TEX4.0

Enabling Industry 4.0 Skills in Textile SMEs

Robotics

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1. Introduction to Robotics

1.1. What is a Robot?

There are few terms that are as widely known as 'robot' and yet are so difficult to describe precisely. Although most people have a vague idea of what a robot is, they usually associate it with some kind of humanoid machine that is modelled on humans and is usually familiar from various science fiction books or films. In today's world, however, we use the term 'robot' to describe a whole range of machines that are primarily used in the production of goods and perform tasks more or less autonomously. However, the exact boundary between a robot and simply automatic machines is imprecise. Therefore, there is no generally valid definition of what exactly constitutes a robot. The following are some definitions from various institutions:

1: Robot Institute of America, 1979

"A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of task."

2: Oxford English Dictionary, 2010

"A machine capable of automatically carrying out a complex series of movements, esp. one which is programmable."

3: ISO 8373 Robotics - Vocabulary

"A programmed actuated mechanism with a degree of autonomy to perform locomotion, manipulation or positioning"

Robots, in the broadest sense, are automated machines capable of performing tasks autonomously. One of the key characteristics of robots is their ability to operate independently of the specific tasks they will ultimately perform or the environment in which they will be deployed. For example, an industrial robotic arm can be utilized for a wide range of applications, many of which may not have been anticipated at the time of its design and manufacture.

This principle applies to nearly all types of robots. Even a simple robotic vacuum cleaner, despite being highly specialized for a specific function, must be able to dynamically adapt to its operating environment. The exact nature of this environment is unknown at the time of production and can often change over the device's lifespan.

The adaptability of robots is made possible through programming. All robots, in some form, can be programmed. However, this does not necessarily require the traditional

input of code lines. A wide range of graphical interfaces and interactive methods exist that allow users to "teach" a robot, effectively programming it without writing conventional code.

In summary, all robots share the following fundamental characteristics: they are automated and autonomous mechanisms that can adapt to various tasks and working environments. To emphasize the wide range of robots, one can take a look at the various areas of everyday life, where robots are used:

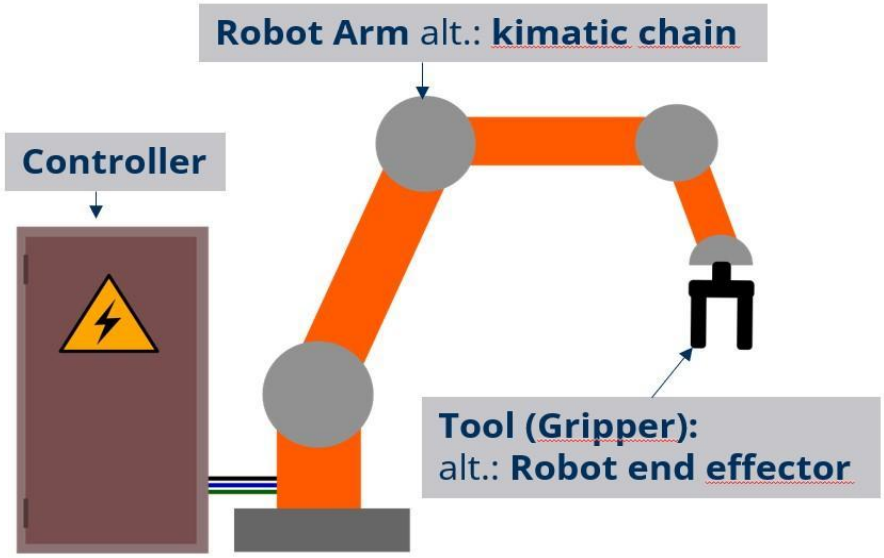
Figure 1-1: From Left to right: 1: Humanoid robots, 2: Service robots, 3: Mobile robots, 4: Industrial robots, all pictures are Designed by Freepik

In this course, we will focus solely on **industrial robots,** as they are the only type used in textile production.

2. Types and Terminology - Industrial Robots

An industrial robot is a programmable, automated machine specifically designed to perform repetitive tasks in **industrial environments**. These robots are widely used in various manufacturing processes due to their ability to handle tasks that require precision, speed, and consistency. Industrial robots can be programmed to execute a wide range of functions, making them versatile tools in modern production lines. One of the key attributes is their precision and speed. They are capable of performing tasks with an exceptionally high level of accuracy (e.g.: up to 0.03 mm), often surpassing human capabilities. Whether it is assembling intricate electronic components or welding automotive parts, industrial robots can carry out these operations with minimal errors and at a much faster rate than human workers. Their ability to maintain consistent quality and repeatability makes them indispensable in industries where precision is paramount and makes them increasingly a subject of research and development in the textile industry. Despite their efficiency and performance, the use of industrial robots necessitates stringent safety measures. Since these machines often operate in proximity to human workers, it is crucial to implement comprehensive safety protocols. Advanced sensors, protective barriers, and emergency shutdown mechanisms are commonly employed to prevent accidents and ensure a safe working environment. The structure of an industrial robot typically consists of several key components that work together to achieve efficient operation. At the core of every robot is a **controller**, which

serves as the brain of the system, processing instructions and coordinating movements. The robotic arm, also known as the **kinematic chain**, provides the necessary range of motion to perform tasks, and the **end effector** —such as a gripper or specialized tool—



interacts with the workpieces. These elements are shown in graphic number 2-1.

