SECTION 1

ROBOT CONTROL PRINCIPLES 1

Principles of Robotic Systems

Robot Control Principles

Introduction

This section of the course is developed to help you understand the distinct features and advancements that characterise 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. 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 robotic. This part of the course is designed to help you acquire knowledge in the use of logic and loop diagrams and develop skill in their use in control system design. This course will introduce you to how robots, much like us, think and act to achieve their tasks. You will explore the principles of robotic systems, focusing on the application of logic and control loops, and their significance in designing robot control systems.

At the end of the section, you will be able to:

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.
3. 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

Key Ideas

- **Industrial Revolutions:** These are periods that have introduced innovations such as mechanisation, steam power, and mass production, transforming economies and lifestyles worldwide.
- **Roboethics:** Roboethics is concerned with how robots can be used effectively and responsibly

THE INDUSTRIAL REVOLUTION – UNVEILING THE EVOLUTION OF MODERN INDUSTRY

The changes that have happened over the years in industry and technologies have led to advancements in robots, their effect on humans, and how they both co-exist. To understand their impact, it is crucial to explore the distinct features and advancements characterising the transition from each of the industrial revolutions.

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.

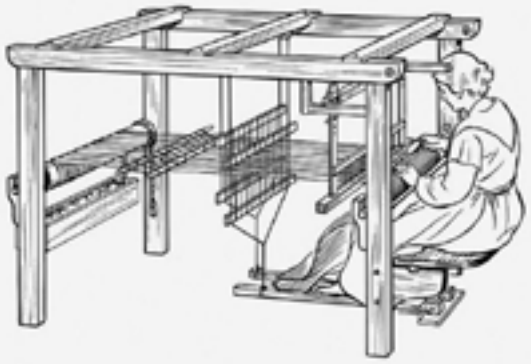
1. First Industrial Revolution (1760-1830)

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 (farming-based) economies into industrialised urban-centred economies. 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. An example of this is the machinery

used to weave kente in Bonwire in Ashanti Region and other areas in Ghana. This introduction reduced reliance on human labour and boosted productivity.



https://en.wikipedia.org/wiki/Loom

Fig. 1.1 A loom used in the textile industry

b. Mechanisation in mining; In 1712, the first steam engine was built. It used steam power for mechanical work. Steam pushed a piston up and was cooled by water, creating a vacuum that let the piston down by gravity. It was also used to pump water. Later, other 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. In Ghana, however, it wasn't until the year 1901 was railway constructed by the British colonial government to connect the inland mining town of Tarkwa to the port city of Sekondi. This railway was essential for transporting minerals such as gold and manganese to the coast for export.

Fig. 1.2: A steam train

2. Second Industrial Revolution (1870-1914)

The Second Industrial Revolution, which is also referred to 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. This innovation of the light bulb and electricity transmission system was in the 1800s by Thomas Edison. During this time in Ghana, locals still used kerosene powered lamps and candles. It was not until 1900s did Ghana enjoy the innovation of electrical power systems.

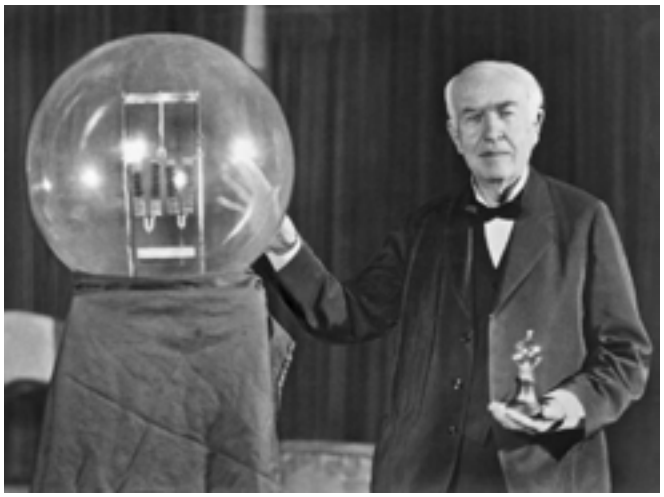


Fig. 1.3 Thomas Edison at the Light Bulb's Golden Jubilee anniversary (Duranton, 2023)

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. In the same sense, in 1968, there was a vehicle assembly plant in Ghana which locally produced public buses into service. There were other plants that cropped up later in the first republic that boosted the use of automobiles.

