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IEC 61499: primer course

Module 1: Software for industrial automation

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What is Industrial Automation?



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Fruit sorting factory, equipment producer Compac sorting equipment, New Zealand **UNIVERSAL**
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Key components of Industrial Automation



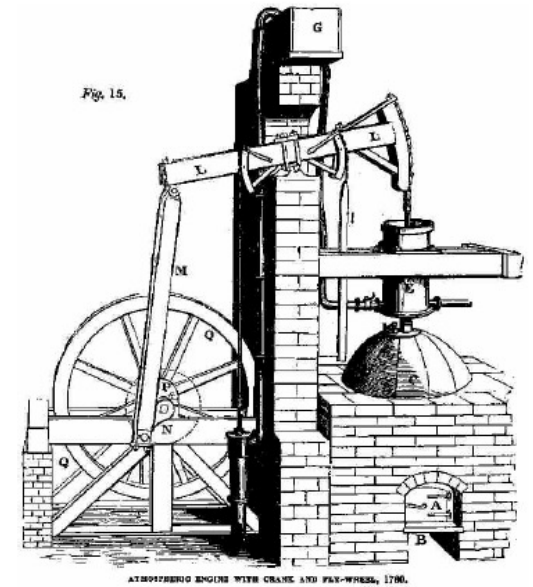
Heathrow Terminal 5 Baggage Handling System <http://www.youtube.com/watch?v=663VWLgT8Lc>

- **Operation Technology (OT) / Control Systems:** Such as Programmable Logic Controllers (PLCs), Distributed Control Systems (DCS), and computer numerical control (CNC) systems.
- **Machines:** Robots, Conveyors, etc., used for tasks like assembly, painting, and welding, enhancing precision
- **Information Technology (IT):** Integration of IT systems for data management, process control, and real-time decision-making.
- **Human-Machine Interface (HMI):** Interfaces that allow for interactions between human operators and machines, providing critical information and controls.

Evolution of Industrial Automation

- The First Industrial Revolution (Late 18th to Early 19th Century)
- The Second Industrial Revolution (Late 19th to Early 20th Century)
- The Third Industrial Revolution (Late 20th Century)
- The Fourth Industrial Revolution (21st Century Onwards)

How it all began



Mine in Cornwall equipped with first steam engine in 1790. First industrial regulator invented by James Watt to keep the wheel's speed constant.

The First Industrial Revolution

(Late 18th to Early 19th Century)

- Key Characteristics:
 - Introduction of Mechanical Production: The transition from hand production methods to machines.
 - Steam Power: The invention and widespread use of the steam engine.
 - Textile Industry: Major advancements in textile manufacturing, including the spinning jenny and power loom.
 - Iron and Coal: Significant developments in iron making techniques and increased use of coal.
- Impact:
 - Initiated a shift from agrarian societies to industrialized urban centers.
 - Led to significant socioeconomic changes, including the growth of factories and the working class.

The Second Industrial Revolution

(Late 19th to Early 20th Century)

- Key Characteristics:
 - Mass Production: Introduction of production lines and the concept of economies of scale.
 - Electrification: Widespread adoption of electrical power, which further enhanced manufacturing efficiency.
 - Steel and Chemicals: Major advancements in steel production and the chemical industry.
 - Transportation and Communication: Significant developments in railway networks, telegraph, and telephone systems.
- Impact:
 - Marked the beginning of the modern industrial economy.
 - Led to urbanization and significant changes in lifestyle and work.

The Third Industrial Revolution

(Late 20th Century)