Figure 2-1: Principal components of a robot

Often, robots are combined with advanced external sensors and interact with powerful ERPsoftware to tightly integrate their workflow into the production process. The advantages of using industrial robots in manufacturing are numerous: They significantly increase productivity by automating repetitive tasks, allowing human workers to focus on more complex and strategic activities. Robots help reduce labor costs by performing tasks that would otherwise require significant manpower. Additionally, their consistent performance leads to improved product quality, as they minimize the risk of errors and defects. Lastly, industrial robots contribute to a safer work environment by taking over dangerous and physically demanding tasks, thereby reducing the risk of workplace injuries.

2.1. Structure of a Robot

A robot is composed of several essential components that work together to perform various tasks efficiently. The key components include the control unit, the robot arm, and the tool or end effector.

- **Control Unit (Controller)**

  The control unit serves as the brain of the robot, processing input signals, executing programmed instructions, and managing the movement and operations of the robot. It ensures precise control of the robot's actions through feedback loops and communication
  with sensors.

- **Robot Arm (Kinematic Chain)**

The robot arm, also known as the kinematic chain, consists of interconnected segments and joints that allow the robot to move in different directions. Depending on the design, it may have multiple degrees of freedom, enabling complex and precise movements necessary for various industrial or service applications.

- **Tool (Gripper, End Effector)**
  The tool, also referred to as the end effector, is the component that interacts directly with objects or the environment. Depending on the application, it can be a gripper for picking up and manipulating objects, a welding tool, a suction cup, or any specialized attachment required for the task.

These components work together to enable robots to perform tasks ranging from simple pick-andplace operations to complex automated processes in industries such as manufacturing, healthcare, and logistics.

2.2. Types of Motion

Robots can be classified based on their motion types. The primary types of motion include rotational motion, translational motion, hybrid motion, and special designs.

- **Rotational Motion (Articulated Robot)**
  Rotational motion involves movement around a fixed axis or pivot point. This type of motion is commonly found in robotic arms and joints, where segments rotate to achieve specific orientations and positions. A common example is the **articulated robot**, which consists of multiple rotary joints, allowing for high flexibility and a wide range of motion.

- **Translational Motion (Cartesian Robot)**
  Translational motion refers to linear movement in a specific direction without rotation. Robots with this motion type can move along the X, Y, or Z axes, allowing for precise positioning in industrial and automation applications. A well-known example is the **Cartesian robot**, which moves along linear paths using three perpendicular axes, making it ideal for pick-and-place tasks and CNC machinery.

- **Hybrid Motion (Polar Robot)**
  Hybrid motion combines both rotational and translational movements, enabling more complex and flexible motions. This is typical in advanced robotic systems, such as humanoid robots or multi-jointed manipulators, which require both types of motion for efficient operation. A classic example is the **polar robot**, which has a combination of rotational and linear movements, using a pivoting arm mounted on a sliding base for a large working envelope.

- **Special Design (Delta Robot)**
  Some robots feature a special design that does not fall strictly into the above categories. One such example is the **Delta robot**, which consists of parallel arms

connected to a common base. This design enables high-speed and precise movements, making it particularly useful in applications such as packaging, assembly, and pick-and-place operations.

Different robots employ various motion types depending on their design and intended applications, ranging from industrial automation to service robotics.

2.3. Degree of Freedom (DOF)

The Degree of Freedom (DOF) refers to the number of independent movements a robotic system or mechanical structure can perform. Each DOF represents a possible motion in either a translational or rotational manner. In robotics, a higher number of DOFs provides greater flexibility and maneuverability. For example, a simple robotic arm with three joints has three degrees of freedom, allowing movement along three independent axes. Industrial robots typically have 6 DOFs, enabling complex and precise operations in various applications such as manufacturing, assembly, and medical robotics.

2.4. Reach

Reach refers to the maximum distance a robot can extend from its base to the end of its end-effector. It is a crucial factor in determining the working range of the robot and influences its ability to interact with objects within its workspace. A longer reach allows the robot to cover a larger area, which is essential for applications such as assembly, welding, and material handling.

2.5. Payload

Payload defines the maximum weight a robot can carry, including the weight of the tool or end effector. Exceeding the payload capacity can lead to reduced accuracy, slower operation, or mechanical failure. Industrial robots are designed with specific payload capacities ranging from a few kilograms to several hundred kilograms, depending on the application.

2.6. Payload Diagram

A Payload Diagram is a graphical representation of a robot's load-handling capacity based on different positions within its workspace. It illustrates how the payload affects the robot's reach and speed, providing essential data for optimizing robotic performance and ensuring safe operation. A basic example can be seen in figure 2-2.