Fig. 1.4 Assembly Line in Henry Ford's Automobile 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.

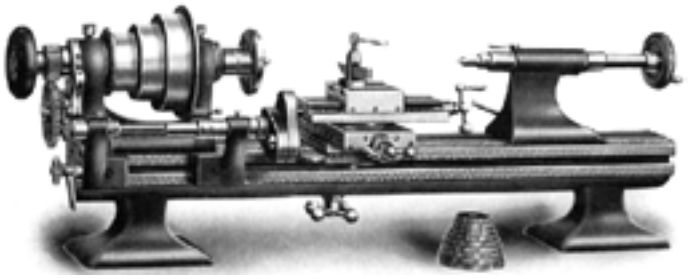


Fig. 1.5 An early generation Lathe and Milling Machine (Murray, 2022)

3. Third Industrial Revolution (1950s–1990s)

The Third Industrial Revolution, also known as the Digital Revolution or Industry 3.0, involved the use of computers and electronics in the use of industrial production processes. 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 actions in the real world but lacked a brain to mimic human thinking.

By the third industrial revolution, some machines (with basic robotic functionalities) began to replace humans to perform repetitive tasks by using computers or processors acting on data received from sensors. These computing systems process data from sensors into actionable decisions used to coordinate the movement of mechanical subsystems. Robotic arms in factories are typical examples of these computer-controlled repetitive tasks. Robot arms were first used in factories in the 1970s. This forms the true definition of machines that fully qualify as robots.

Some key technologies of the third 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 and

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 – present)

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 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.

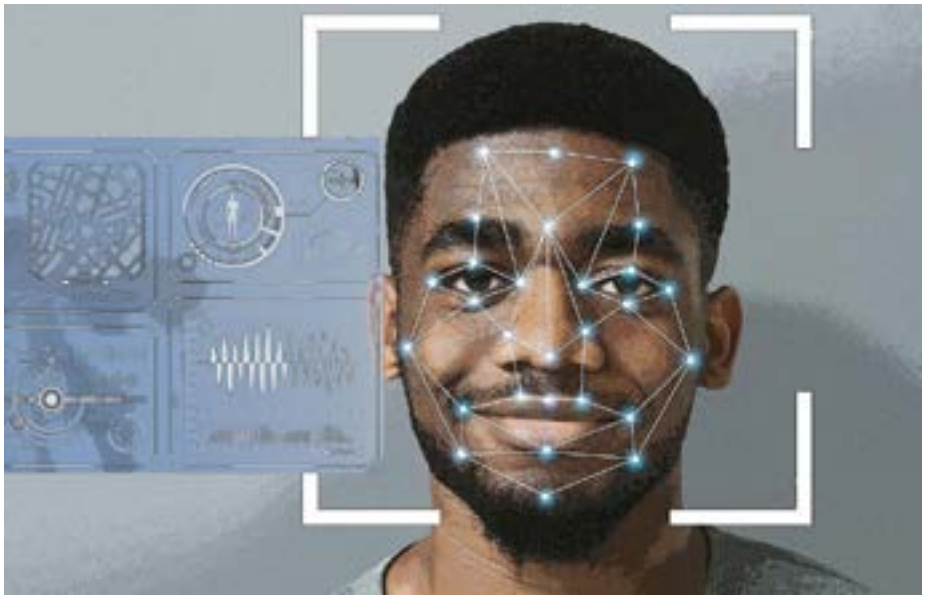
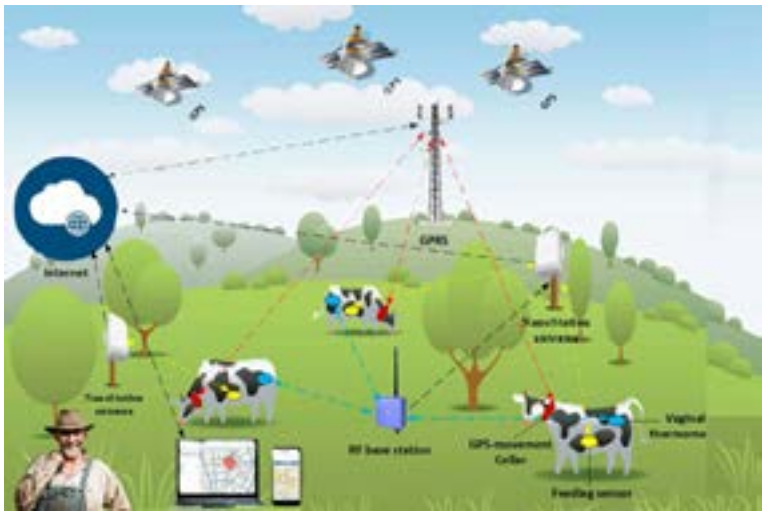