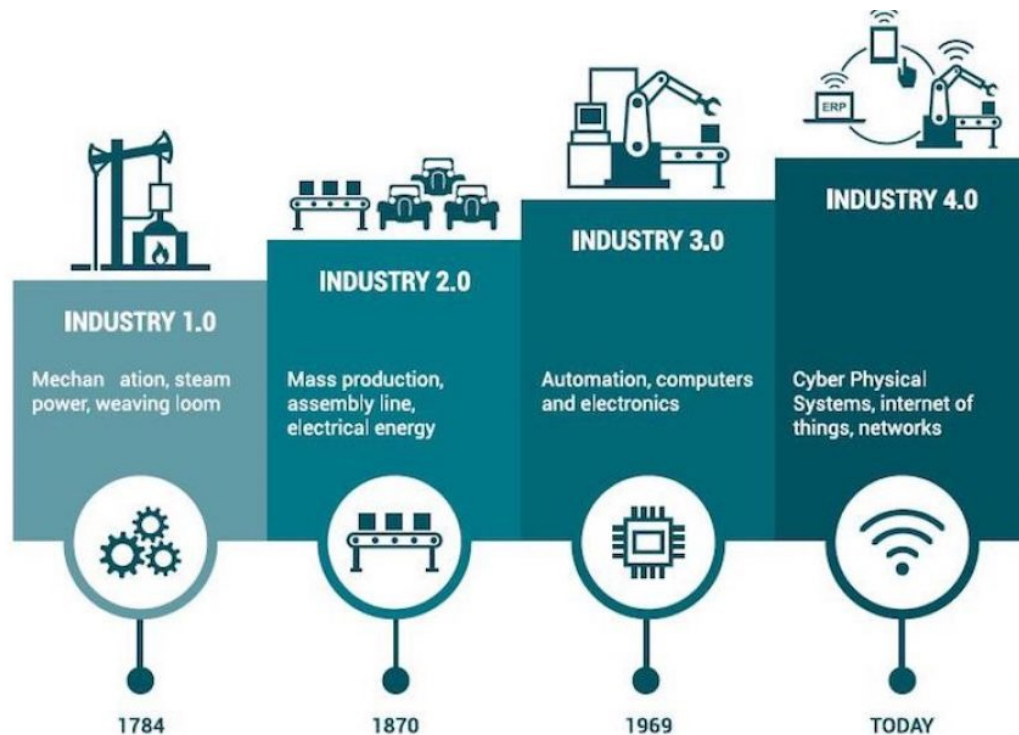
- Key Characteristics:
 - Digital Revolution: Transition from analog and mechanical technology to digital technology.
 - Computers and Automation: The rise of computers, automation, and information technology.
 - Internet and Communication: The advent of the internet and mobile communication.
 - Renewable Energy: Shift towards renewable energy sources.
- Impact:
 - Transformed industries with digital technology, leading to increased automation and efficiency.
 - Revolutionized the way people communicate, access information, and work.

The Fourth Industrial Revolution

(21st Century Onwards)

- Key Characteristics:
 - Cyber-Physical Systems: Integration of physical systems with digital and network technologies (e.g., IoT, IIoT).
 - Artificial Intelligence and Machine Learning: Advanced AI and machine learning impacting various sectors.
 - Advanced Robotics and 3D Printing: Significant advancements in robotics, automation, and additive manufacturing.
 - Biotechnology: Breakthroughs in genetic engineering and biotechnology.
- Impact:
 - Blurring the lines between physical, digital, and biological spheres.
 - Leading to transformative changes in all aspects of human life and industry, including personalized medicine, smart cities, and more.

Summary



- From Steam to Cyber-Physical Systems: The industrial saga began with steam-powered looms in the 18th century and has now reached the era of AI-driven smart factories.
- Revolutionary Milestones:
 - First Revolution: Introduction of mechanization and steam power, birthing modern manufacturing.
 - Second Revolution: Mass production and electrification, leading to 24/7 factories and global communication networks.
 - Third Revolution: Digital transformation with personal computing, internet, and renewable energy, revolutionizing data management and collaboration.
 - Fourth Revolution: Fusion of physical, digital, and biological technologies, marked by IoT, AI, 3D printing, and biotech innovations.

"Industry 4.0 is the fusion of the real world with the digital world".