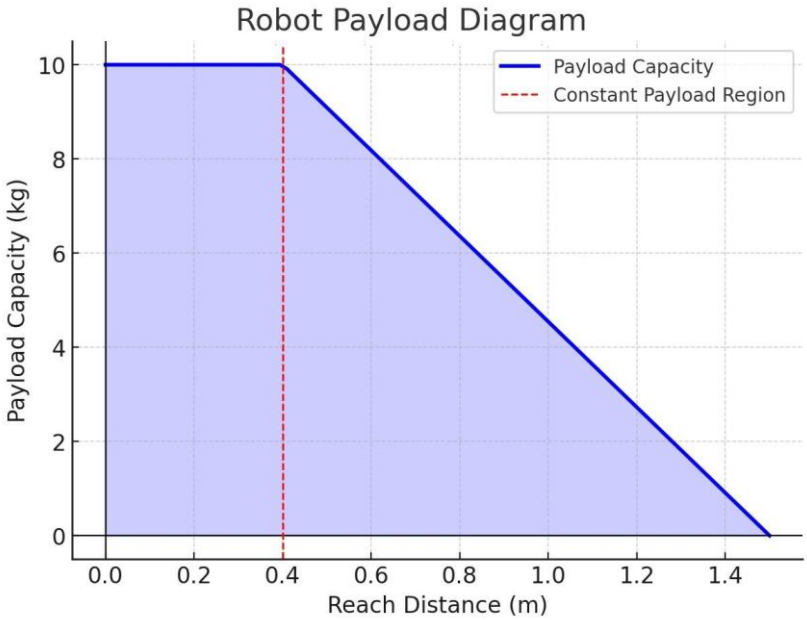


Figure 2-2: Example of a basic payload diagram

In the diagram, the initial section (0 to 0.4 meters) maintains a constant payload capacity of 10 kg. Beyond this point, the payload capacity gradually decreases as the reach increases. This behavior is typical for industrial robots, as mechanical constraints and torque limitations reduce the effective payload at greater distances. When selecting and programming robots, this behavior must be kept in mind, as the maximum load capacity is typically advertised.

2.7. Repeatability

Repeatability refers to a robot's ability to return to a specific position with high precision after multiple operations. It is a key performance metric in automated systems where consistent accuracy is required, such as in assembly lines and precision manufacturing. Repeatability is usually measured in millimeters or microns. For industrial robots, typical values fall within a range of +/- 0.02 mm to +/- 0.4 mm.

2.8. Work Envelope

The Work Envelope, also known as the workspace, defines the three-dimensional area within which a robot can operate. It is determined by the robot's structure, the number of degrees of freedom, and the length of its arms.

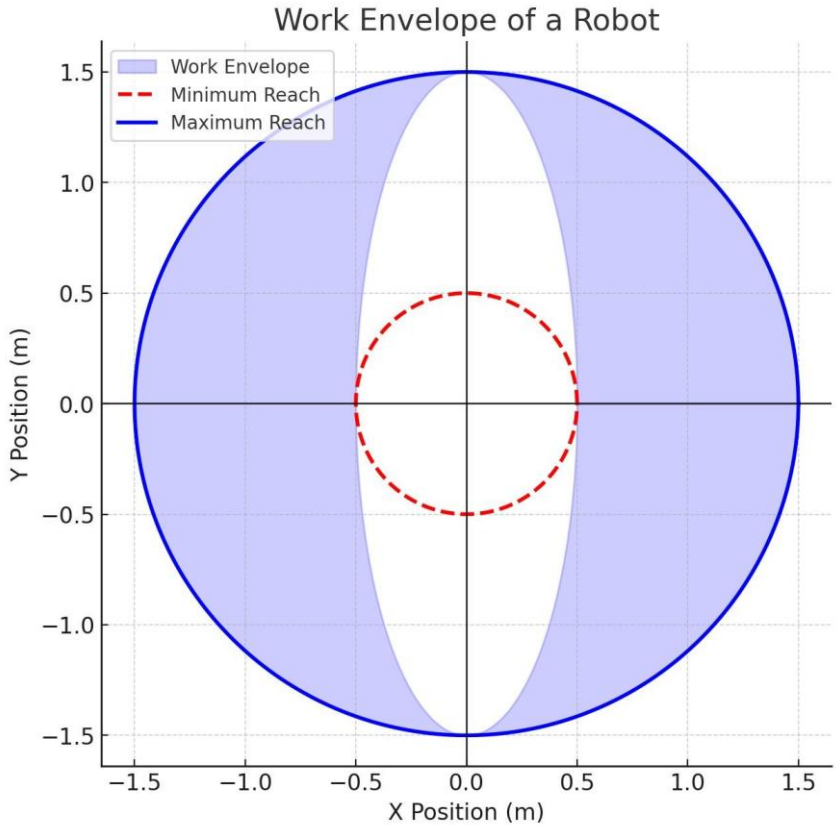


Figure 2-3: Example of a worn envelop diagramm

In the diagram, the shaded blue region represents the robot's complete working range. The inner red dashed line marks the minimum reach, while the outer blue solid line indicates the maximum reach. The robot can only interact with objects located within this defined envelope.

3. Robots in the textile Industry

3.1. The Current State

The level of automation in textile assembly remains relatively rudimentary compared to other manufacturing industries. Unlike sectors such as automotive or electronics, where fully automated assembly lines are common, the textile industry still relies heavily on manual labor due to the complexity and flexibility required in handling fabrics.

Current advancements in textile robotics primarily focus on automating individual tasks and processes rather than achieving fully integrated automation. Specific operations such as fabric cutting, sewing assistance, and quality inspection have seen some degree of robotic intervention. However, most of these systems function in isolated stages rather than as part of a fully automated production chain.

Despite these advancements, transport, machine setup, and coordination remain human-driven processes. The adaptability and decision-making required for handling different textile materials and production variations still surpass the capabilities of current robotic systems. As a result, human workers continue to play a crucial role in organizing workflows, setting up machines, and ensuring seamless production.