Fig. 1.8: AI being used in facial detection and recognition systems (Players, 2020)

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.



https://hashstudioz.com/blog/how-internet-of-things-is-transforming-the-agriculture-sector/

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)

In summary, 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.

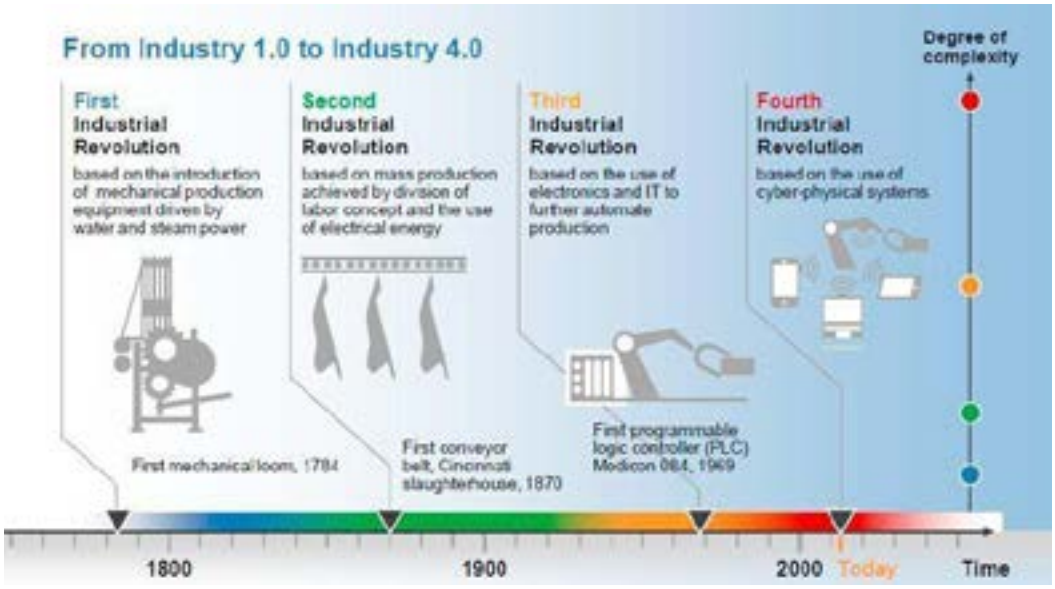


Fig. 1.11: The Industrial Revolutions' timeline (Rutkowska & Sulich, 2020)

Activity 1.1

1. Read on the Industrial Revolutions from books from the library, or watch the videos below on industrial revolution:

   https://www.britannica.com/video/222419/did-you-know-Industrial-Revolution

   https://youtu.be/NDTvCO5ifKo?si=UNqLTb-VbQCCvbw0s

Identify one keyword unique to each industrial revolution and write them on flashcards with descriptions or definitions on the back.