Summary

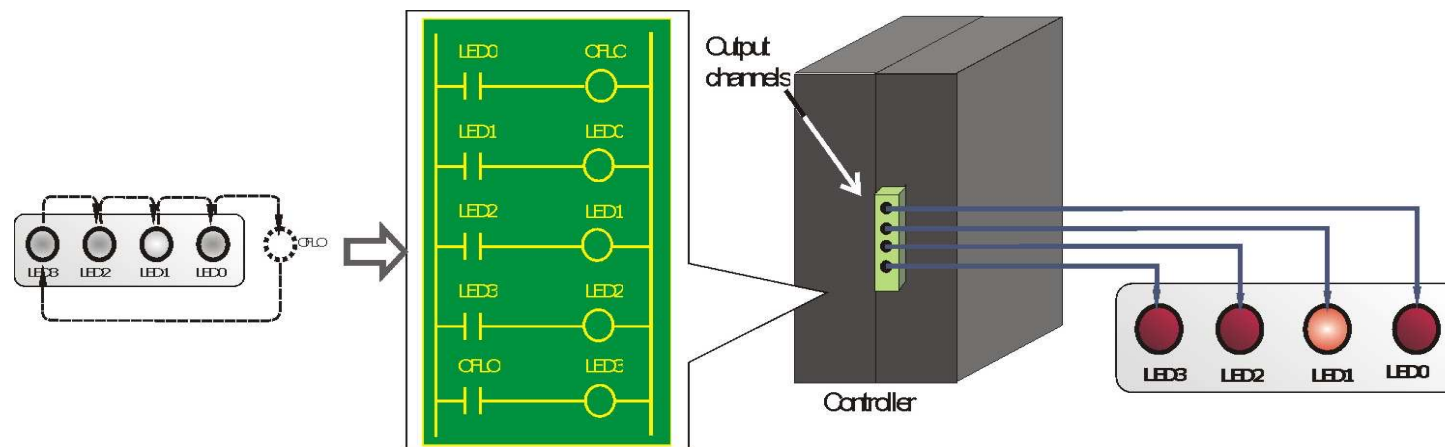
- Impact on Society and Industry:
 - Each revolution profoundly altered industrial practices, workforce dynamics, and societal structures.
 - The relentless pursuit of efficiency and innovation reshaped not just industries but also societal norms and human identity.
- The Future:
 - As we navigate the Fourth Industrial Revolution, we face the challenge of integrating these advanced technologies, promising a future that redefines the essence of human-machine interaction and our place in a digital world.

From relay programming to computer programming

The evolution from relay programming to computer programming is a fascinating journey that marks the transition from electromechanical systems to digital computing in industrial automation and control systems. This evolution reflects broader technological advancements and has significantly impacted how industrial processes are controlled and automated.

Relay Programming (Early 20th Century)

- Characteristics:
 - Electromechanical Devices: Relays are electromechanical switches used to control circuits. They were the backbone of early automation systems.
 - Hard-Wired Logic: Relay programming involved physically wiring relays to create logic circuits. This process was manual, time-consuming, and required extensive physical space.
 - Limited Flexibility: Changing the control logic meant reconfiguring the wiring, which was labor-intensive and prone to errors.
- Applications:
 - Used in early telephone exchanges, control of machinery, and simple automation tasks in industries.

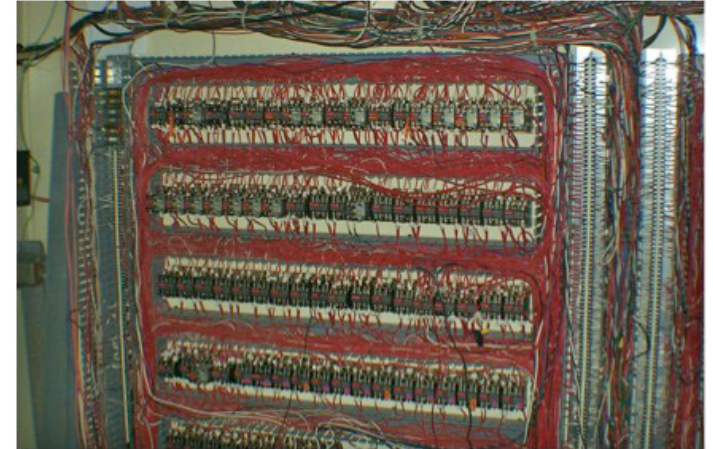


Relay Programming (Early 20th Century)