Furthermore, overarching processes that are fully adapted to an automated environment have barely been developed. Unlike other industrial sectors where end-to-end automation is achievable, textile manufacturing lacks a unified system that integrates material handling, sewing, finishing, and packaging into one seamless robotic operation. The high variability in fabric types, flexibility, and design complexity presents significant challenges to developing comprehensive automation solutions.

As technology progresses, future developments in AI-driven robotics, soft robotics, and adaptive automation could lead to more sophisticated systems capable of handling the complexities of textile production. At present, however, the industry continues to rely on high levels of human labour with some partial automation of repeatable processes.

3.2. Impact of recent Crises and global Trends

In recent years, the textile industry has faced significant challenges due to multiple global crises affecting supply chains and consumer behavior. These disruptions have highlighted the vulnerabilities of a production model heavily dependent on offshore manufacturing and complex logistics networks. As a response, companies are increasingly prioritizing supply chain diversification to reduce reliance on a single region and create more resilient production strategies.

One key trend emerging from this shift is the rising demand for localized production facilities in Europe, aiming to make supply chains more crisis-proof. However, the feasibility of bringing large-scale textile production back to high-wage regions remains a major obstacle. Given the current labor costs in manual production, traditional manufacturing methods are not economically viable without significant technological advancements.

This challenge has sparked a renewed interest in automation solutions that go beyond isolated task automation. Instead of just optimizing individual processes like fabric cutting or quality control, there is now a stronger focus on fully automated production lines with minimal human intervention. The goal is to develop end-to-end automation systems that can handle textile processing, assembly, and logistics efficiently—making local production not only feasible but also competitive.

3.3. Challenges in Textile Automation

Despite the growing demand for automation in the textile industry, several major challenges hinder widespread implementation. One of the most significant obstacles is the high variability of textile materials. Unlike rigid industrial components, fabrics exhibit widely differing mechanical and technological properties, such as elasticity, thickness, and surface friction. This variability makes automated handling extremely complex, particularly when it comes to tasks like picking fabric from a stack, placing it precisely without wrinkles, or aligning multiple layers accurately. Current robotic solutions struggle to achieve the same level of adaptability and dexterity as human workers in these tasks.

Another key challenge is the low wage levels in existing textile production regions, which provide little economic incentive for modernization. Since manual labor remains a cost-effective solution in many parts of the world, companies often hesitate to invest in expensive automation systems, especially when short-term labor costs are significantly lower than the capital investment required for robotic solutions. This economic reality has slowed the adoption of fully automated production lines.

Additionally, the textile industry operates on short production cycles, with new garments typically having a lifecycle of only three months before being replaced by new designs. This rapid turnover, combined with a high number of variations per piece, requires modular and easily adaptable production systems. Unlike in other industries where automation can be designed for stable, longterm manufacturing processes, textile automation must be fluidly convertible to accommodate frequent product changes and evolving fashion trends.

These challenges highlight why automation in the textile sector remains limited and why future solutions must prioritize flexibility, material adaptability, and economic feasibility to gain
widespread adoption.

Handling in Textile Assembly

One of the biggest challenges in automating textile assembly lies in the complex handling of fabrics. Unlike rigid materials, textiles exhibit **low shear strength**, meaning they can easily deform or shift under minimal force. Additionally, their **low bending stiffness** makes them prone to folding, sagging, or wrinkling, further complicating precise positioning.

Another critical factor is the **high elasticity** of many textile materials, which can cause unpredictable stretching or contraction during manipulation. Combined with the **high variability in mechanical and technological properties**, such as different thicknesses,

surface textures, and friction coefficients, these characteristics make textile handling inherently difficult for conventional robotic systems.

To overcome these obstacles, specialized grippers and handling systems are required. Traditional robotic end effectors designed for rigid objects are insufficient for dealing with flexible and deformable materials. Instead, innovative gripper technologies must be developed to enable precise, reliable, and efficient handling of textiles in automated production environments.

The following section will explore gripper technology, examining different approaches and innovations that are helping to bridge the gap between human dexterity and robotic automation in textile manufacturing.

4. Gripper Technologies

Currently, numerous grippers designed for handling various textile materials are available. Since
2005, there has been a significant increase in the development of new grippers specifically tailored for textile products. However, despite these advancements, no single gripper exists that is universally suitable for all textile materials and applications.

One of the major challenges in textile automation is the lack of reliable data on the suitability of different grippers for specific textile types. With a growing variety of gripper designs, manufacturers and researchers struggle to identify which grippers are most effective for handling specific fabrics. This issue is further complicated by the absence of clear suitability criteria, making gripper selection difficult for industrial applications.

Despite these challenges, some common gripper types have been successfully established in textile assembly. The following section will examine some of these gripper technologies in more detail.