2. Choose an industrial revolution of your interest and research additional significant advancements from that era not covered in the provided materials.
   a. Why do you think those advancements were uniquely developed during that specific industrial revolution?

b. Research on how various historical events are linked to technological advancements.
c. Present your findings to the class.

INTERDEPENDENCE OF HUMANS AND ROBOTS - IMPACT ON ORGANISATIONAL PERFORMANCE INDICATORS

In this lesson you will look at how the four organisational performance indicators (such as price, quality, flexibility, and innovation) have been impacted by the interdependence of humans and robots in working environments. As humans and robots increasingly work together in 21st century environments, it is essential to analyse how this interdependence affects organisational performance indicators. Price, quality, flexibility, and innovation play a significant role in assessing the effectiveness and competitiveness of organisations.

ORGANISATIONAL PERFORMANCE INDICATORS AFFECTED BY ROBOT INTEGRATION

An organisation's performance indicators are measurable values that determine how effectively an organisation achieves its objectives. Below are the four key organisational performance indicators.

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 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 to the market faster and gain a competitive edge.

HUMAN ROLES IN ROBOT-CENTRED 21ST-CENTURY WORKING ENVIRONMENTS

During the progress made in the working environment discussed above, it is important 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.

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.

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.

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.

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.

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.

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.

Activity 1.2

1. Read the two narratives on maize farm below and perform the activities that follow.

Narrative 1

In the pre-automation era of a maize-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 maize 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 maize 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

In 2023, Mrs. Kusi had a one-acre maize farm and employed a number of workers. In each quarter of the year, Mrs. Kusi tasked his workers to handle soil preparation, seed selection, planting, weed control, irrigation, fertilization 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 Mrs. 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 maize 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 lb. (GHC)	4,500	4,600	4,500	4,800

That same year, Mrs. Nzoley also had a one-acre maize farm and employed some workers. In addition to her workers, she leased an agro-based robot from QUARM 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 Worker (hrs)	360	360	360	360
Salary per worker (GHC)	900	900	1,000	1,000
Expected Yield (lbs)	4.5	4.5	5	5
Marketable Yield (lbs)	4.2	4.3	4.6	4.7
Price per lb (GHC)	4,500	4,600	4,500	4,800

The data provided in Tables 1.1 and 1.2 give insights into both farmers' labour needs, production costs, yield expectations, and revenue generation throughout the year.

2. Sit in groups with classmates and conduct a thorough performance analysis of at least one of the maize farm narratives, which show the changes that took place from pre-robot to post-robot integration in a working environment.
3. Examine and critique in your groups, each of the maize narratives, focusing on your findings from (1) above and carefully highlighting any significant observations.
4. Present your group's findings to the class, organising them into a comparative narrative, table and/or graph highlighting key differences between the two eras.

ECONOMIC AND SOCIAL BENEFITS OF ROBOTS IN 21ST-CENTURY ENVIRONMENTS — BALANCING STANDARDS AND ETHICS

In this lesson, you will be guided to acquire knowledge of the economic and social benefits of robots in a 21st-century environment.

The co-existence of man and robots can help in increasing productivity in the field of work. In view of these, standards and ethics have to be upheld to make the existence

achieve the needed results in the 21st-century environment. You will be introduced to a 21st century environment, social and economic benefits of robots and roboethics.

The 21st-Century Environment

A 21st-century environment goes beyond just the physical surroundings. It emphasises creating environments designed with human needs and well-being in mind. It refers to an environment with a modern setting and conditions where people live.