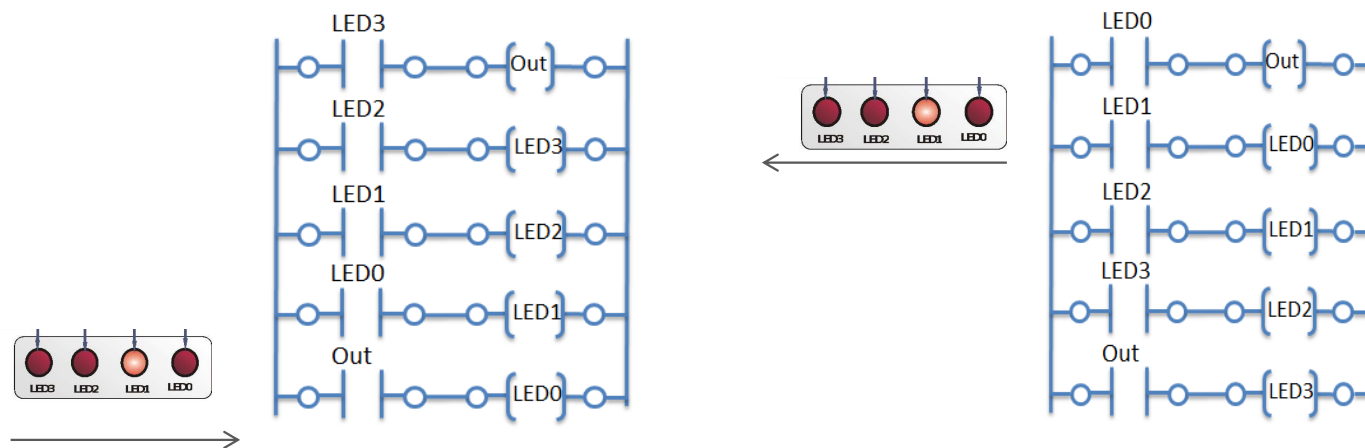
- Make LED runner with relays 

- AND 

- OR 

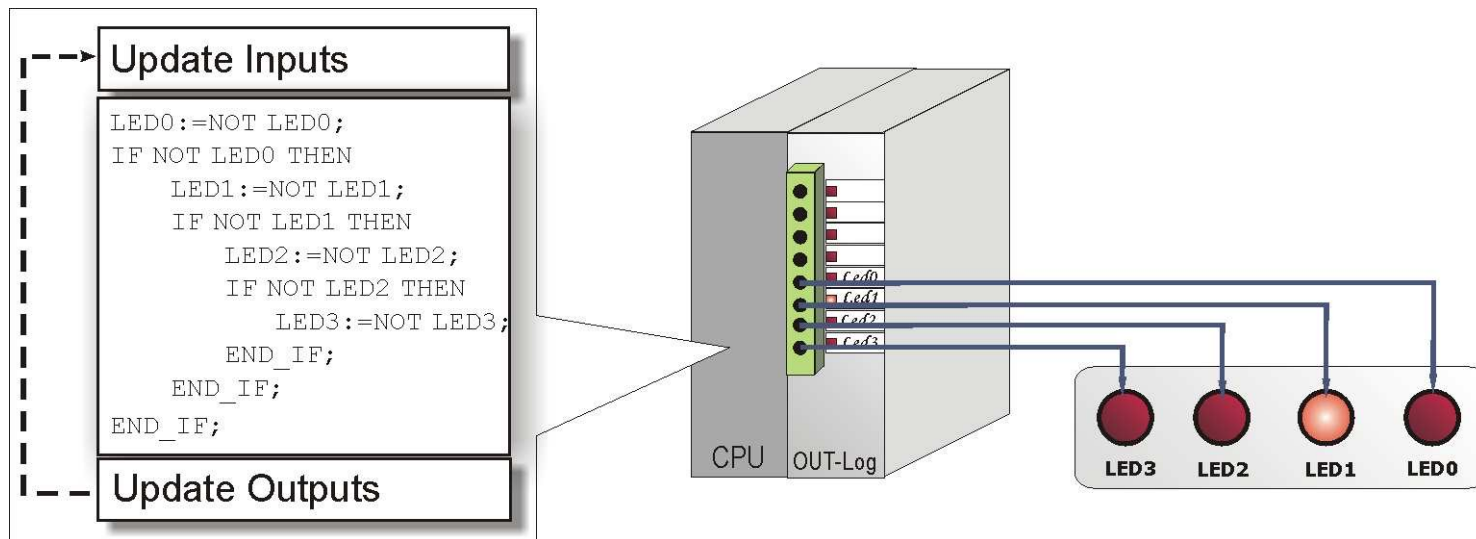


- Now, reprogram this!