4.1. Needle Gripper

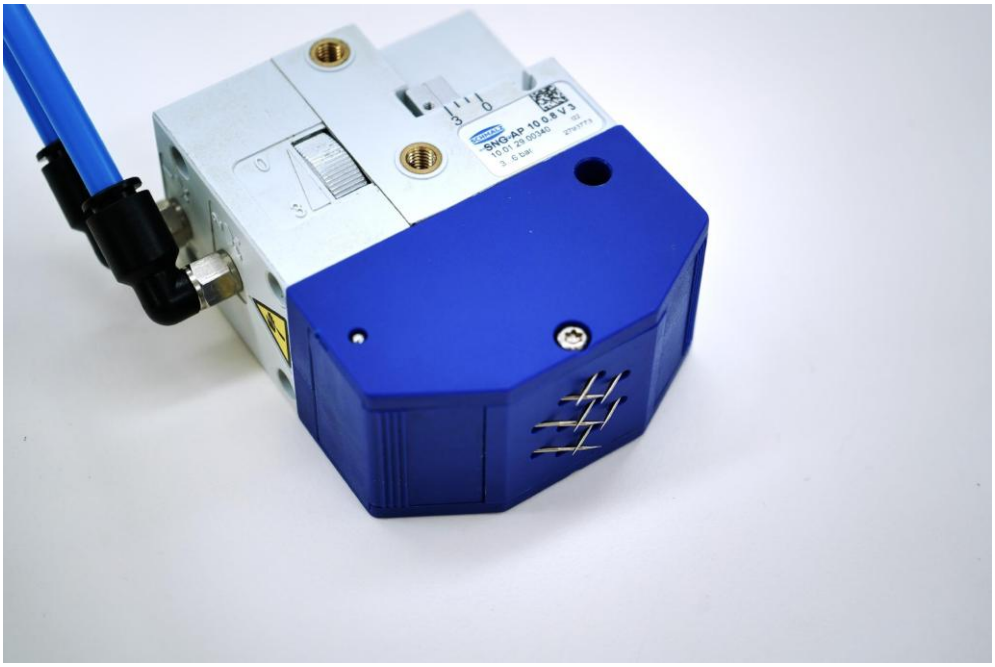


Figure 4-1: Needle Gripper from Schmalz GmbH

Needle grippers operate by penetrating the workpiece with V-shaped needles to establish a secure grip. The needles are pneumatically extended, and their opposing movement generates the necessary clamping force to hold the material in place. After completing the gripping process, the needles can be retracted either by spring force or pneumatically. This mechanism makes needle grippers particularly suitable for handling **flexible** or **dimensionally unstable materials**.

One of the key advantages of needle grippers is their adaptability to different applications. Various designs are available to accommodate specific operational requirements, and both the needle diameter and stroke length can be selected based on the material properties. As a result, needle grippers are widely used for handling **porous and/or flexible materials** such as textiles, insulation and foam materials, fiber-reinforced composites like carbon and glass fibers, non-woven fabrics, felts, carpets, filters, woven fabrics, polystyrene (Styrofoam), and metallic foams.

However, despite their versatility, needle grippers have certain limitations. They are most effective for materials that are **without coating**, have a **high pore size**, and possess a **high thread density**. Additionally, their suitability for fine material separation is limited, as **separation tasks are hardly manageable**. The needle penetration can also cause structural damage to delicate textiles, making them less suitable for highly sensitive fabrics.

4.2. Suction Cups

Figure 4-2: Suction Cup from Schmalz GmbH

Suction cups function by placing a round attachment of the gripper onto the textile surface. A vacuum pump then creates negative pressure inside the hollow body of the gripper, causing the textile to be securely fixed to the suction cup. This method is widely used in textile automation due to its gentle handling characteristics and its ability to operate without mechanical penetration. Most suction cups are externally controlled and pneumatically operated, ensuring efficient and rapid gripping.

The effectiveness of suction cups largely depends on the material properties of the textile. They are particularly well-suited for fabrics **with coatings**, as well as those with

low pore sizes and **high thread and surface densities**. These characteristics allow for optimal sealing between the textile and the suction cup, ensuring a stable grip.

However, suction cups have notable limitations. They are **not suitable for materials with high air permeability**, as excessive airflow prevents the creation of sufficient negative pressure to maintain a secure hold. This makes them ineffective for handling loosely woven, highly porous, or highly elastic textiles that allow significant air passage. Despite this drawback, suction cups remain a widely used solution for handling coated or dense textile materials in automated processes.