Twenty-first century environments are characterised by features such as digitalisation, automation, diversity, and innovation. These features reflect its multifaceted nature, shaped by technological progress, social change, economic forces, and environmental challenges.

Adaptation to this evolving landscape requires innovative approaches, collaboration across sectors, and a commitment to sustainability and inclusive growth.

On a whole, a 21st-century environment holds certain basic features which include:

1. Technology integration
2. Focus on skills
3. Sustainability and environmental awareness
4. Globalisation and interdependence
5. Shifting demographics

Some 21st- century environments include smart homes, smart cities, and smart workplaces.

Fig 1.12 Picture of a smart city

Smart cities are urban areas that utilise advanced technologies to improve quality of life, efficiency, and sustainability. By integrating IoT, big data, AI, and citizen engagement, smart cities collect and analyse data to optimise infrastructure, services, and resources. This leads to improved quality of life, economic growth, environmental sustainability, and enhanced governance.

Smart cities are rapidly emerging around the world, demonstrating the potential of technology to transform urban living. Here are some notable examples:

Singapore: Often hailed as one of the most advanced smart cities, Singapore utilises technology for efficient transportation, waste management, and urban planning.

Barcelona, Spain: Known for its innovative approach to urban development, Barcelona has implemented smart solutions for energy management, transportation, and citizen participation.

Copenhagen, Denmark: A pioneer in sustainable urban development, Copenhagen focuses on cycling infrastructure, renewable energy, and smart waste management.

New York City, USA: The Big Apple has embraced smart technology for various initiatives, including smart traffic management, energy efficiency, and public safety.

Songdo, South Korea: This planned city is designed to be a model of sustainability and smart living, featuring smart grids, smart transportation, and green infrastructure.

Dubai, UAE: Dubai is known for its ambitious smart city projects, including self-driving cars, smart buildings, and a focus on innovation.

Seoul, South Korea: Seoul has invested heavily in smart technologies for areas such as transportation, energy, and public safety.

Fig 1.13 A smart working environment

A smart working environment uses advanced technologies like IoT, automation, and AI to improve productivity and well-being. Key parts include smart devices to improve environmental factors like lighting and temperature, automation to handle simple tasks, online tools for working together, AI to help make better decisions, and flexible spaces that allow both remote and in-person work. Smart security systems, such as biometrics, ensure a secure workspace. These features create an efficient, adaptable, and intelligent work ecosystem that allows collaboration and streamlines operations.

Fig 1.14 A smart home

Smart homes are equipped with interconnected devices and systems that can be controlled remotely or automatically. These homes leverage technology to enhance comfort, convenience, and security. Key elements include connected devices, home automation, voice control, smart security, energy efficiency, and entertainment. Smart homes offer a more connected, comfortable, and secure living experience by incorporating these features.

Economic Importance of Robots

The activities of robots in the 21st century have become more advanced and touch all manner of work in the environment, the resulting wave came with lots of economic benefits. Some of the economic benefits include:

1. **Economic Growth;** Robots have helped create jobs in areas such as the programming, industry, and engineering field. The economy of a country sees the needed growth when its members have jobs in the required fields.

Fig 1.15 Robots in a working environment

2. **Improved Standardisation and Quality;** Robots can perform tasks with high precision and minimal errors. This may lead to significant improvement in product quality control. Robots can work for longer hours and may not experience fatigue, hence showing a high level of reliability and consistency in their performance. Waste, rework, and unnecessary costs are therefore reduced. Quality and standardisation of tasks are achieved.

Fig 1.16 Robots in a packaging warehouse

3. **Increase in Productivity and Efficiency;** Automation: Robots can perform repetitive tasks better, which often exceed human capabilities in speed and accuracy. This behaviour of robots helps to increase production in industry.

Labour costs can be reduced drastically since few robots may be required to perform tasks that many humans would be required to do as shown in Figure 2.5.

