly useful in generating smooth analogue-like control signals from digital systems.

**Digital Communication and Networking**: Digital communication protocols, such as UART, SPI, and I2C, enable discrete-time machines to communicate with other devices or systems. Robots can exchange data with sensors, actuators, or central controllers, facilitating coordinated actions and distributed intelligence.

**Digital Feedback Control**: Digital feedback control loops play a crucial role in ensuring accurate and stable control of discrete-time machines. Sensors provide feedback on the machine's current state, which is processed digitally to calculate error signals and adjust control actions for precise regulation.

**Programmability and Flexibility**: Digital systems offer high programmability and flexibility, making it easier to modify, update, or adapt the control algorithms and behaviour of discrete-time machines. This flexibility enables robots to perform various tasks and adapt to changing environments efficiently.

**Signal Processing**: Digital systems process discrete signals using binary digits (0s and 1s) to control robotic actions and computations. The processing of discrete signals involves the manipulation of binary data through logic gates and digital circuits. Here is a detailed analysis of how digital systems achieve this control in robotics:

**Binary Representation**: Digital systems use binary representation to encode information. Each binary digit (bit) can either be a 0 or a 1, representing two distinct states. By combining multiple bits, digital systems can represent more complex data, such as numbers, characters, or sensor readings.

**Logic gates and combinational circuits**: By combining these logic gates in various configurations, digital circuits can perform complex computations and make decisions based on input conditions

1. **Digital Control**: Understand the role of micro controllers and programmable logic controllers (PLCs) in discrete-time machine control.

   Micro controllers and programmable logic controllers (PLCs) play crucial roles in discrete-time machine control, enabling precise and efficient management of robotic systems. Let us explore their roles in more detail:

   a. *Real-Time Computation*: Micro controllers can execute complex algorithms and perform real-time computations to process sensor data, make decisions, and generate control signals for the robotic system.
   b. *Sensor Interface:* Micro controllers' interface with various sensors (e.g., proximity sensors, encoders, temperature sensors) to gather data from the robot's environment. They convert analogue sensor signals into digital data for processing.
   c. *Actuator Control*: Micro controllers control actuators, such as motors and solenoids, based on computed control signals. They ensure precise and timely actuator responses, crucial for discrete-time control tasks.
   d. *Event-Driven Control*: Micro controllers can be programmed to respond to specific events or input conditions, enabling the robot to execute predetermined actions at precise moments.
   e. *Feedback Control*: In closed-loop control systems, micro controllers receive feedback from sensors and adjust the control signals accordingly to maintain desired system behaviour

**Programmable Logic Controllers (PLCs) in Discrete-Time Machine Control:** PLCs are industrial-grade digital computers designed for robust and reliable control of discrete processes in automation and manufacturing environments. In discrete-time machine control, PLCs offer several advantages:

1. *Modularity and Flexibility*: PLCs are highly modular, allowing easy integration with various input and output modules to interface with sensors and actuators. They can be easily reprogrammed for different control tasks, providing flexibility in robot operation.
2. *Ruggedness and Reliability*: PLCs are built to withstand harsh industrial environments, making them suitable for demanding robotic applications that require robust and reliable control.
3. *Distributed Control*: PLCs support distributed control architectures, enabling multiple PLCs to communicate and coordinate tasks in complex robotic systems.
4. *Time-Based Sequencing*: PLCs execute control logic based on a fixed time cycle, ensuring precise timing and synchronisation of discrete events, such as robotic movements and material handling tasks.
5. *Fault Tolerance*: PLCs often include built-in fault detection and recovery mechanisms, enhancing the reliability and safety of robotic systems.

**Constructive interaction of microcontrollers and PLCs:** In many robotic applications, microcontrollers and PLCs work together to achieve efficient and comprehensive control. Micro controllers manage specific low-level tasks, such as motor control and sensor interfacing, while PLCs oversee higher-level control and coordination of multiple robotic processes. This combination optimises the use of resources, enhances system responsiveness, and simplifies the overall control architecture.

## D. Continuous-Time Machine Design

Continuous-time control systems operate by continuously adjusting input signals to regulate and modify the system's output**.** Real time reactions are critical in Continuous-Time Machine design. Actuators (such as motors, valves, or heaters) receive the control signal and modify the system.

Sensors measure the system's output and provide feedback to the controller. The controller adjusts the control signal to achieve the desired output.

An analogue oscilloscope is an example of a machine that utilizes continuous-time principles in electronics. By connecting an analogue oscilloscope to an electrical circuit, it continuously samples the input voltage at specific time intervals and produces a wave form. These devices are used in testing and calibration and troubleshooting of analogue circuits.

Investigate how analogue systems are applied in continuous-time machine design in the following areas

1. **Sensor interfacing**: Observe how analogue circuits interface with sensors to convert continuous physical quantities into electronic signals.
2. **Real-Time control**: Analyse how analogue feedback control systems are used in continuous-time machine design.