4.3. Bernoulli Gripper or Floating Suction Cups

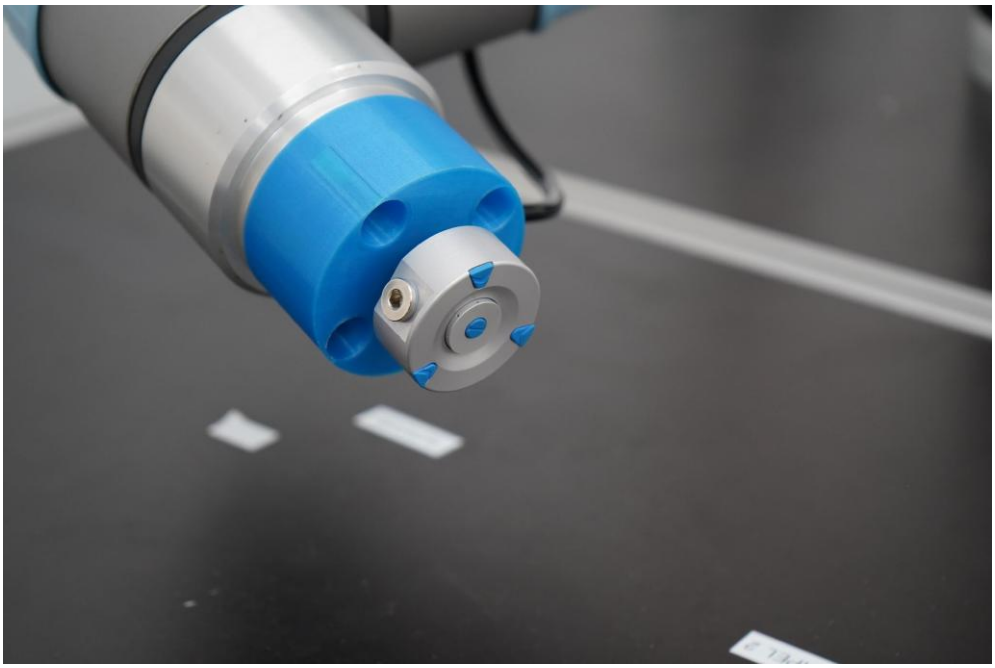


Figure 4-3: Floating Suction Cup from Schmalz GmbH

Bernoulli grippers operate by directing a stream of air horizontally along the bottom surface of the gripper. According to the Bernoulli principle, this airflow generates a vacuum underneath the gripper, which results in the textile being gently lifted and fixed in place. This type of gripper is entirely pneumatically operated and allows for non-contact or minimal-contact handling of delicate materials.

Bernoulli grippers are particularly well-suited for materials **with coatings**, as well as those with a **low pore size** and **high thread and surface density**. These properties enable a stable vacuum effect, ensuring a secure grip without requiring direct mechanical contact.

One of the primary advantages of Bernoulli grippers is their suitability for transporting **thin, highly sensitive,** and **brittle workpieces**. Due to the minimized contact with the material, they enable gentle handling, reducing the risk of damage or deformation.

Additionally, they are known for their low energy consumption, as the design optimizes air usage to achieve maximum efficiency. This makes them an ideal solution for low-contact handling of flexible, porous, or brittle materials.

However, Bernoulli grippers have their limitations. They are **not suitable for materials with high air permeability**, as excessive airflow through the textile structure prevents the necessary vacuum from forming. As a result, their effectiveness is reduced when handling loosely woven or highly porous fabrics.

Despite this restriction, Bernoulli grippers remain a highly effective solution for applications requiring non-contact handling, particularly in industries where delicate and flexible materials must be transported with minimal mechanical influence.

4.4. Other Types of Grippers

In addition to the previously described gripper technologies, several other approaches exist for handling textiles, each suited to different material properties and applications.

One widely used technology is the **Finger Gripper**, which can be operated either **mechanically or pneumatically**. This type of gripper allows for a **regulated or controlled gripping process**, enabling adjustable pressure on the material. This makes it particularly suitable for delicate or variably shaped workpieces.

Another approach is the **Clamping Gripper**, which secures the material through a clamping motion. This method is especially useful for rigid or multilayered textiles that require a firm hold.

Freezing Grippers use a freezing technique to temporarily fix the material. These grippers are particularly beneficial for handling delicate or hard-to-grip materials where mechanical or pneumatic gripping methods may be less effective.

An alternative solution is the **Adhesive Film Gripper**, which relies on **adhesive surfaces**, such as tape, to secure the material. This type of gripper is particularly useful for handling thin and lightweight textiles where traditional gripping systems may struggle.

Velcro Grippers utilize the principle of hook-and-loop fastening to temporarily hold materials. This method is especially advantageous in textile applications where a reversible connection is required.

Finally, **Scraper Grippers** employ a scraping motion to lift and grip materials. This technique is particularly effective for separating and handling thin or difficult-to-pick fabric layers.

The variety of available gripper technologies demonstrates that no universal solution exists for all types of textiles. Instead, the choice of an appropriate gripper depends on the specific material properties and the requirements of the application.

5. Programming Methods for Robots

5.1. Information Flow

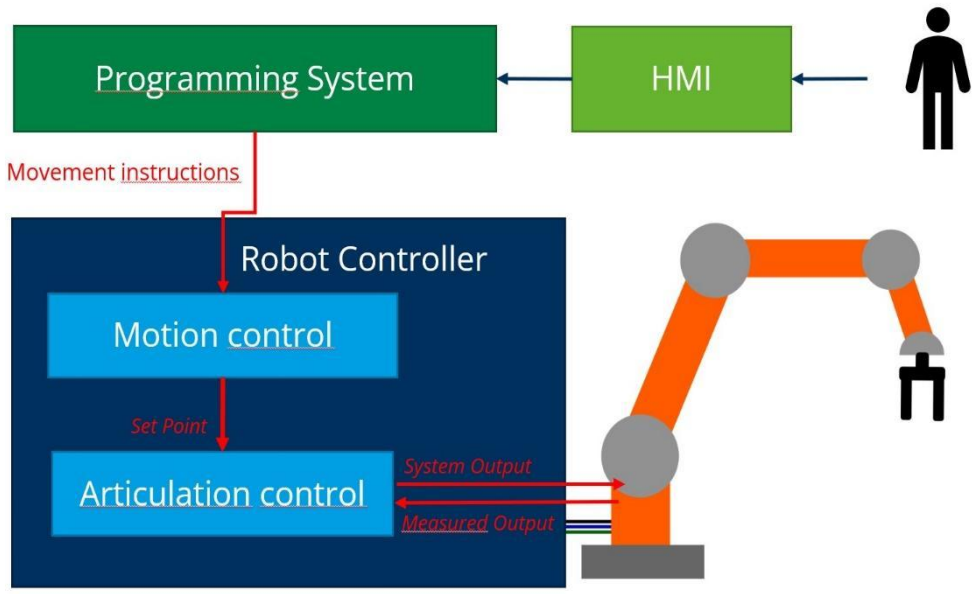


Figure 5-1: Information flow in robotic programming and control

Robotic controllers are typically manufacturer-specific, meaning that different robot manufacturers provide their own proprietary control systems. The **robot controller** is responsible for directly managing the robot's movements by sending commands to its axes, reading sensor values, and regulating the overall system performance.