4. **Flood Gates to Innovation;** Innovation in the field of health care, where robots are made to help in complex surgeries are typical examples, as well as in agriculture where robots are used in operating huge tractor equipment and in harvesting.

Fig 1.17a Robots in agriculture

Fig 1.17b Robots in healthcare

5. **Job Creation and skill enhancement;** While there are concerns about the potential impact of automation on employment, robots can also create new job opportunities and demand for skilled workers. As businesses switch to involve robots in their activities, there is a growing need for engineers, technicians, programmers, and other professionals with expertise in robotics and automation.
6. **Safety and risk reduction;** Robots can perform hazardous or dangerous tasks in environments such as in manufacturing plants, construction sites, and disaster zones, reducing the risk of injury or harm to human workers. This improves workplace safety and mitigates occupational health hazards, leading to lower healthcare costs and improved worker well-being.
7. **Global competitiveness;** Countries and industries that embrace robotics technology can enhance their global competitiveness by improving efficiency, reducing costs, and delivering high-quality products and services.
8. **Supply chain optimisation;** Robots play a crucial role in supply chain management by automating material handling, inventory management, and distribution processes. This makes the supply chain more efficient, reduces lead times, and enhances performance, contributing to economic resilience and agility.

Social Benefits of Robots

The inclusion of robots in our social environment uniquely addresses the challenges of social isolation and offers a range of social benefits. Some of the benefits include:

1. **Promoting social inclusion and accessibility;** Here robots may be designed and programmed to assist persons with disability with their day-to-day activities such as navigating public places and effective commuting.

Fig 1.18 A prosthetic leg with integrated robotics

2. **Addressing challenging rescue missions in the 21st century environment;** Robots can be deployed in hazardous environments for search and rescue operations, minimising risks for human personnel in natural disasters, robots can be deployed for search and rescue operations. This can minimise the risk that may be associated when humans are deployed.

https://www.howeandhowe.com/news-flash/articles/featured-news/howe-howe-keeps-firefighters-safe-through-use-thermite

Fig. 1.19: A robot on a rescue mission

3. **Enhancing public services in a technological age;** In education, robots can also be used for simulations and practical exercises. This makes learning

more engaging and interactive. Also, Robots equipped with telepresence technology can facilitate remote collaboration and communication.

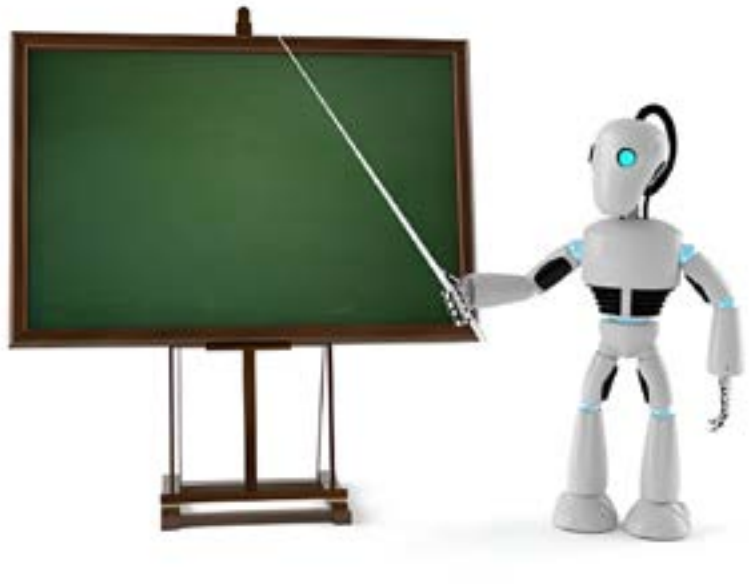


Fig. 1.20 A picture of a robot facilitating a class

4. **Providing the aged with assistance;** The need for elderly care increases as those responsible for their care are engaged with equally important issues. Robots can assist the aged with daily living activities like bathing, dressing, and medication reminders. This care by robots fosters independence and dignity within man-robot coexistence.