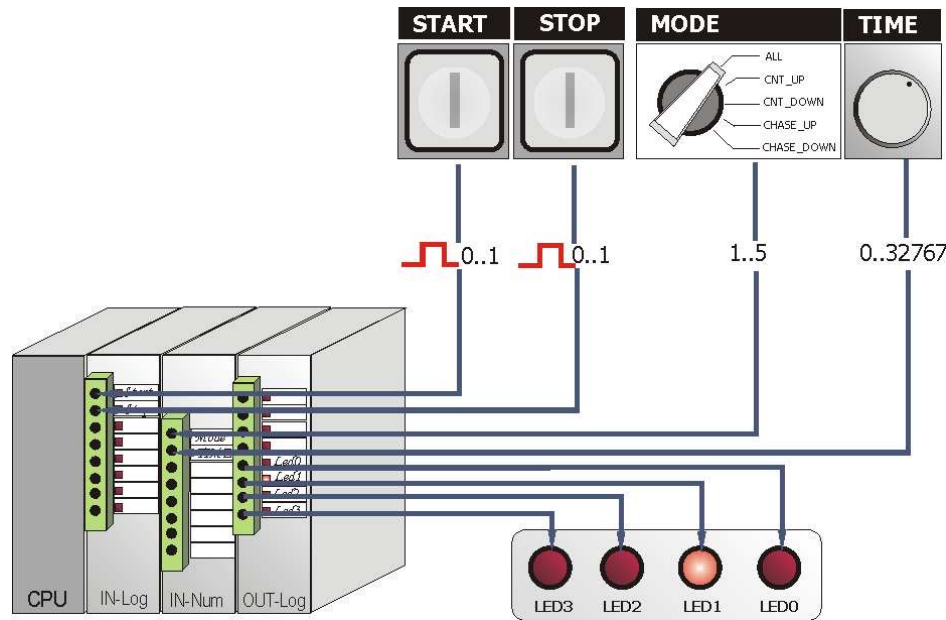


Transition Phase (Mid 20th Century)

- Developments:
 - Solid-State Electronics: The invention of transistors and later integrated circuits began to replace electromechanical components. This shift marked the beginning of the transition from relay-based systems to electronic control systems.
 - Miniaturization and Increased Reliability: Electronic components were smaller, more reliable, and consumed less power than their electromechanical counterparts.
 - Early Computers: The development of early computers provided the foundation for more advanced control systems.



Computer Programming (Late 20th Century Onwards)



- Characteristics:
 - Digital Computing: The advent of microprocessors and digital computing revolutionized control systems. Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCS) emerged.
 - Software-Based Logic: Control logic was now programmed in software, offering immense flexibility. Programming languages like Ladder Logic (mimicking relay logic), Structured Text, and Function Block Diagram became standard.
 - Scalability and Integration: Computer programming allowed for scalable, integrated systems capable of complex control tasks and data analysis.
- Applications:
 - Extensively used in all forms of industrial automation, including manufacturing processes, robotics, process control, and data acquisition.

Summary: Impact of the Evolution

- **Efficiency and Complexity:** The shift to computer programming allowed for more complex and efficient control systems, capable of handling tasks far beyond the scope of relay-based systems.
- **Flexibility and Adaptability:** Software-based systems could be easily modified or updated, providing much greater adaptability to changing industrial needs.
- **Data Processing and Connectivity:** Modern systems are not just control mechanisms; they are also capable of processing large amounts of data and connecting to other digital systems, paving the way for the Internet of Things (IoT) and smart factories.

From Electrical Engineering to Software Engineering

The evolution from Electrical Engineering to Software Engineering in the context of industrial automation and technology reflects a significant shift in skill sets, driven by the changing nature of technology and its applications. This transition mirrors the broader move from hardware-centric to software-centric systems in various industries.

Electrical Engineering: Traditional Skill Sets

- Focus Areas:
 - Circuit Design and Analysis: Proficiency in designing and analyzing electrical circuits, including analog, digital, and power electronics.
 - Control Systems: Understanding of control theory and the ability to design control systems, often for machinery and industrial processes.
 - Electromechanical Systems: Knowledge of electromechanical devices like motors, generators, and relays.
 - Power Systems: Expertise in power generation, transmission, and distribution.