The **programming system** defines the desired movement of the robot and is the part that is modified when the robot needs to learn a new task. As shown in Figure 5-1, the movement instructions generated by the programming system are sent to the robot controller, which consists of multiple layers. The **motion control** layer processes these instructions and sets the required movement parameters, which are then executed by the articulation control system. This system generates the actual joint movements and continuously compares the system output with the measured output, adjusting accordingly to maintain precision.

Unlike conventional programming, robot programming languages are not standardized. Different manufacturers utilize distinct languages, such as KUKA KRL, URScript, and ROS, which are commonly based on C++ and Python. This lack of standardization requires specialized knowledge when working with different robotic systems, making cross-platform programming a challenge.

5.2. Offline Programming (OLP)

Offline Programming (OLP) allows robots to be programmed externally, without being physically engaged in the production process. Instead of directly teaching the robot through manual input, programming is performed using simulation software on a

computer. This approach enables engineers to design, test, and optimize robot movements in a virtual environment before deploying them to the actual system.

One of the key advantages of OLP is that it reduces production downtime. Since programming and optimization occur independently of the physical robot, the system can continue operating while new programs are being developed. This significantly enhances productivity and minimizes interruptions in manufacturing workflows.

OLP is particularly suitable for complex tasks that require precise path planning and optimization. Industries that demand high accuracy, such as aerospace, automotive, and high-precision assembly, benefit greatly from this programming method.

Common implementations of OLP include CAD-based programming and simulation environments such as RoboDK and ROS, which allow for advanced kinematic simulations and process validation before real-world execution.

5.3. Online Programming

Online Programming involves programming the robot directly while it is in operation, often using a teach pendant or collaborative teaching methods. Unlike offline programming, where robot movements are designed in a virtual environment, online programming requires direct interaction with the physical robot.

Programs are created by manually guiding the robot or entering commands in real-time. This method allows for immediate adjustments and fine-tuning of movements, making it particularly useful for applications where flexibility and quick modifications are needed.

One of the main drawbacks of online programming is the potential for production downtime, as the robot must be stopped for adjustments. This can lead to inefficiencies in high-volume production environments where continuous operation is essential.

Online programming is best suited for simple or repetitive tasks that do not require complex pre-planning. It is commonly used in applications such as teach-and-playback methods and direct pendant programming, where operators define robot paths interactively without requiring advanced simulation tools.

5.4. Trajectories and G-Code in Robotics

In robotic programming, movement is typically defined in an abstracted manner, where waypoints and motion commands are specified instead of direct motor controls. As discussed in previous sections, the programming system determines these movements, which are then interpreted by the robot controller. From these predefined waypoints and motion commands, the **trajectory** emerges—representing the precise path that the robot's tool or end-effector follows through space.

A trajectory is more than just a set of waypoints; it is a dynamically calculated path that considers **kinematic and dynamic constraints** to ensure smooth and efficient motion. This includes defining not only positions but also velocity and acceleration at any given moment. Well-optimized trajectories are particularly critical in **precision-dependent**

applications, such as **welding, painting, and CNC machining**, where accuracy and efficiency are essential.

One common approach to defining robot trajectories is through **G-Code**, a widely used programming language in **CNC machining and additive manufacturing**. G-Code consists of a series of commands that control the movement of a robotic system, specifying parameters such as **position, speed, and tool actions**. While traditional G-Code is primarily used in CNC machines, many robotic systems—especially in **3D printing and robotic milling**—have adapted it for precise motion control. However, due to the **complexity of multi-axis robotic systems**, standard G-Code often requires modifications or extensions to accommodate robotic kinematics.

Below is a simple example of G-Code that moves a robotic tool along a square trajectory:

```
G21                 ; Set units to millimeters
G90                 ; Absolute positioning mode
G1 X50 Y50 F1000    ; Move to (50,50) at a feed rate of 1000 mm/min
G1 X100 Y50         ; Move to (100,50)
G1 X100 Y100            ; Move to (100,100)
G1 X50 Y100         ; Move to (50,100)
G1 X50 Y50          ; Return to start position
M30                 ; End of program
```

This sequence instructs the system to follow a **square movement pattern**, demonstrating how a trajectory can be programmed using a series of commands. In robotic applications, G-Code is often customized to handle the **complex motion planning** required for multi-axis systems, ensuring optimal path execution and precision.

6. Summary

The integration of robotics in the textile industry is still in its early stages compared to other manufacturing sectors. While industries such as automotive and electronics have achieved high levels of automation, textile production remains heavily reliant on manual labor due to the complex and flexible nature of fabrics. Current developments primarily focus on automating individual tasks such as fabric cutting, sewing assistance, and quality control rather than achieving fully integrated robotic production lines.

One of the key challenges in textile automation is the variability of textile properties, including low shear strength, high elasticity, and surface irregularities, which complicate automated handling. Conventional robotic systems struggle with tasks such as fabric alignment, gripping, and manipulation. Furthermore, low labor costs in existing production regions reduce incentives for automation, while short product lifecycles and frequent design changes demand highly adaptable and modular robotic systems.