Fig. 1.21 A dignity robot providing assistance

5. **Environmental conservation;** Robots can be useful in environmental monitoring and conservation efforts. They can be made to collect data on ecosystems, track wildlife populations, and identify environmental threats. They

can operate in remote or harsh environments where human access is limited, contributing to the preservation of natural habitats and biodiversity.

Fig. 1.22: A robot collecting data on an ecosystem

6. **Public safety and security;** Robots employed in law enforcement and security roles contribute to public safety by patrolling public spaces, monitoring potential threats, and assisting in emergency situations. In warehouses and industrial facilities, robots can be used to detect unauthorised entry or suspicious activity. They can help reduce crime rates, enhance surveillance capabilities, and provide support to first responders during crises.

Fig. 1.23 A robot used to patrol a pack to reduce crime.

ETHICAL CONSIDERATIONS - ROBOETHICS

Roboethics is a combination of the words 'ROBOT AND ETHICS' and is concerned with how robots can be used effectively and responsibly considering the potential impact on society, humans, and human well-being. In integrating robots into the 21st-century environment, the following considerations and guidelines can be considered.

This includes:

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, you will 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 confidential 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.

Activity 1.3

List three economic and three social benefits gained through the integration of robots into 21st century environments.

1. Form a group of 3. In your group, rank your benefits considering:
   a. The potential gains from robot integration.
   b. Any potential drawbacks or ethical concerns associated with each benefit. How you can mitigate these drawbacks while maximising the benefits.
2. Share your thoughts with the class. Be ready to provide examples as to why you selected this ranking.

Activity 1.4

Consider the following statement:

'Robots will create more jobs than they replace'

1. Your teacher will divide you into two groups:
   Group 1 – To debate for the motion.
   Group 2 – To debate against the motion.
2. In your group, gather your thoughts on the statement and present your argument following the rules of the debate as set by your teacher.

Activity 1.5

Your teacher will organise you in groups to do the following:

1. Consider the benefits and potential ethical concerns of the increasing use of robots in society.
2. Create a video, poster or infographic to raise awareness in your school community.

Activity 1.6

Watch the video demonstration (by clicking the link or scanning the QR Code below) on robot-human coexistence: https://youtu.be/pCXUigomiLE?si=tHctrBZRgI_kp2Ss

Using ethical frameworks and standards, explain how people might work, live, and communicate with robots. Should robots have the same rights as people?

Note: If you cannot watch the video, imagine you live in a world where there are the same number of robots as people.

Review Questions 1.1

1. List two key advancements from the Fourth Industrial Revolution.
2. Describe the difference between machines of the first two Industrial Revolutions and robots that emerged in the Third Industrial Revolution.
3. Draw up a table to show potential drawbacks alongside the advancements brought about by each Industrial Revolution.
4. How might the Fourth Industrial Revolution, with its emphasis on AI and data analysis, further transform the role of robots in industries?

Review Questions 1.2

1. Explain the impact robots have on the performance indicators of ‘price’ and ‘quality’.
2. State one way robot flexibility contributes to an organisation’s ability to adapt.
3. Explain one potential benefit and one drawback increased robot integration has on job availability.
4. Explain how the introduction of robots into maize farming might impact the four performance indicators of price, quality, flexibility, and innovation. Use the data and descriptions from the two case studies of maize farming.
5. 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.

Review Questions 1.3

1. List six items that can be considered ‘smart items’ in your homes.
2. Explain any two (2) social benefits robots can bring to society.
3. Explain two (2) economic benefits of robots-human coexistence.
4. Explain two (2) drawbacks of the widespread robot integration in the manufacturing industries.
5. How far do you agree with the statement ‘The manufacturing industries of the future will no longer need to employ any humans? In your response you should refer to the benefits and drawbacks of robots and show your knowledge of the role humans will play in factories of the future.