Electrical Engineering: Traditional Skill Sets

- Skills:
 - Hands-On Skills: Proficiency in soldering, wiring, and using electrical instruments like oscilloscopes and multimeters.
 - Mathematical Proficiency: Strong background in mathematics, particularly in calculus, differential equations, and linear algebra.
 - Hardware Troubleshooting: Ability to diagnose and fix hardware-related issues.

Software Engineering: Emerging Skill Sets

- Focus Areas:
 - Programming and Development: Proficiency in programming languages such as C++, Python, Java, and knowledge of software development methodologies.
 - Data Structures and Algorithms: Understanding of data structures, algorithms, and their applications in solving complex problems.
 - System Design and Architecture: Skills in designing software architecture and systems, including knowledge of databases, APIs, and microservices.
 - Cybersecurity: Knowledge of cybersecurity principles to protect systems and data.

Software Engineering: Emerging Skill Sets

- Skills:
 - Problem-Solving: Strong analytical and problem-solving skills, particularly in a digital context.
 - Collaboration and Version Control: Experience with collaborative tools and version control systems like Git.
 - Continuous Learning: Keeping up with rapidly evolving software technologies and methodologies.

Convergence of Skill Sets

- **Embedded Systems:** Modern industrial systems often require knowledge of embedded systems, which blend electrical engineering and software engineering.
- **IoT and Connectivity:** Understanding of Internet of Things (IoT) technologies, requiring both hardware (sensors, devices) and software (networking, data processing) expertise.
- **Interdisciplinary Knowledge:** Increasingly, professionals need a blend of skills from both domains, understanding how software integrates with and controls hardware.

Summary: Impact on Industry and Education

- **Industry Demand:** There is a growing demand for professionals who can bridge the gap between electrical and software engineering, particularly in fields like robotics, automation, and smart systems.
- **Educational Shift:** Educational institutions are adapting by offering interdisciplinary courses and programs that combine electrical engineering, computer science, and software engineering.

From HW expertise to SW expertise

The transition from hardware-dominated to software-dominated environments marks a significant shift in the technological landscape, impacting various industries from consumer electronics to industrial automation. This change reflects a broader trend where the value and functionality of products and systems are increasingly defined by software rather than hardware.

Hardware-Dominated Era

- Characteristics:
 - Physical Limitations: Product capabilities were primarily determined by hardware specifications. Upgrades or enhancements typically require physical changes or new hardware.
 - Design Focus: Emphasis was on the design and manufacturing of physical components. Material properties and manufacturing techniques often constrain innovation.
 - Cost Structure: High material and manufacturing costs. The cost of goods sold (COGS) was a significant portion of the total product cost.
 - Lifecycle: Products had longer lifecycles, and updates were infrequent due to the need for hardware revisions.

Hardware-Dominated Era

- Skills and Knowledge:
 - Expertise in electrical engineering, mechanical engineering, and materials science was crucial.
 - Product development cycles were longer, with a strong focus on reliability and manufacturability.

Software-Dominated Era

- Characteristics:
 - Rapid Innovation: Software allows for continuous and rapid product enhancements without the need for physical alterations.
 - Functionality and Flexibility: Products can have multiple functions, and new features can be added through software updates.
 - Reduced Marginal Cost: Once developed, software can be duplicated and distributed at a minimal cost.
 - Ecosystem and Integration: Software enables integration into broader ecosystems, enhancing product utility through network effects.

Software-Dominated Era

- Skills and Knowledge:
 - Proficiency in software development, data analytics, and cybersecurity is paramount.
 - Agile and iterative development methodologies are commonly used, allowing for faster product evolution

Convergence of Hardware and Software

- **Embedded Systems:** Products increasingly include embedded systems, where hardware and software are tightly integrated (e.g., IoT devices).
- **User Experience:** The focus has shifted towards user experience (UX), where software plays a key role in how users interact with and perceive the product.
- **Data and Connectivity:** Products are often designed to be part of connected systems, with software enabling data collection and analysis for improved functionality and user insights.

Summary: Impact on Industries

- **Consumer Electronics:** Smartphones and smart devices are quintessential examples where software defines the user experience and functionality.
- **Automotive Industry:** Modern vehicles are increasingly software-driven, with features like infotainment systems, advanced driver-assistance systems (ADAS), and over-the-air (OTA) updates.
- **Industrial Automation:** The shift towards Industry 4.0 is characterized by software-driven processes, data analytics, and machine learning.