**Learning Tasks**

Depending on the available time or resources, administer the following learning tasks to help learners reinforce understanding and acquire new knowledge or skills.

Learners:

1. Observe and contrast the outputs of digital and analogue systems to spot the differences from examples of discrete and continuous-time machines. e.g., analogue radio sets, ceiling fans, wall clocks, pulse metres, digital and analogue scales, etc.
2. Observe the inputs and outputs of these machines and classify them as analogue or digital.

## Pedagogical Exemplars

**Project-Based Learning**: Introduce learners to analogue and digital signals. Learners observe and contrast the outputs of digital and analogue systems to spot the differences. Provide learners with examples of discrete and continuous-time machines (e.g., analogue radio sets, ceiling fans, wall clocks, pulse metres, digital and analogue scales, etc). Observe the inputs and outputs of these machines and classify them as analogue or digital.

1. Provide step-by-step explanations for assembling analogue circuits and designing digital circuits. Utilize clear visuals and annotated diagrams throughout.
2. Offer a range of examples for each concept. Beginners can start with simpler examples like single logic gates, while advanced students can explore more intricate circuits with multiple components and functionalities.
3. Present information in multiple formats to cater to different learning styles. This can include text explanations, visual aids like diagrams and flowcharts, and even interactive simulations for digital circuits.
4. Encourage collaborative learning during circuit building activities or design tasks. Students can learn from each other and provide explanations or troubleshooting support within groups.
5. Provide varying levels of support throughout the lesson. Beginners might benefit from more direct guidance, while advanced students can work more independently with resources available for reference.
6. Offer project variations with different complexity levels. Beginners can focus on classifying simple machines like wall clocks (analogue) and digital scales (digital) based on inputs and outputs. Advanced students can explore more complex machines like radios (analogue) and pulse meters (digital), analysing their internal functionalities and signal processing.

7. Allow students to choose from a range of machines to observe. Consider their interests and prior knowledge when offering options. This promotes ownership and engagement in the project.
8. Form groups with a mix of learning styles and abilities. Collaborative learning fosters peer support and allows students to learn from each other's explanations and observations.
9. Provide project materials with varying levels of complexity. This could include pre-made observation checklists for beginners or detailed information on internal workings of machines for advanced students.
10. Encourage advanced students to act as "experts" within their groups, sharing their knowledge and guiding discussions on specific machine functionalities.
11. Offer graphic organisers specifically designed for project tasks. These can help students structure their observations by categorising inputs, outputs, and signal types (analogue or digital) for each machine.
12. Consider alternative observation methods for students who might benefit from a different approach. This could involve watching video demonstrations of machine operation or utilizing online simulations for closer examination of internal functionalities.
13. Complement the project with kinaesthetic activities. Students can build simple models representing analogue and digital systems using readily available materials. This reinforces understanding of how these systems process information and generate outputs.
14. Allow students to present their findings in creative ways beyond just written reports. This could involve creating diagrams with annotations, building physical models with clear labelling, or even short skits demonstrating the operation of different machines.

## Key Assessment

1. **Assessment Level 1:** What are the two basic building blocks of digital circuits?
2. **Assessment Level 1:** List two functions of resistors in analogue circuits.
3. **Assessment Level 2:** Explain the difference between a discrete and a continuous signal.
4. **Assessment Level 2:** Describe the role of operational amplifiers (op-amps) in analogue circuits.
5. **Assessment Level 3:** Imagine you are designing a robot arm that needs to move to precise positions. How could you use both digital and analogue systems in this design?
6. **Assessment Level 4:** Using diagrams and real world examples explain how digital and analogue systems are interfaced with and combined in machine designs.

**Conclusion:** In this robotics lesson, you have explored digital and analogue systems in both discrete and continuous-time machine design. Assembling electronic circuits from schematic diagrams is a crucial skill for any robotics engineer, as these circuits are the backbone of robotic functionality. Understanding how digital systems enable discrete-time control and how analogue systems facilitate continuous-time control will empower you to design and build sophisticated robotic systems.

## Section Review

This section of the manual focused on the building blocks of robots - electronic circuits! Over the past four weeks, learners tackled essential components like resistors and capacitors, learning their functions in both digital and analogue circuits. They gained fluency in the language of circuits by interpreting and labelling schematic diagrams, including system inputs and outputs.

Next, students put theory into practice by assembling electronic circuits on a breadboard using pre-designed schematics. This hands-on experience solidified their understanding of the building process. Finally, they delved deeper by critically analysing the differences between digital and analogue systems. They explored how these systems contribute to the design of robots, differentiating between discrete-time machines with pre-programmed actions and continuous-time machines that utilise real-time sensor feedback. By mastering these concepts, students have built a strong foundation for understanding and working with the electronic brains of robots.

## References

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