To address these challenges, various gripper technologies have been developed. Needle grippers use penetrating needles to fix textiles, making them suitable for porous materials but unsuitable for delicate fabrics. Suction cups create vacuum pressure to handle coated textiles with low porosity, while Bernoulli grippers enable non-contact gripping for fragile textiles using airflow. Additional solutions include freezing grippers, Velcro grippers, and adhesive film grippers, each tailored for specific textile applications.

Robotic programming in the textile industry follows two main approaches. Offline programming
(OLP) allows programming in a virtual environment using simulation tools such as RoboDK or ROS, minimizing production downtime. Online programming, in contrast, involves direct robot control using a teach pendant, which requires pausing production for adjustments. Trajectories are defined based on kinematic and dynamic constraints to ensure smooth and efficient movement. In industrial applications, G-Code is often used to specify precise movement paths and tool actions, particularly in CNC machining and robotic 3D printing, though modifications are often required to accommodate complex robotic kinematics.

Despite advancements, fully automated textile production remains a challenge. However, continuous improvements in gripper technology, AI-driven control systems, and adaptive programming will enhance the feasibility of robotic textile manufacturing in the future, particularly as companies seek more resilient and localized supply chains.

7. References

International Organization for Standardization. (2021). ISO 8373:2021 — Robotics — Vocabulary. https://www.iso.org/standard/75539.html

International Organization for Standardization. (1998). ISO 9283:1998 — Manipulating industrial robots — Performance criteria and related test methods. https://www.iso.org/standard/22244.html

International Organization for Standardization. (2025). ISO 10218-1:2025 — Robotics — Safety requirements — Part 1: Robots. https://www.iso.org/standard/73933.html

International Organization for Standardization. (2016). ISO/TS 15066:2016 — Robots and robotic devices — Collaborative robots. https://www.iso.org/standard/62996.html

International Organization for Standardization. (2009). ISO 6983-1:2009 — Automation systems and integration — Numerical control of machines — Program format and definitions of address words — Part 1: Data format for positioning, line motion and contouring control systems. https://www.iso.org/standard/34608.html

International Federation of Robotics. (2024, September 24). Record of 4 million robots working in factories worldwide. https://ifr.org/ifr-press-releases/news/record-of-4-million-robots-working-in-factories-worldwide

International Federation of Robotics. (n.d.). Robot definitions at ISO. https://ifr.org/standardisation

Universal Robots. (2025). UR10e — e-Series Datasheet (Pose repeatability per ISO 9283 ±0.05 mm). https://www.universal-robots.com/media/1807466/ur10e_e-series_datasheets_web.pdf

FANUC. (n.d.). M-10iD/12 — Small payload handling robot (Repeatability ±0.02 mm). https://www.fanucamerica.com/products/robots/series/m-10/m-10id-12

KUKA. (n.d.). KR 6 R900-2 — Pose repeatability (ISO 9283): ±0.02 mm. https://my.kuka.com/s/product/kr-6-r9002-ep/01tc10000059t5dAAA

RoboDK. (n.d.). Offline Programming. https://robodk.com/doc/en/Robot-Programs-Offline-Programming.html

Open Robotics. (2022–2025). ROS 2 Humble — Documentation. https://docs.ros.org/en/humble/index.html

Universal Robots. (2025). The URScript Programming Language for e-Series (SW 5.12) — Script manual. https://www.universal-robots.com/download/manuals-e-seriesur-series/script/script-manual-e-series-sw-512/

KUKA Roboter GmbH. (2015). KUKA System Software 8.3 — Operating and Programming Instructions for System Integrators. https://www.wtech.com.tw/public/download/manual/kuka/krc4/KUKA%20KSS-8.3-Programming-Manual-for-SI.pdf

National Institute of Standards and Technology. (2000). The NIST RS274/NGC Interpreter (Version 3). https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=823374

LinuxCNC Project. (2025). G-code Overview (RS274/NGC). https://www.linuxcnc.org/docs/stable/html/gcode/overview.html

Bonev, I. A. (2002). Delta Parallel Robot — The Story of Success. Parallemic. https://www.parallemic.org/Reviews/Review002.html

École polytechnique fédérale de Lausanne (EPFL). (2011, November 14). The delta robot — Swiss-made and fastest in the world! https://actu.epfl.ch/news/the-delta-robot-swiss-made-and-fastest-in-the-worl/

Schmalz GmbH. (n.d.). Needle Grippers SNG-M. https://www.schmalz.com/en/vacuum-technology-for-automation/vacuum-components/special-grippers/needle-grippers/needle-grippers-sng-m-306152

Schmalz GmbH. (n.d.). Floating Suction Cups (Bernoulli principle). https://www.schmalz.com/en/products/vacuum-technology-for-automation-301607/vacuum-components-301608/special-grippers-306034/floating-suction-cups-306035

Longhini, A., Wang, Y., Garcia-Camacho, I., Blanco-Mulero, D., Moletta, M., Welle, M., Alenyà, G., Yin, H., Erickson, Z., Held, D., Borràs, J., & Kragic, D. (2024). Unfolding the literature: A review of robotic cloth manipulation. Annual Review of Control, Robotics, and Autonomous Systems. https://www.annualreviews.org/content/journals/10.1146/annurev-control-022723-033252

Siciliano, B., & Khatib, O. (Eds.). (2016). Springer Handbook of Robotics (2nd ed.). Springer. https://link.springer.com/book/10.1007/978-3-319-32552-1