**Software is the building block of modern
Industrial Automation**

Early Automation Era (1900-1950s)

- The advent of programmable logic controllers (PLCs) in the 1960s marked a pivotal shift from electromechanical relay systems to digital automation.
- The development of supervisory control and data acquisition (SCADA) systems in the 1970s enabled centralized monitoring and control of industrial processes.
- The emergence of manufacturing execution systems (MES) in the 1980s introduced a higher level of control and optimization for production lines.

Advanced Automation Era (1990s-Present)

- The integration of artificial intelligence (AI) and machine learning (ML) into industrial automation is driving predictive maintenance, anomaly detection, and optimization algorithms.
- The rise of cloud computing has enabled real-time data collection, analysis, and decision-making across geographically dispersed industrial operations.
- The adoption of cyber-physical systems (CPS) is blurring the lines between physical and digital domains, enabling seamless data and control integration across the entire industrial ecosystem.

5 Key Industrial Automation Trends in 2023

- Increasing use of automation to deal with the skilled worker shortage
 - Autonomous robots, cobots, AMR, ...
- Artificial Intelligence
 - Improves precision, helps with inspection, maintenance and material handling. Reduces the need for human intervention and lowers the risk of accidents, and improves maintenance efficiency and prolongs equipment life.
- Immersive technologies, including VR and AR
 - See streaming IIoT and sensor data, while improving condition monitoring, troubleshooting and repairs.
 - View immersive 3D work instructions for assembly, inspection and service procedures.
 - Access step-by-step instructions and on-demand help from tenured experts.
- Edge computing and cloud computing
 - supporting gathering, analyzing, processing and storing data locally in real time at or near the collection site
- Blockchain
 - Decentralize communication and secure data-sharing between machines, people and organizations

Growth of software use in industrial automation – Some statistics

- The overall industrial automation market, which heavily relies on software, is expected to grow from USD 205.86 billion in 2022 to USD 395.09 billion by 2029, at a CAGR of 9.8%
- The PLC market size was estimated at USD 12.31 billion in 2023.
- It is expected to reach USD 14.46 billion by 2028, growing at a Compound Annual Growth Rate (CAGR) of 4.23% during the forecast period (2023-2028).
- The global market for PLCs was sized at some 11 billion U.S. dollars in 2022.
- The market is expected to grow at a CAGR of more than five percent until 2026.
- In 2026, the market size should amount to over 15.5 billion U.S. dollars
- References
 - <https://www.fortunebusinessinsights.com/industry-reports/industrial-automation-market-101589>
 - <https://www.mordorintelligence.com/industry-reports/programmable-logic-controller-plc-market>
 - <https://www.statista.com/statistics/486345/projected-global-programmable-logic-controller-market-size/>

Growth of software use in industrial automation – Some statistics

- The number of IoT devices worldwide was 15.1 billion in 2020.
- This number is forecast to almost double to more than 29 billion IoT devices in 2030.
- In 2021, there were more than 10 billion active IoT devices.
- It's estimated that active IoT devices will surpass 25.4 billion in 2030.
- By 2025, there will be 152,200 IoT devices connecting to the internet per minute.
- The global Industrial Internet of Things Market size was valued at USD 321.81 billion in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 23.2% from 2023 to 2030.
- References
 - <https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/>
 - <https://dataprot.net/statistics/iot-statistics/>
 - <https://www.grandviewresearch.com/industry-analysis/industrial-internet-of-things-iiot-market>

Software in Automation

- A considerable portion of industrial automation projects involves software development, which includes the integration of various hardware components, configuration of control systems, and development of user interfaces. This software development effort is crucial for ensuring that the automation systems function correctly and efficiently.
- In many industrial automation projects, software development can constitute up to 30-50% of the total project effort. This includes developing control algorithms, creating user interfaces, and integrating various systems
- For example, the market for cloud-based industrial automation software was valued at approximately USD 13.6 billion in 2018 and continues to grow as industries adopt more advanced automation solutions

Summary

- Role of software is the most essential aspect of today's and future Industrial automation systems
- Advances in software technology will continue to grow

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