Extended Reading

1. Bartneck, C., Lütge, C., Wagner, A., & Welsh, S. (2021). *An introduction to ethics in robotics and AI*. Springer International Publishing
2. Sethi, K. (2024). *Autonomous vehicles and systems: a technological and societal perspective*. River Publishers
3. Olson, J.S. & Kenny, S.L. (2015). The *industrial revolution: Key themes and documents.* Santa Barbara, California : ABC-CLIO, pages ix - xiii
4. Saeed, B. N. (2020). *Introduction to robotics, analysis, control, applications, (3rd ed)* Hoboken, New Jersy, United States: Wiley pages 29–30
5. Judith, D. (2022). Meaningful features with ROBOTS "*Designing a New Coexistence*" CRS Press.

References

1. Arnold, C. (2016). Disruptive innovation, toxic poison, and LAT - who is stopping your company from innovating? Retrieved March 22, 2024, from https://www.linkedin.com/pulse/disruptive-innovation-toxic-poison-lat-who-stopping-chris-arnold
2. China Briefing (2016, June 2). The Adoption of Advanced Robotics in Manufacturing: A Reality Today, or a Revolution for the Future? - China Briefing News. China Briefing News. https://www.china-briefing.com/news/adoption-advanced-robotics-manufacturing-reality-today-revolution-future/
3. Duranton, S. (2023). Thomas A. Edison exhibits a replica of his first successful incandescent lamp, ... [+]. Lightbulb Moment: Big Business Needs "mini-Edisons" To Drive Invention. Retrieved March 8, 2024, from https://www.forbes.com/sites/sylvainduranton/2023/04/28/lightbulb-moment-big-business-needs-mini-edisons-to-drive-invention/?sh=13caa06e2228
4. Murray, J. Q. (2017). Machining history: Lathe, the mother of all tools. https://blog.mmi-direct.com/machining-history-lathe-the-mother-of-all-tools
5. Players, B. C. (2020, December 16). Governor Baker, regulating facial recognition technology is a racial justice issue. BostonGlobe.com. https://www.bostonglobe.com/2020/12/16/opinion/governor-baker-regulating-facial-recognition-technology-is-racial-justice-issue/
6. Rutkowska, M., & Sulich, A. (2020). Green jobs on the background of Industry 4.0. *Procedia Computer Science*, 176, 1231-1240.

Glossary

Mechanisation	The use of machines exclusively to work.
Innovation	The process of bringing out new ideas, methods or products.
Augmented Reality	This is the overlay of digital information on reality.
Environment	Refers to our surroundings or all the things around us.
Innovation	The process of bringing out new ideas, methods or products.
IoT	Internet of things
Pricing	Setting the price for goods and services.
Quality	refers to the standard or degree of excellence for a good or service.
Flexibility	refers to the ability to adapt and quickly respond to change.
Automation	Using machines, programs, and technology to complete tasks without any human interference.
Augmented Reality (AR)	Augmented reality overlays digital information onto the real world, enhancing user experiences by adding virtual elements to the physical environment.
Virtual Reality (VR)	Virtual reality immerses users in a completely digital environment, simulating real-life experiences through computer-generated environments.
Ethics	Ethics are the set of values that guide behaviour and determine what is acceptable and unacceptable, the question of what is right and wrong, for example.
Social benefits	The benefit from programmes that are designed to provide assistance or support for an individual or group of individuals.
Economic benefits	The benefit from programmes that are designed to improve the wealth or the financial well-being of an individual, business, or the entire economy.
Robots	Robots are machines that are designed to carry out complex series of tasks or actions automatically.

Smart home

A smart home is an arrangement of devices which use digital technology to make a home more responsive, efficient, and secure. A smart home consists of interconnected devices that automate and streamline domestic tasks, such as adjusting room temperature, controlling lighting, and managing security systems.

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